A

DESCRIPTIVE TREATISE

ON

MINING MACHINERY,

TOOLS, AND OTHER APPLIANCES USED IN MINING.

BY

GEORGE G. ANDRÉ, F.G.S.,

ASSOC. INST. C.E.; MINING CIVIL ENGINEER; MEMBER OF THE SOCIETY OF ENGINEERS.

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PREFACE.

HITHERTO no descriptive illustrated treatise on the Machinery used in Mining has been published in the English language. In my work on 'Coal Mining,' I had occasion to describe much of this class of machinery, and the descriptions were illustrated by drawings to scale. But it did not come within the scope of that work to treat the subject in its entirety, and the limits of space to which I was restricted forbade the adoption of a scale sufficiently large for every purpose. I have, therefore, deemed it desirable to supplement that treatise by the present. In this, much of the same ground is necessarily covered a second time; but it will be observed that the descriptions in the present work are more full, and that the drawings are here to a larger scale than in the treatise on 'Coal Mining.' In selecting the drawings, I have taken every possible care to obtain and to preserve accuracy; and in compiling the text, I have endeavoured to give the fullest and clearest descriptions.

GEO. G. ANDRÉ.

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HAULING AND HOISTING MACHINERY.

The following description of the most approved form of winding engines is given by Daglish.

In Figs. 475 and 476 is shown a single-cylinder vertical winding engine, having double-beat gun-metal valves and seats, with parallel motion and tappet-valve motion. A number of winding engines have been constructed of this type, of which one of the earliest has been at work over twenty-six years, having a cylinder 34 inches diameter and 5 feet stroke, and a pair of flat winding drums D D 9 feet diameter. This engine winds coal from a shaft 10 feet diameter and a depth of 450 yards in 55 seconds, or at the rate of 16 miles per hour; the time of banking is 30 seconds. The ropes used are flat, made of steel, and last about eighteen months. The engine winds four tubs at a time, each weighing $1\frac{3}{4}$ cwt., and containing $6\frac{1}{4}$ cwt. of coal, making 32 cwt. for the four. The cage and chains, which are of iron, weigh together 30 cwt., and the flat rope weighs 50 cwt. The total quantity of coal raised in ten hours' work is 250 tons, being at the rate of 25 tons per hour, from the depth of 450 yards, or 112 tons per hour per 100 yards depth. The conductors are of iron. The boiler pressure is 45 lbs. per square inch. The repairs to this engine have been very few indeed; a new piston and a crank-pin having been the only renewals since the engine was started; and it has worked night and day since its erection in 1848. Another similar engine has been at work between twenty and thirty years, and in the shape of repairs has had only a new piston and crank-pin.

A single-cylinder vertical high-pressure winding engine of similar construction, which has been at work about seventeen years, has a cylinder 30 inches diameter and 5 feet stroke, with parallel motion, and double-beat gun-metal valves, worked by two tappit rods T T, Fig. 476, one for each direction of winding. The boiler pressure is 50 lbs. per square inch, and a cast-iron feed-water heater H is attached to the engine. The winding drums are flat, 9 feet diameter. The pit shaft is 11 feet diameter and 212 yards depth. The time of winding is about 35 seconds, and of banking 20 seconds, the average speed in the shaft being about 12 miles per hour. The rope is flat and of steel, weighing about 28 cwt., and it lasts from ten to fourteen months. The tubs are of wood, and four of them are raised at each winding; each weighs 4 cwt. and contains 8 cwt. of coal, making 32 cwt. of coal at each winding. The cage and chains weigh about 20 cwt. The engine winds about 520 tons of coal in ten hours' time, being at the rate of 52 tons per hour, or 110 tons per hour per 100 yards depth. The conductors are of iron. In consequence of the boilers driving this engine being pretty well worn out, it has been considered advisable to reduce the steam pressure upon them to 40 lbs. per square inch; and this has been effected by putting in a new steam cylinder of 32 inches diameter, so as to keep about the same power of the engine.

In Fig. 477 is shown a coupled pair of vertical winding engines, erected some twelve years ago, having cylinders 24 inches diameter and 5 feet stroke, and working with a boiler pressure of 40 lbs. per square inch; the valves are slide-valves, with Bristol's antifriction rollers, and are worked by a link motion. The winding drum is of internal conical form, $11\frac{1}{2}$ to 13 feet diameter. The depth of the pit is 260 yards, and the winding is done in 35 seconds, or at the rate of 15 miles per hour. The ropes are round and of charcoal iron, and last twelve months in the wet pit, and eighteen months in the dry pit. The weight of the cage and chain is 20 cwt. The tubs, four in number, each weigh 3 cwt., and hold 7 cwt. of coal, making 28 cwt. of coal at each load; and the number of windings in ten hours is 480, equal to 672 tons of coal, or at the rate of 67 tons per hour, or 174 tons per hour per 100 yards depth.

Up to 1850 the direct-acting steam winding engines used in Lancashire or the neighbourhood of St. Helen's were principally beam engines, or vertical engines. About 1851 the horizontal single-cylinder high-pressure winding engine was introduced, and several such engines were put to work at different collieries. At that time great prejudice existed against the horizontal engines, in consequence of the prevailing idea that the cylinders would become oval by the weight of the piston; and this must be considered the reason why the piston rods were carried through the back cover of the cylinders, and a slide or shoe attached to them for taking the weight of the piston off the bottom of the cylinder.

Amongst a number of engines of this class may be mentioned one that is shown in Figs. 478 and 479, having a cylinder 36 inches diameter, and 5 feet stroke, with double-beat gun-metal valves, worked by a loose eccentric. In Fig. 480 is shown a transverse section of the cylinder and valves. The drum D is flat, 10 feet diameter, and on the drum shaft is a fly-wheel 20 feet diameter, which is used for the brake, Fig. 478. The back piston-rod was originally used for a feed pump, P, but for the last five years the engine has had no back piston-rod. This engine has been at work night and day for the last twenty-two years at the Rose Bridge Colliery, near Wigan, and has required very slight repairs indeed; the writer believes it was the first winding engine of the horizontal type, and the largest size of its class when first erected. The pressure of the steam in the boilers is 40 lbs. per square inch.

The pit shaft is 11 feet diameter and 290 yards deep, fitted with iron conductors. The winding takes 35 to 40 seconds, giving a speed of from 17 to 15 miles per hour in the shaft. The rope is flat and of iron, weighing about 35 cwt., and it requires renewing about every twenty-four months. The number of tubs raised at each winding is four, each weighing 3 cwt., and containing 8 cwt. of coal, or 32 cwt. gross load of coal. The weight of the cage, which is of steel, is 28 cwt. with the chains. The total weight of coal raised in ten hours is 800 tons, being at the rate of 80 tons per hour, or 232 tons per hour per 100 yards depth.

A coupled pair of horizontal high-pressure winding engines similar to that shown in Figs. 478 and 479 were erected in 1860 at the Rose Bridge Colliery, having cylinders 36 inches diameter and 6 feet stroke, with double-beat gun-metal valves. Steam was supplied by eight egg-ended boilers, $5\frac{1}{2}$ feet diameter, and 36 feet long, working at 45 to 50 lbs. pressure per square inch. Up to 1870 these engines wound from a shaft 14 feet diameter, and 605 yards deep. The ropes were made of steel, and were flat and taper, each weighing 57 cwt. total, and 48 cwt. in the pit; they had to be renewed about every eighteen months. The number of tubs raised at a winding was four; they were of wood, weighing 12 cwt. each, and containing $8\frac{1}{2}$ cwt. of coal, making 34 cwt. of coal raised at each winding. The cage and chain 30 cwt. The number of windings in ten hours was 500, raising 850 tons of coal per day, or at the rate of 85 tons per hour, or 514 tons per hour per 100 yards depth. The time occupied in each winding was 48 seconds, giving an average speed of 26 miles per hour in the shaft; the time of banking was 27 seconds. The winding drum was flat, 20 feet diameter at starting, and $23\frac{1}{2}$ diameter with all the rope on. The conductors in the pit were iron-wire ropes, with a steel stranded core.

In consequence of the seams at this colliery being worked out in 1870 at the shallower depth of 605 yards, these engines were then called upon to wind from a depth of 806 yards; and it was accordingly found requisite by Mr. John Bryham, the engineer and manager of the colliery, to increase the winding drum to 24 feet 4 inches diameter, and 28 feet diameter with all the rope on. The ropes now in use are flat and taper, made of steel, and each weighs 65 cwt. total, and 57 cwt. in the pit, and lasts eighteen months. Four tubs are brought up at each winding, each weighing $3\frac{1}{4}$ cwt., and containing $7\frac{1}{2}$ cwt. of coal, or 30 cwt. of coal altogether; the cage and chain weighs 30 cwt. The number of windings in ten hours is 450, equal to 675 tons of coal, or 67 tons per hour, or at the rate of 544 tons per hour per 100 yards depth; the time taken in each winding is 55 seconds, giving an average speed of 30 miles per hour in the shaft; the time of banking is 27 seconds. The conductors are iron-wire ropes $1\frac{7}{16}$ diameter with steel stranded core.

As it was considered advisable not to subject the present boilers to a higher pressure than 60 to 65 lbs. per square inch, the back piston-roads were taken away, and the result has been that four to five lbs. per square inch pressure of steam has been saved, while the piston rings, which are of cast iron, have been found to last eighteen months. The cylinders have never been bored, or otherwise touched, since they were erected, and it is considered the repairs have been less since the back piston-rods were taken away. Looking at the fact that these engines are now running at the maximum piston speed of 700 feet per minute, the writer considers this severe test sufficient to answer all objections to the abandonment of the back piston-rods and slides, and he consequently recommends that no slides should be used.

In Figs. 481 and 482 is shown one of the most modern style of coupled horizontal winding engines, having cylinders 36 inches diameter and 6 feet stroke, and fitted with an external conical winding drum of 19 to $30\frac{1}{2}$ feet diameter. These engines are working at Pemberton Colliery, near Wigan, and wind from a depth of 638 yards in 55 seconds, giving an average speed of 24 miles per hour; the time of banking is 35 seconds. The cage is of steel, and with chains, weighs 29 cwt. It holds six steel tubs, weighing together $18\frac{3}{4}$ cwt., and raising 46 cwt. of coal at each winding. The winding is done at the rate of 92 tons of coal per hour, or 587 tons per hour per 100 yards depth. The ropes are of steel, tapering from $1\frac{1}{2}$ to $1\frac{1}{4}$ inch diameter, and each weighing 59 cwt.; they have now been in work from September 1871, and are not much worn. The pit is 16 feet diameter, and the conductors are iron T rails, weighing 42 lbs. per yard. The drum makes 22 revolutions in each winding, and the steam is shut off from the engines at $2\frac{1}{2}$ to 3 revolutions before stopping, or 80 to 90 yards from the top of the pit. The pressure of steam at the engines is 53 lbs. per square inch. The several handles for controlling the working of the engines are all brought together to the same place, within convenient reach of the engine-man, as shown in the plan, Fig. 482. S is the handle controlling the steam stop-valves. V and R is the reversing lever of the link motion. F is the foot lever for applying the brake which acts upon the centre portion D of the winding drum, and B is the handle for applying the steam gear A to work the brake. The whole of the head gear, framing, and heapstead is of iron, and the roofing over the stage is of galvanized iron. The arrangements enable twelve railway trucks to be loaded at a time, namely, six with best coal, two with nuts, and four with slake; the level of the truck rails is $23\frac{1}{2}$ feet above the pit mouth. The head-gear pulleys are 18 feet diameter, and centered 45 feet above the pit mouth.

The winding machinery used in the Western States of America offers some peculiarities worthy of notice. In hoisting apparatus, the winding reels or drums are operated either by cog or friction gearing. The latter was much used a few years ago, but as the depth of the mines has increased, it has been abandoned by some and replaced by cog gearing, which is thought safer and more effective for deep works.

The kind of junction gear formerly in general use is that known as the V-wheel and pinion, the construction of which is shown, in detail, in Fig. 483. The face of the wheel, usually about 8 or 10 inches wide, is formed with V-shaped grooves, two or three in number, which extend continuously entirely around the periphery; the face of the pinion is of corresponding form, but it is so placed with regard to the wheel that the projecting ribs, between the grooves, fit into the recesses in the face of the wheel. The pinion is keyed to the engine shaft, and may be set in revolution by it. The wheel, being so placed that its face may be brought into contact with the face of the pinion, is caused to revolve by friction, if the two surfaces of wheel and pinion be forcibly pressed together.

The friction wheel forms one end of, or is attached to, the drum on which the rope or cable is wound. In Fig. 483 the wheel W is cast in one piece, and the drum or spool consists of two flanges, F F, which are connected together by plate of iron, bolted as shown in the drawing. The spool is joined to the friction wheels by bolts *b*, *b*, passing through the flange F. To the opposite flange F is bolted a broad rim R, to which is applied a brake-strap. This strap is usually a band of iron, 4 or 5 inches wide, which encircles the rim R of the spool, and may be made to grasp it tightly, thus arresting the movement of the same. There are various methods of applying the brake to the rim. One of them is shown in Fig. 484. L is a long lever, broken off in the drawing. The strap shown in Fig. 484 is for a smaller drum than that represented by Fig. 483; but the method of application may be the same.

The general method of arrangement of this kind of machinery is shown in the drawings. Fig. 485 is a side elevation, and Fig. 486 a plan of the hoisting gear. In Fig. 486 the relative position of the engine to the winding drums is shown. In the case illustrated there are two drums, each of which is independent of the other. The friction pinions P, are keyed to the engine shaft S, and are caused to revolve by it. Each friction wheel W forms a part of a winding drum D, which is supported on pillow blocks B, that may slide backward on the bed-plate beneath them. They move horizontally between guides or flanges, which prevent any upward motion.

The sliding movement is imparted to the pillow blocks by means of the arms *a*, connecting them with a short lever at *b*, which is keyed to a rock-shaft *c*. If this rock-shaft be slightly turned toward the drum, the arms are advanced and the friction wheel brought into contact with the pinion. If it be turned from the drum the wheel is removed from such contact, and may be held by a brake. The desired motion is given to the rock-shaft *c*, by the short lever *b*, and the long arm L, which is at the hand of the attendant. On the opposite end of each drum is a rim R, for the brake-strap. The brake is controlled by the short lever *f*, and the arm F, which, like the arm L, is within easy reach of the operator.

This method of operation has some advantages in the simplicity with which the machinery is controlled and economy in the labour employed. The engine runs steadily in one direction, and, not needing to be reversed, requires but little attention. It may also be applied to other continuous work, such as pumping, the driving of air-blowers or other machinery, which cannot be done when the engine is stopped and reversed at short intervals.

One man, in small mines, or where the quantity of rock to be hoisted is not very great, may attend to the whole work of controlling the engine and disposing of the material hoisted. The attendant stands at the mouth of the mine shaft. He has, at one hand, a lever to set the winding drum in motion; at the other a lever operating the brake on the drum, and, within easy reach, the means of opening or closing the throttle-valve of the engine, so that he may diminish or increase the quantity of steam, according to circumstances. On the arrival of the loaded car at the surface, the same man may attend to its discharge and send it below again. One objection to this method is, that with very heavy loads the wheels are liable to slip against each other; and another, that it is not readily practicable to lower a loaded cage into the mine under the control of steam, making it therefore necessary to depend entirely on the brake for that purpose. This is particularly objectionable in deep mines where the weight of the long cable is itself very considerable. In the Comstock mines the men employed underground are lowered into the ground on the cages; and it is always deemed safer to do this under the control of steam rather than by the brake alone.

Where cog gearing is employed, the motion of the engine is imparted to the shaft, carrying the winding drums or reels by toothed wheel and pinion. There are various ways of applying this kind of gearing. In some cases the spur-wheel and winding reel are keyed to the same shaft, and driven by a pinion which is keyed to the engine-shaft, so that the reel must always have a motion corresponding to that of the engine, and cannot, as is practicable in some other methods of arrangement, be reversed, for lowering the cage, unless the engine be reversed also.

At the Savage Works there is a separate engine and independent winding gear for each hoisting compartment of the mine shaft, and so arranged that each engine is connected with but one reel, and cannot work either of the others. In this arrangement the practice, sometimes desirable, of hoisting one cage as the other descends, in such manner as to allow the descending cage and rope to counterbalance the ascending, is impossible.

Another method, similar to the above in some respects, but possessing important modifications, is that which is in use at the Crown Point Works, shown in Fig. 487. In this case there are two winding spools or drums, A and B, one for each hoisting compartment. There are also two hoisting engines, C and D, each of which, under ordinary circumstances, is used for a single compartment. Each spool, with its spur-wheel, is keyed to a spool-shaft and driven by a pinion, which is keyed to the engine-shaft. The engine must therefore be reversed, in order to reverse the motion of the spool: but the engine-shaft of either engine is long enough to control both spools, and each shaft is provided with two pinions, one for each spool. Under ordinary circumstances, the machinery is arranged as shown in the drawing. The engine on the right, C, drives the spool A, nearest to it, by the pinion E, the pinion F for the remote spool B being thrown out of gear; while the engine on the left D drives the remote spool B, by the pinion H, the pinion G, for the nearer spool A, being thrown out of gear. In case of accident to one engine, the other can work either spool; or, by throwing out of gear both pinions of one engine, and putting in gear both pinions of the other engine, both spools may be driven at the same moment, one hoisting and the other lowering a cage. In this case, of course, the two ropes or cables must be wound upon the spools in opposite directions. There are no brakes on these spools; but one is applied to the fly-wheel of each engine. The pumping engine P, in the case illustrated, has no connection with the hoisting gear, and is devoted exclusively to driving the pump by means of the pinion J, and wheel K, as shown in the drawing, nor can either hoisting engine be applied to the pump, in the arrangement indicated.

Another method of arrangement is one by which the motion of the hoisting reel may be reversed without reversing or arresting the motion of the engine.

In some cases where this method is in use, as at the Ophir and Empire Imperial Works, the winding reels are supported upon the reel-shaft, not keyed to it, but turning freely upon it in either direction. The reel-shaft receives its motion from the engine by means of a pinion and spur-wheel, but may turn freely without imparting motion to the reels except when the latter condition is desired. In such case a reel is caused to revolve with the shaft, by throwing into contact with it a clutch that slides upon a feather on the shaft. As the clutch always has the motion of the shaft, it causes the reel to turn with it, while in contact, and on being withdrawn from contact the reel is free to be reversed, for lowering the cage, while the motion of the engine-shaft is continuous. Such reels are cast with a flange or rim for a brake-strap, by which the reverse motion is controlled. This method of arrangement requires but one hoisting engine for two or more reels. The latter are all upon the same reel-shaft, but work independently of each other, and as the reel-shaft moves continuously in one direction, the engine may be applied to other work, such as pumping, or driving other machinery that requires continuous motion. If desired, however, two reels may be permanently clutched to the shaft and revolve with it, one winding and raising a loaded cage from the mine, while the other is unwinding and lowering an empty cage, gaining in this case the advantage of the weight of the descending cage and rope. In the last case, the engine must, of course, be reversed for each operation of hoisting and lowering, and the ropes must be wound upon the reels in opposite directions.

In the Hale and Norcross works, a plan of which is shown in Fig. 488, this method is in use, with some modifications that appear in the drawing. In this case each of the two reels R R, is keyed to a separate reel-shaft with a spur-wheel W, and brake-rim B. The reels are entirely independent of each other. There are two pinions P P, one for each reel, on the engine-shaft S. These pinions are not keyed to the engine-shaft, but turn freely in either direction, independently of the motion of the shaft. They may be made to revolve with the shaft by the clutches C, which being fixed to the shaft by a feather, may slide toward or from the pinions. If the clutch C be moved into gear with the pinion P, the latter receives the motion of the engine-shaft and transmits it to the reel; if the clutch be withdrawn from its contact with the pinion, the reel may turn in the opposite direction, while the motion of the engine is uninterrupted. The reel may therefore be moved by the engine for hoisting, and, when reversed for lowering, may be controlled by the brake. The clutches are moved in and out of gear by the levers L L; the brakes are applied by similar levers I I. If it be desired to lower a cage under control of steam, as is usually the case when men are descending, it is only necessary to leave the clutch in gear and reverse the engine. It will be seen that both reels may hoist at the same moment; or by fixing both clutches permanently in gear and reversing the engine for each operation, one reel may hoist while the other lowers, using the descending cage as a counterweight for the ascending one, as already described. It will also be seen that by this arrangement the single engine E may not only do all the hoisting, but drive the pump also. The engine-shaft extends beyond the reels and, by the wheel H, if the latter be moved into gear with the pinion J, of the pump-wheel K, may set that in motion. The pumping engine F is commonly used for this purpose, but in case of necessity, its work may be done by the hoisting engine E. Hoisting may also be performed by the pumping engine, if the wheel H be put in gear with the pinion J. Thus, if desired, either engine may serve as a substitute for the other.

At the Savage mine the position of the cage in the shaft, at any moment of its ascent or descent, is shown to the operator by an "indicator" connected with the winding machinery, and in full view of the engine driver. It consists of a circular plate or dial, about the centre of which a pointer, like the finger of a clock, revolves, showing, by means of points marked upon the circumference, the position of the cage in the shaft. When the cage is at the surface the finger stands vertically, marking on the circumference the starting or zero point. As the cage descends, the finger turns on the dial, passing successively the points corresponding to the several stations or intermediate places in the shaft. The construction of this apparatus is illustrated by Figs. 489 to 491. S is the main engine-shaft, set in motion by the crank C. The pinion P drives the spur-wheel W, by means of which the winding reel R, is caused to revolve. The relations of the pinion to the spur-wheel being as $1 : 3\frac{1}{2}$, the winding reel R makes 100 revolutions for 350 of the engine-shaft. On the latter, near the pinion P, is fixed a light gear-wheel g, 2 feet in diameter, which drives by means of a similar wheel, g', the countershaft c. This countershaft is provided with a worm, shown at a in elevation, above which is a worm-wheel b. This is a disc, 2 feet in diameter, the face or periphery of which is cut to correspond with the worm a, and has 350 threads. As the countershaft c, and worm a, revolve with the same speed as that of the engine-shaft S, the disc b is caused to make one complete revolution by 350 revolutions of the engine-shaft S, equal to 100 revolutions of the winding real R. The journal on which the disc b is supported projects beyond its face, and is provided at h with a pointer p. The latter revolves with the disc. Between the disc and the pointer a dial, d, is interposed, which is fixed upon an independent support. As the disc is revolved the pointer moves on the face of the dial like a clock-finger, making, as before stated, one entire revolution for 100 turns of the reel on which the cable is wound. Its position, therefore, is always determined by the length of cable that is paid off from the reel. If the position of the pointer be once marked on the circumference of the dial, at points corresponding to any given depth in the mine shaft, the engine driver can readily see the place of the cage at any moment of its ascent or descent.

The following Table, for which we are indebted to the 'Colliery Guardian,' gives some useful facts relating to several of the finest winding engines in England.

TABLE SHOWING SOME OF THE PRINCIPAL FACTS

Name of the Colliery at which the Winding Engine is situated.	Description of the type to which it belongs.	Number of Cylinders.	Diameter of Cylinders.	Length of Stroke.	Pressure of Steam observed in Cylinder.	Maximum Vacuum in Cylinder.	Maximum Velocity of Piston.	Mean Velocity of Piston.	Description of Valves.	Diameter of Steam Valves.	Diameter of Exhaust.	Lift of Valves.	Area of Port.	Ratio of Area of Port to Area of Cylinder.	Diameter of Steam Pipe.	Length of Steam Pipe.	Diameter of Exhaust Pipe.	Maximum Diameter of Drums.	Minimum Diameter of Drums.	Mean Diameter of Drums.	Weight on Counterbalance at Start.	Maximum Diameter of Counter-balance Drum.
			in.	ft.	lbs. per sq. in.	lbs. per sq. in.	in feet per min.	in feet per min.		in.	in.		sq.in.		in.	ft.	in.	ft.	ft.	ft.	tons.	ft.
Harton Colliery	Vertical, condensing, balanced.	1	65	7	16	9½§	..	176	Double beat brass or Cornish.	13	14	..	114	1–21	..	..	..	27	25	26	..	..
Monkwearmouth	Vertical, condensing, balanced.	1	68	7	19 to 20	10½	300	224	"	15	15	1⅛, 1¼	about the	same ratio	17	66	13	25	22	23½	10	8¾
Usworth	Horizontal, high-pressure, balanced.	1	48	6	36	..	320	232	Lifting slide valve.	13	13	2⅛	..	..	11½	77	..	22⅓	20¾	21	4½	7⅔
Denaby	Coupled, horizontal, high-pressure, unbalanced.	2	42	6	42	..	700	360	Cornish	13	15	1½, 1⅞	80	1–17	Branch 9½	..	10	18	18	18	None	
Boldon *	Coupled, horizontal, high-pressure; compensating drum.	2	40	6	35	..	410	253	"	..	..	2, 2½	..	..	..	..	..	26	16	21	None	
Douglas Bank ..	Coupled, horizontal, high-pressure; compensating drum.	2	30	5	49	..	462	260	"	..	10	..	48	1–14	Main 16	50	8	25⅛	18	21·38	None	
Rose Bridge† ..	Coupled, horizontal, high-pressure, unbalanced.	2	36	6	53	..	720	376	"	9	..	1½, 1¾	..	..	..	..	18	27⅔ 23¾	25 20¼	26⅓ 22	None	
Houghton - le - Springs.	Coupled, horizontal, high-pressure; cone drum.	2	34	6	30 to 40	..	522	291	Piston slide valve.	..	..	8	..	..	..	..	12	18⅛	16·83	17·58	None	
Cinderhill, No. 1‡	Single, vertical, high-pressure, balanced.	1	40	5	40 to 42	..	..	300	Cornish	..	13	⅞, 1¾	..	..	..	..	..	15·4	13·2	14·3	1 1–5	3½
Hucknall, No. 2‡	Coupled, horizontal, high-pressure, unbalanced.	2	36	6	48	..	..	376	"	12	..	1¾, 1¾	..	..	..	..	..	18·3	15·4	16·9	None	
Kiveton Park‡ ..	Coupled, horizontal, high-pressure; compensating drum.	2	36	6	48	..	..	228	"	..	..	1½, 1¾	..	..	..	..	..	30	20·6	27·7	None	
Kiveton Park‡ ..	(Observed another time)	2	36	6	48	..	..	228	"	..	..	1½, 1¾	..	..	..	..	..	30	20·6	27·7	None	
Biddick	Coupled, horizontal, high-pressure, engine and boiler; drum on second motion.	2	12	11–6	80	..	560	..	Slide	..	..	..	..	..	..	..	..	8	8	8	None	

* This engine, at the time of observation (1871), was not doing more than half the work for which it was intended, and of which it is capable.
† The drums are of different sizes; one winding from a depth of 807 yards, and the other 674 yards.

A new type of winding engine has of late been introduced for the purpose of raising the stuff from the shaft during the operation of sinking. This type, which is that of the locomotive, and which is known as the "Robey engine," offers great advantage for the temporary purpose alluded to. No strong foundations or buildings are required beyond a light shed to protect it from the weather; it is exceedingly compact, and can be brought upon the ground almost in a state to receive steam ; it may be readily removed when its services are no longer required; it is very economical of fuel, its first cost is light, and it may be built of any power up to 200 horse. In all ordinary cases this engine may be made to do both the winding and pumping, when pumps are used. The following is a general description of this type of engine which is shown in Figs. 492 and 493. The dimensions are those of the largest size engines, capable of working up to 200 horse-power effective.

The general arrangement is that adopted for the locomotive; but the frames are suppressed, and

RELATING TO ENGLISH WINDING ENGINES.

Total weight of moving parts, that may be taken as moving at the same velocity as the Cages.	Total Weight of Moving Parts.	Number of Revolutions of Drums per Journey.	Mean number of Revolutions per Minute.	Description of Ropes.	Weight per Fathom of Rope.	Material of Cage.	Weight of Cage.	Weight of Trams.	Weight of Coal.	Mean Speed of Cage in Shaft.	Maximum Speed of Cage in Shaft.	Depth of Pit.	Time occupied each Journey.	Time occupied in Landing, &c.	Tonnage per Hour.	Power exerted by the Engine each Journey in foot-pounds.	Duty done each Journey, as measured by Weight of Coals and Height lifted.	Ratio of Power to Duty.	Ratio of Maximum Pressure on Piston to lift at commencement.	Number of Boilers and description.	Dimensions of each Boiler.	Heating Surface.	Grate Surface.	Maximum Indicated Horse-power of Engine.
	lbs.				lbs.		cwt.	cwt.	cwt.	ft. in a min.	ft. in a min.	ft.	sec.	sec.	tons.	foot-pounds.	foot-pounds.	per cent.			ft.	sq. ft.	sq. ft.	No. of b.p.
..	208,000	15·65	12·5	Flat iron wire, 6½ × ⅞ in.	42	Iron	50	30	54	1020	..	1278	75	30	91	10,342,350	7,729,344	75	100:50	Cornish 10 At work, 6	..	..	..	..
..	280,000	23¾	16	Flat iron wire, 6 × ⅞ in.	43	Steel	35	33	50	1180	1630	Say 1740	89	35	72½	15,403,000	9,744,000	63	100:42	At work, 6	33 × 7½	400	55	422
..	..	14½	19⅓	Iron wire, flat.	28½	Iron	22⅓	16	36	1300	1706	966	45	..	..	5,281,107	3,956,178	74	100:37½	Externally fixed, 5	50 × 6	300	42	344
80,000	158,000	23¾	30	Iron and steel round rope.	29 & 23	Iron	48	19	40	1691	3080	1351	47	21	102	12,120,000	6,300,000	50	100:48	8 plain, 7 at work	30 × 5½ 30 × 6	Say 200	35	950
..	..	19⅓	21	Steel, 1⅝ in. round rope.	27	Iron	40	15½	24½	1689	2788	1548	55	..	..	7,470,000	4,077,000	53½	100:36	..	..	..	..	470
..	133,000	22·6	26	Steel, round.	11	Steel	20	12	24	1765	3100	1530	52	25	56	6,851,700	4,131,000	60	100:37	..	..	..	..	461
80,000	148,000	29¼	31⅓	Steel, flat taper.	Average, 22	Steel and Iron.	22 34	22	26	2590 2166	5100 4302	2418 2022	56	25	58	19,196,400	6,464,640	33·7	120:80	Plain, externally fixed, egg ends 8	36 × 5½			900
..	..	13½	25	Iron, round 1⅜ in.	21	Steel	18	15	35·8	1302	2436	738	34	25	110	4,375,596	2,700,000	61	100:43	..	..	..	..	497
60,480	..	14¾	29½	Iron flat	33	Iron	25⅓	25	33	1320	..	666	30	30	91	3,363,568	2,460,000	73	..	Plain, externally fixed, egg ends				‡
67,200	..	23½	31⅜	Iron flat.	29	Iron	30	11	45	1652	..	1239	45	25	128	10,542,411	6,265,023	59½	100:58	6 6	36 × 5 40 × 5½	..	..	‡
134,400	..	14⅛	19	Round.	18	Iron	20	22	22	1624	..	1218	45	15	90	7,165,905	3,000,026	41·8	100:29	..	..	..	..	‡
25,760	..	14⅛	19	Round.	18	Iron	48	8	44	1624	1500	1218	45	25	120	7,955,782	5,999,948	75·4	100:29	..	..	..	..	‡
..	..	27	33	Iron, round	8	Iron	9½	..	12	821	..	684	50	..	..	..	919,296	..	..	1 multitubular boiler, forming foundation for engine.				150 to 200

‡ Not observed with velocimeter, therefore the horse-power cannot be accurately stated, but Hucknall and Kiveton appear to develop about 1000 h.p.
§ Hot summer evening; a better vacuum in the morning and in cold weather.

the engine is erected upon a cast-iron bed-plate, formed at one end into an ashpit, with damper doors, which carries the fire-box end of the boiler; the other end is carried by a saddle casting fixed over the cylinder. The end of the bed plate under the cylinder constitutes a feed-water tank into which the cylinder cocks discharge all the condensed water, and into which also a portion of the exhaust is directed to heat the feed water to near the boiling point before it is forced into the boiler. The latter is bolted to the cylinders at the smoke-box end, and as the fire-box is carried on small rollers, it is free to expand, on steam being got up, no strain being thrown upon either the plates or the joints; upon the bed-plate is fixed one plumber block and bearing for the winding drum. This drum stands by the side of the engine, the outer bearing being carried on a heavy balk of timber. The drum is 9 feet diameter, lagged with oak, and made up with cast-iron ends. On the end next the engine, is bolted up a spur-wheel 8 feet 4 inches diameter. On the end of the crank-shaft is keyed a pinion

2 feet 4 inches diameter, which gears with the spur-wheel. Both these wheels are shrouded on one side. They are 9 inches wide on the working faces of the teeth, and 4 inches pitch. They work smoothly and quietly at a high velocity, the drum, when winding, running at the rate of 24 or 25 revolutions a minute, and the engine a little less than four times as fast. Two brakes are fitted to the engine; one to the fly-wheel, which is the one ordinarily used, and an extra one, of great power, round the drum itself. This last is provided to avert an accident should the spur-wheel or pinion give way. The whole of the parts, both of the engine and the boiler, being erected upon one bed-plate, heavy and expensive foundations are rendered unnecessary. The weight of the boiler and its contained water tends to keep the whole machinery firmly in position. All the levers for working the engine and the winding gear are brought together near the fire-box, so that one man may attend to both the driving and the stoking.

The principal dimensions of such an engine are as follows: Cylinders, each 16 inches diameter by 24 inches stroke; crank-shaft, bent out of one piece of Lowmoor iron, $6\frac{3}{4}$ inches diameter; drum-shaft, best scrap, 10 inches diameter; drum, 9 feet diameter by 6 feet wide, cast-iron ends, lagged with best English oak; boiler, 10 feet 10 inches long, by 4 feet 9 inches diameter; fire-box, 5 feet 9 inches long, and 4 feet 9 inches wide; tubes, 74 in number, and 3 inches in diameter, working pressure, 100 lbs. to the square inch.

MAN-ENGINES.—In some mines, instead of a winding engine or cage, an apparatus, consisting essentially of two oscillating rods, set in motion either by a steam engine or by a water wheel, is used. This apparatus is called a man-engine.

The principle of the man-engine will be made clear by reference to Fig. 494. R R and R′ R′ represent portions of two heavy rods or beams, extending from the top to the bottom of a shaft, and suitably guided and supported throughout their length. To these rods, and at equal distances, small stages or platforms, A B C, and A′ B′ C′, are securely fixed. An alternate upward and downward movement is given to each of these rods; while the rod R, with its stages, is ascending, the opposite rod R′ is descending. This movement brings the platform A on the rod R opposite to the platform B′ on rod R′, and the platform B opposite the platform C′. The motion is then arrested for a moment, and is immediately afterward reversed, and the platforms return to their original position. If miners are standing upon the platforms R, they will all be raised by the upward movement a distance equal to half the distance between the platforms. At this point, the motion ceasing, the miners step from the platforms of the rod R to those upon the rod R′, and by the next movement are again lifted, when they step across as before, and so on until the top of the shaft is reached. The descent is similarly accomplished.

In some mines only one of the rods moves, and the other remains stationary, or rather the second rod is omitted, and stages are fixed to the side of the shaft in the rock itself; in such cases the single rod has to move the whole distance between two stages instead of half that distance, as when two rods are used. When a single rod is used in connection with fixed stages, the miners pass alternately from the stage on the rod to the stage fixed in the rock. They then wait until the half stroke brings a fresh stage opposite to them, on which they place themselves, and so on.

The distance between the two stages on the same rod generally varies from 4·50 m. to 8·00 m. The stroke of the apparatus with two movable rods is always half the distance between the stages, consequently it varies from 2·25 m. to 4·00 m. There are from four to eight double strokes per minute.

The single-rod man-engine is the one most used in Cornwall. It makes three strokes of 12 feet each per minute. The rods are generally about 7 or 8 inches square, decreasing in size towards the bottom. The weight is counterbalanced by levers or by balance-bobs, attached at different levels.

Motion is imparted to the rods of the man-engine by means of water wheels with cranks, steam engines with crank motion, or direct-acting steam engines, the two rods being connected by balance beams in such a way that their motion, though inverse, is equal and simultaneous.

The crank motion is particularly well suited to the movement of the man-engine, inasmuch as the velocity of the movement decreases gradually at the beginning and end, and becomes almost nothing as the crank passes the centre, thus giving time for the miner to step from one beam to the other, or from the beam to the stage fixed to the side of the shaft.

When direct-acting engines are used, there is a stoppage after each stroke to give the miners time to pass from one stand to the other. This stop varies from two to eight seconds, which is ample, as the passage from one stand to the other does not take more than one second. This would be a very good system if the stop were always rigorously the same. But all who have worked the machine with direct single action and cataract know that it is impossible to obtain this regularity. The irregularity may indeed cause accidents. The miner, relying on the normal time of the stoppage, may be surprised in the midst of the movement he is making, and as the single-action engine starts suddenly, and very quickly acquires a great velocity, he may have one leg roughly taken up while the other remains on the stage which rapidly goes down.

When the man-engines receive their reciprocal motion from a crank on a revolving shaft, there is, so to speak, no stoppage. The stages which approach each other are hardly on the same level when they separate again; but by taking care to have the machines provided with regulators and heavy fly-wheels, the movement is regular, and there is no change to surprise the miner at the moment of his passage from one stage to the other.

It must not be forgotten that the movement of the machine being uniform, that of the connecting rod which commands the man-engine is variable. It is very slow at the commencement of its stroke, is accelerated at the middle of the stroke, and becomes slow at the end. The miner, thanks to the regularity of the movement and the slowness of speed, when the stages approach the same level and separate from each other, can begin his passage from one rod to the other a little before the stroke, and continue it a little after.

Man-engines worked by direct-acting engines, in order to raise the same number of men in a given time, must move more rapidly than when the motion is communicated by a crank.

The machine with single action predominates in Belgium, while the crank machine is more used in Germany and England. The single-acting machines are generally placed directly over the shaft.

These engines are composed of two steam cylinders joined together; the piston rods are attached directly to the man-engine. The steam acts directly and alternately underneath or above one or the other of the pistons.

But there is an important condition to be observed, which complicates this arrangement a little. The platforms of the man-engines must have exactly the same velocity, and the strokes must terminate at exactly the same moment, so that both sets of platforms will be connected. This problem has been solved in two principal ways.

One method designed by M. Havrez, is to connect the rods by a pinion, as shown in Fig. 495.

A strong rack is placed on each rod, and these work into opposite sides of the same pinion, steadied by an intermediate guide-rod. Uniformity of motion has thus been secured, for it is evident that when one rod descends the other must move simultaneously and equally. Every precaution has been taken by the constructor to prevent breakage. The teeth of the pinion and the racks are strong and carefully cut; and very few accidents have occurred.

The other method consists in extending the piston rods through the upper cover of the cylinders, so that these two rods may be connected by a chain working over a pulley. They then necessarily move simultaneously. As a pulley working between the cylinders would have too small a diameter, two leading pulleys are placed over the cylinders surmounted by a larger one.

M. Havrez has also proposed to do away with the racks and pinion by the substitution of two balance beams connected with a third and central balance.

When the motion is imparted, not by a direct-acting engine, as we have just been considering, but from the rotation of a crank, it is also necessary that the two rods should be connected together in order to secure an equal amplitude and speed of movement. In general, balance-beams and varlets are worked together by a connecting rod moved by another connecting rod, taking its motion from a gearing, the pinion of which is placed on the main shaft of the steam engine.

The power required for the movement of the man-engine varies from ten to fourteen horse-power for 100 metres of height. The amplitude of motion varies from 2·25 m. to 4·00 m. In Cornwall it is about 12 feet.

The rods are either made of wood or of iron. Iron is lighter, with the same power of resistance, and requires less room.

Whether the rods are made of wood or of iron, they are all made with a decreasing section from the top to the bottom of the apparatus. The wooden rods are made in two ways—either of beams adjusted end to end, like the rods of lifting pumps, or they are made with planks, the ends of which are stepped together, as indicated in the annexed figure. Gradually, as the load to be carried allows of it, a plank is left out so as to reduce the weight as much as possible, and yet retain all the necessary solidity. Iron rods have been made in various forms, but generally in the shape of angle iron. The round or flat iron has the inconvenience of allowing too much vibration, especially at the bottom.

The number of rods for each side of the man-engine may be 1, 2, 3, or 4. The single rod is generally used in the inclined shafts. It is composed of a piece of wood running on rollers at about 6 or 8 metres apart. These rollers of wood or cast iron are laid on sills of wood fixed in the rock.

The stages or platforms are made of planks large enough to receive both feet, and are firmly supported by iron brackets below; iron handles are securely fixed by bolts to the rods, at a height of about 1·00 m. to 1·30 m. above each stage, to enable the miner to keep his balance.

Where the rods are separated by fixed ladders, as in some instances, the distance required to pass over from one stage to the other varies from 0·65 m. to 0·75 m., which renders the apparatus incommodious and even dangerous. The stages are sometimes made large enough to carry two men at once, which permits the miners to pass each other with ease in going up and down, some ascending while others are descending; but in Freiberg the miners pass each other without much difficulty on the small and single stages.

The landing places or stages are made of the lightest wood possible, and their dimensions vary according to the space at command; they should not be less than 0·50 m. to 0·60 m. square; but some are made with are only 0·40 m. But with these small dimensions they are dangerous. These stages are generally put in iron frames, which serve at the same time to bind the rods. When two stages, one on the ascending, the other on the descending rod, are level with each other, the distance which separates them varies from 0·03 m. to 0·25 m., and even to 0·30 m.

When the space is wide, there is danger in crossing from one stage to the other, for the miner may step into the empty space and be precipitated to the bottom. But if, on the contrary, the space is very narrow, the passage is very easy, but there is danger that the miner may imprudently let his head or his shoulder project beyond the stage on which he is, so as to be struck or caught by the stage of the opposite rod during the movement. This difficulty is avoided in two ways—either by making the stage in two pieces, one fixed and the other hinged, so that it rises when it meets with an obstacle, or in fixing under each stage inclined planks, well dressed and smoothed, which push against an obstacle and force it back within the limits of the opposite stage. This last plan can only be used where the movement of the man-engine is not too rapid; if the motion is rapid, the first is preferable. The hinges of the stages are made either of copper or of very strong leather to avoid oxidation. In the mines of Freiberg, Saxony, the stages are not placed opposite each other, but side by side.

The rods and stages work in guides at distances which vary from 20 to 50 metres from each other. But this is not sufficient. It would not be prudent to leave such a mass, 200 to 500 metres long, suspended without any other support.

The whole weight is therefore balanced by what are called balance pulleys. They are placed two and two alongside the rods. The opposite rods are then connected by chains, which pass over these pulleys and thus sustain a part of the weight of the rods. The weight of one rod also counterbalances the weight of the other. Adjusting screw rods at the ends of the chains give the means of changing the length of the chain so as to secure the proper strain on each support or pulley. The arrangement of the rods, the central ladder-way, and the balance pulleys and chains, are shown in Fig. 496.

The hydraulic balance has been tried for the same purpose. It is composed of two pistons: one is placed on the first set of rods, the other on the second. To these pistons two pump-barrels correspond, connected with each other by a pipe giving free communication. The descending set of rods, taking the piston with it, forces the water into the other pump-barrel, and as the water has no outlet, it forces up the other piston, lifting the other set of rods with it.

The hydraulic balance would be very good if the packing of the piston could be kept tight. Unfortunately it cannot; water is lost, and then the descending piston does not transmit its pressure to the rising piston before some part of the stroke is lost, so that the balance is disturbed. It has been abandoned for this reason. When the man-engine is single-acting—that is to say, where there is not more than one rod and the other rod is replaced by a line of fixed stages—the rod must be balanced to prevent the shock it would receive at the bottom by the impetus gained during its descent. This balance can be obtained by chains attached at different heights of the lift, passing them over pulleys attached to the rock and attaching to their ends counterpoises of sufficient weight. Such an arrangement is very dangerous from the liability of the chains to breakage.

In England such pulleys are replaced by beams carrying balance weights; but although this arrangement is safer, it is much more expensive. The stroke, always a long one with a man-engine, requires beams of large dimensions, and they cannot be lodged in the shaft without making very large excavations in the rock, which are very expensive.

In order to estimate the time required for the ascent and descent of miners by the man-engine, let us take as an example, 400 metres of depth, and 200 men to send down or lift up for each shift.

Allowing the stages to be 6 metres distant from each other, and the man-engine to make 6 double strokes per minute, in one minute a man will then have passed upon and from 6 stages; he will then have been lifted 6·00 m. × 6 = 36·00 m., and consequently will rise the 400 metres in $\frac{400}{36} = 12$ minutes, in round numbers. Each double stroke thereafter will deliver another man at the surface, or, which is the same thing, the machine will lift 6 men per minute; the 200 men will therefore arrive at the surface in $\frac{200}{6} = 34$ minutes in round numbers, which, added to the 12 minutes required for the whole ascent of the first man on the stages, gives in all 46 minutes; doubling this for the lowering and lifting of one shift of men, we have 92 minutes, 1 hour and 32 minutes, for the whole, and that without any danger or fatigue.

CHAPTER IV.

PUMPING MACHINERY.

Machinery for raising water from mines is of two kinds. When the quantity of water to be dealt with is not very great, it may often be economically raised by means of buckets or tubs drawn by the winding engine. This kind of draining machinery has the merit of being very simple in construction and action, and consequently not liable to get out of order. But when favourable conditions for its application do not exist, recourse must be had to pumps. These latter constitute one of the most important portions of the machinery of a mine.

Draining Buckets.—The tub commonly used for drawing water is of iron, and is similar in shape to the kibble, that is, it is barrel-shaped. The capacity of these tubs varies, but frequently it is about 100 gallons, when it is intended to be drawn by the engine. The tub is suspended by a bow turning on two pins, placed a little below the centre of gravity, on the outside of the tub, as shown in Fig. 497. The object of this arrangement is to facilitate the discharge of the contents on arriving at surface. Besides the larger bow which turns upon the pin forming the points of suspension, there is a smaller one fixed to the tub, and passing freely beneath the former. On one side of the tub is a spring catch, which, by laying hold of the larger bow, prevents the tub from tilting in the shaft. When the tub is raised full of water to the top of the shaft, the waiter-on seizes the smaller bow, and, releasing the spring catch, pulls the tub over, discharging the water into a shoot, by which it is conveyed away. The position of the centre of gravity above the axis upon which the tub turns, renders the operation of tipping an easy one. When the contained water has been discharged, the man pushes the tub back into the vertical position, where it is seized by the spring catch; in this state it is ready to be again lowered into the shaft. An objection to this kind of tub is that it does not fill well, the water having to flow into it over the top. The objection to the tub described above may be removed by constructing it with a valve at the bottom, through which the water can enter. This arrangement has been adopted in a very neat and effective manner by Mr. C. Bromley, the engineer in charge of the sinking already referred to. Fig. 498 represents a vertical section of the tub or bucket as constructed by that gentleman. The bottom of the tub, which is about 5 feet in height and 3 feet in diameter, is provided with a circular aperture 20 inches in diameter; this aperture is covered by an iron disc or valve, B, mounted on a central spindle, A, which moves between guides D and E. The under side of the disc is faced with a ring of vulcanized indiarubber, to enable it to close water-tight. When this tub is lowered into the water, the pressure of the latter forces up the valve B and the tub fills. When the tub is full, the valve drops upon its seating, and retains the water. The mode of employing this tub, and conveying away the water, is very simple. In the end wall of the rectangle shown in Fig. 499, is fixed a drain-pipe, 2 feet in diameter, leading to a channel provided to convey away the water. A wooden shoot, C, leads from the flooring to this drain-pipe; and on the platform B rests a trough about 8 feet wide and 2 feet deep, open at the end next the shoot. When the tub is raised to a height slightly above the mouth of the shaft, as in the case of the loaded kibble, the waiters-on push the platform forward over the mouth of the shaft until the closed end of the trough is under the tub. The latter is then lowered gently on to the trough, when the projection F of the spindle, coming in contact with the planking, the valve B is forced up till the tub comes to rest upon the stops X X. The water issues through the valve aperture, and flows down the trough into the shoot, and is conveyed away through the drain-pipe in the end wall. Thus it will be seen that the apparatus is self-acting, and it has been found in practice to fulfil the purpose intended in a very satisfactory manner. A tub of this construction, and of the dimensions shown, weighs about 900 lbs., and contains about 220 gallons of water.

Cylindrical water tubs have been used to a considerable extent in the French collieries. They are usually made with a capacity of 20 hectolitres, equal to 528 gallons, and weigh about 700 kilogrammes. The water enters by a large valve at the bottom, and is discharged through a side orifice. With this form of apparatus for hoisting water, it is necessary, in order to avoid loss of time, to provide guides in the shaft, so that the tub may be drawn up and lowered rapidly. It has also been found highly advantageous to commence discharging the water as soon as the tub reaches a sufficient height above the pit. Instead of bringing the tub of water to a complete rest upon catches at the top of the shaft, it is kept slowly ascending, and strikes a movable knocker or framework, which throws open the discharge valve and lets the water escape. The motion may be stopped as soon as the valve is open; and, as soon as the tub is emptied, it may be lowered without any loss of time. The practical value of this improvement is shown by the results obtained with it at the Lucy pits, near Montceau les Mines. At these shafts, 200 metres in depth, 30 tubs of water, containing 25 hectolitres each, were raised per hour, being a total of 750 hectolitres of water; but this being insufficient, the automatic discharge apparatus was added, and the number of deliveries of tubs of water at the surface was increased to 50 or 60, discharging from 1200 to 1500 hectolitres per hour.

Pumps.—The system of pumps most frequently applied to mining purposes is that known as the Cornish. It consists in having a lifting pump at the bottom to raise the water from the sump, and a series of force pumps, set one above another, to drive it up by stages to surface, the whole of the pumps being worked simultaneously from the main rod. As the depth of the shaft in a mine is great, and as the quantity to be raised is frequently very large, it is obvious that this rod must be very strong, and therefore must possess large dimensions. Usually it is composed of balks of memel pine, perfectly sound and straight, and without knots or faults of any kind, such as are used for the masts of ships, and of as great a length as can be obtained. The lengths are put together by scarfed joints, and secured by stout wrought-iron plates, bolted through the timber. To this main rod, the pistons of the pumps at the several levels are firmly attached by means of a set-off and strong iron straps. These piston rods work through the guides to keep them in a straight line; and, for the same purpose, similar guides are placed at intervals down the shaft against the main rod. The rod where it passes through the guides is cased with hard wood, and kept well greased to lessen the friction. It will be seen from this description that the rods are of enormous weight. In deep mines the main rod alone frequently weighs upwards of 70 tons. The mode of working the pumps is to make the motor raise the rods, and then to leave the weight of the latter to force up the water. As, however, the weight of the rods is usually greatly in excess of that required to raise the water, this excess is taken off by means of a loaded lever, called a balance-lever, or, more commonly, a balance-bob. Fig. 500 shows one of these balance-bobs. It consists of a stout balk of timber *a*, often from 20 to 30 feet in length, turning about an axis at *b*, and loaded at the end *d* by a box filled with stones or other heavy materials. The two ends are supported by iron ties passing over an upright support upon the axis. One of these bobs is placed at surface, and others may be set at intervals down the shaft, the unloaded end being fixed to the main rod *c*. When the shaft is inclined, the main rod is made to rest upon friction rollers; in other respects the arrangements are unchanged by this circumstance. A vertical rod is made to communicate motion to an inclined rod, or *vice versâ*, by means of a bent lever, called a V or angle-bob. As the motor may be situate at a considerable distance from the shaft, especially when the pumps in two shafts are worked by the same motor, the rods are carried along the surface of the ground, and connected with the main rod in the shaft by one of these V-bobs. Fig. 501 shows this arrangement. The horizontal, or, as they are usually termed, flat rods *a*, are attached by means of iron straps to the arm C of the lever and the main rod in the shaft *b* is attached in the same way to the other arm A. When in this position, the V-bob is frequently double, as in the figure, the arms D and B serving as counterweights to A and C. Flat rods are carried upon friction rollers where the surface of the ground is level, and upon vibrating rods where the surface is depressed. One of these vibrating rods is shown in Fig. 502; they are arranged to stand vertically when the pump pistons are at the bottom of their stroke.

Cornish "pit-work," that is, the whole system of pumps and rods, will be readily understood from the accompanying drawings, of which the following paragraphs are descriptive.

The Lifting Pump.—Fig. 503 consists of a cast-iron cylinder, or "working barrel," from 8 to 12 inches in diameter, and from 8 to 12 feet long, smoothly turned inside, in which a closely fitting piston, P, that has an upward opening valve, *v*, may be caused to move up and down by means of a rod to which it is attached. At the bottom of the cylinder is a valve, V, opening upward, by means of which the water once drawn from below into the cylinder is retained there. Below the cylinder is the suction pipe, S, dipping below the surface of the water to be lifted. Above the cylinder is an iron pipe or column of elevation, C, in which the water is raised, by the upward movement of the piston, to any desired height. When the piston in the cylinder is moved upward, its valve remaining closed, and the lower end of the suction pipe being immersed in the water, the pressure of the exterior air causes the water to rise in the suction pipe S, and to pass through the retaining valve V, at the bottom of the cylinder, in accordance with the well-known principle involved in all suction pumps. On the downward stroke of the piston, the retaining valve V, at the bottom of the cylinder, closes, while the valve *v*, in the piston, opens, and the water passes through the piston. On the succeeding upward stroke the water, now above the piston, is lifted by it, while a new supply is drawn into the cylinder in the manner just described, to be lifted by the next upward stroke.

The pipe or column in which the water is raised above the piston is sometimes placed upon and directly over the cylinder, in which case the rod to which the piston is attached passes up through it, and is connected above with the motive power; but commonly the pipe, or column of elevation, is fixed at one side, and connected by a short horizontal or curved piece H, with the cylinder, the top of which is then fitted with a stuffing box *g*. The piston rod passes through the latter, and is then connected with the main pump-rod, R, working in the shaft, from which it receives its motion.

The column may be of any desired height to which the strength of the material is adapted. As the lifting pump is generally only employed at the bottom of the shaft to raise the water to the force pump above, the height of its column varies according to circumstances. In shafts where sinking is in progress, the column of the lifting pump is constantly being extended as the shaft deepens, until a sufficient depth, 200 feet or more, has been attained for the convenient establishment of a force pump, when the lifting pump is detached from the column, the force pump put in its place at a suitable distance from the bottom, and the lifting pump again employed for sinking deeper with a short but gradually extending column.

The Force or Plunger Pump.—In Fig. 504 the water is forced up by the descent of the piston or plunger. This pump consists of a cast-iron cylinder or "plunger case," usually 10 or 12 feet long, and from 8 to 12 inches in diameter, in which a solid cylindrical piston, P, nearly as long as the cylinder, is caused to play with an upward and downward motion; the piston passes through a stuffing box, *g*, at the top of the cylinder, and is then connected with the pump rod, R′, that gives it motion. Below the cylinder is a side or branch pipe, H, connecting the cylinder with a valve chamber *o*, and the column of elevation C. The valve, V, in the chamber, *o*, retains the water drawn through it from the wind-bore or suction pipe, S, which is immersed in the cistern. The valve, *v*, at the bottom of the column of elevation, C, opens for the passage of the water into the column, and closes to retain it there. When the piston ascends, the valve, V, opens, and the space in the cylinder, below the piston, fills with water; when the piston descends, the valve, V, closes, the valve, *v*, opens, and the column of water is forced upward to the point of discharge at any desired height.

The piston, or plunger, of the force pump is a smoothly turned cylinder, 8 to 12 inches in diameter, and 10 or 12 feet long. It is cast hollow, of iron about 1 inch in thickness. In order to attach it to the pump-rod, by which it is set in motion, a suitable piece of timber, considerably longer than the piston, is made to fit evenly into the inside of the cylinder or hollow piston entirely occupying the inner space; being driven tightly in, it is wedged at the bottom. The top, projecting above the end of the cylinder, is then attached to the main pump-rod, R, in manner shown in the figure. Another method, Fig. 505, is to have the plunger cast with a stout flange at the upper end, by means of which a head of cast iron is bolted to it, carrying two uprights with a stout iron pin, as shown in the drawing. To the end of the pump-rod is securely attached an iron stub-end, which is furnished with a strap, boxes, gib and key, forming a connecting link such as is commonly used in attaching the connecting rod of an engine to the crank-pin. By means of this link the pump-rod is attached to the pin in the head that is bolted to the plunger, as just described.

The plunger case and valve chambers rest upon stout timbers, which are firmly established in the shaft in the most substantial manner; the column rests upon the valve chamber, and is itself further supported by timbers fixed at intervals in the shaft, and so arranged as to embrace the pipe directly under the flanges by which the sections of the column are joined together, and furnish a bearing for these to rest upon. This is illustrated by Figs. 506 and 507.

The pump column generally used at the more important pumping works in the Western States of America is a pipe having a diameter of 12 to 14 inches. It is composed of sections of about 10 feet long. The sections are made of wrought iron or boiler-plate, usually $\frac{3}{16}$ of an inch thick, strongly riveted together in cylindrical form. The plate employed is little more than 3 feet wide, so that three cylindrical pieces riveted together form a section of the column. At each end of each section a stout flange of cast iron, as shown in Fig. 506, is riveted to the plate, by which means the sections are connected. In other mining regions the pump column is usually formed of cast pipe. On the Pacific coast the pipe, made as above described, is preferred on account of its comparatively less weight, a consideration of much importance where freights are so high.

It will be seen from the foregoing that the force pump performs its work of raising the water on the downward stroke of the piston, while the lifting pump does its duty on the upward stroke. The force pumps need to be very firmly set, and are therefore only employed where they can be permanently and solidly established in a position easily accessible for repair and not very liable to be submerged. The lifting pumps are well adapted to work in the bottom of the shaft, their method of construction and operation fitting them to draw water from the very bottom of the shaft without the use of a cistern, and to be extended, foot by foot, as the sinking proceeds, not requiring to be placed with so much care as the plunger pumps, and having also the advantage of being operated as well even when the water rises above them in the shaft.

In order to extend the pump in depth as the sinking proceeds, the working parts of the pump, namely, the suction pipe and working barrel, being suspended by heavy chains to a winch or windlass fixed at the station above, are detached, with the connecting pipe from the bottom of the column, and lowered to 10 or 12 feet, sufficiently to allow of introducing another length of pipe under the column already in place; this additional length having been attached to the column, the working parts are again connected with the column thus extended, and are continued in operation until the sinking has so far progressed as to require the addition of another length of pipe, when the above-described proceeding is repeated. Frequently the suction pipe dipping into the pool or sump at the bottom of the shaft is a stout hose-pipe, of diameter equal to that of the short iron pipe below the working barrel, to which it is closely fitted and attached. It is made of one or more thicknesses of canvas, rendered water-tight by applications of tar or other materials of like properties. It has the advantage of flexibility, and may be more easily protected against injury during blasting than iron pipes. The lifting pump discharges into a cistern, from which the force pump takes its supply, to be raised to the surface or to the next cistern above.

The motion of the piston, or plunger, in its cylinder, is imparted to it by the pump-rod, a continuous piece of timber which is suspended in the shaft alongside of the column, extending from the surface to the bottom of the mine, and to which the plungers are attached. The pump-rod is composed of timbers 8, 10, or 12 inches square, joined to each other so as to form a continuous piece. The method of joining the sections composing the rod varies in different mines. In the drawings the rod is of pine, 12 inches square, each section being 30 feet long. The sections are joined by a simple splice, as shown in *a*, Fig. 506, and strapped on four sides with iron plates, 12 feet long, 6 inches wide, and $\frac{1}{2}$ inch thick, securely bolted together by bolts 1 inch in diameter. Sometimes the sections of the rod are joined in a more complicated manner by a bevelled splice and key, as shown at *b* in Fig. 508, and strapped in a manner similar to that just referred to. Also the square ends of the sections may be brought together without any splice whatever, and joined simply by means of the iron straps. The straps on two sides of the rod are formed as shown in Fig. 509, so that a key can be inserted at *c*.

When these keys are driven in as tightly as possible, so as to bring the two ends of the timber closely together, and so prevent any lost motion in the action of the rod, the two straps for the remaining two sides are put on and bolted together.

The motion of the rod is communicated to it from the engine by means of an oscillating "bob," established at the surface. The construction of a wrought-iron bob may be seen by reference to Figs. 510 and 511. The pumping engine drives, by means of the pinion, the pump-wheel, to one side of which is attached, by means of a wrist-pin, one end of the pitman. As the wheel is set in revolution by the engine, the pitman receives a reciprocating motion, the length of stroke being determined by the distance of the wrist-pin from the centre of the wheel.

The other end of the pitman, being connected to the king-post of the bob, causes that to oscillate, giving to the pump-rod in the shaft an upward and downward motion. The upper section of the rod is usually connected to the nose of the bob and the next lower section of the rod by means of a strap and boxes, so as to allow for the vibration caused by the angular motion of the bob; deeper in the shaft the sections are joined together as already shown, forming one continuous piece, which is guided in its movement by timbers, *t*, *t*, Fig. 509, fixed across the shaft at right angles so as to confine the rod on four sides, and prevent vibration.

The timbers, *t*, *t*, which are placed in the shaft at frequent intervals, also serve to prevent the rod from falling far, in case of fracture, by furnishing support to the catching pieces, *d*, *d*, which are attached to the rod for this purpose. These catch pieces are attached by iron clamps or straps which are sometimes applied as shown in Fig. 509, where each clamp embraces the main and only one side piece; or sometimes, as shown in the attachment of the plunger to the main rod in Fig. 504, where each clamp embraces the rod and both side pieces. The arrangement in Fig. 509 is preferred by some, as each side piece is thus attached independently of the other.

The length of stroke, or upward and downward movement of the rod, varies from 3 or 4 to 7 or 8 feet, and the number of strokes per minute varies from 3 or 4 to 10 or 12 according to the size and character of the pump, and the duty required of it. The pump-rod being continuous, where several pumps are employed in a series, one above the other, as in the case of deep shafts, the plungers or pistons of all the pumps so placed are attached to the rod, in manner shown in Fig. 504.

The weight of the rod in most cases considerably exceeds that of the water to be raised, so that, descending by its own gravity, it exerts sufficient force to raise the column of water without requiring additional power from the engine. For the next stroke, however, the engine must lift the total weight of the rod to the required height.

In order to prevent the too rapid descent of the rod, and to equalize the work of the engine on either stroke, counterweights are attached to the opposite ends of the oscillating bob at the surface. The descending rod must raise the counterweight, which, on the reverse stroke, assists in lifting the rod. In deep shafts, as the rod increases in length and weight, additional counterweights are applied by establishing at various stations in the shaft similar oscillating bobs attached at one end to the rod, and bearing at the other end a heavily weighted box.

The German miners have given great attention to pumping machinery, and some of their erections of this character are among the best examples to be met with. In Fig. 512 a view is given of the lower portion of a pumping shaft, showing two lifting sets. It will be seen that the bottom lift is suspended from stout balks of timber firmly set in the sides of the shaft. In this case both sets are lifting; but usually all above the lowest are forcing. The mode of suspension will be understood from the drawing, and also from Figs. 513 and 514, which show a somewhat different arrangement to a larger scale. It will be seen that the method adopted in all cases allows the set to be readily raised or lowered at pleasure. One of the forcing sets of this pump is shown in Figs. 515 and 516.

The details of one of the 28-inch forcing sets of a pump lately erected at a coal mine at Saarbrücken, is shown in Figs. 517 and 518. This pump is worked by a single-acting Woolf engine of an improved design, and with the engine constitutes one of the best examples of mine pumping machinery in existence.

A forcing set with weighted plunger from a mine at Rudersdorf, is shown in Fig. 519. As the action of these pumps has already been fully described, the drawings of the foregoing sets are self-explanatory.

Wrought iron is frequently used by the Germans as a material for the construction of pump-rods. These are made up by a combination of plates and angle iron in various forms of section. Some of the forms are shown in Figs. 520 to 527. The rods are made up in lengths and bolted together, as shown in the drawings. This material offers certain advantages over wood for pump rods. It is remarkable that it has not yet been adopted in England, where iron has been so extensively applied to structural purposes.

Pumping Engines.—The type of engine most frequently adopted for heavy pumping is that known as the Cornish. The following general description of the Cornish engine is given by H. Bauerman, who has added some details of one of the most notable examples to be found in Cornwall.

The engine called Taylor's engine was erected in the year 1840 at the United Mines in Gwennap, now included in the Clifford Amalgamated Mines, and is worked with high-pressure steam, with expansion and condensation. It is single-acting, that is, the steam is only employed for lifting the pump-rods and filling the pump-barrels in the shaft; the return stroke, which drives the water out of the pump-barrels into the rising pipes, being effected by the fall of the shaft-rod, as soon as an equilibrium is established in the cylinder, by opening a communication between the two faces of the piston. The steam piston moves vertically in a cylinder formed of two concentric tubes, the inner one forming the cylinder, and the outer one a protecting case or jacket; the small annular space between the two is constantly filled with steam at the maximum pressure produced in the boilers, in order to keep the walls of the inner cylinder at a uniform temperature. In practice, it is customary to surround the cylinder with other non-conducting envelopes; thus, a shell of brickwork enclosing an air-space is first placed round the jacket, which is further enclosed with coatings of felt, lagged with wood; these outer envelopes are not shown in the model. The piston rod is attached by Watt's parallel motion to the end of a beam oscillating about a horizontal axis, whose bearings are carried on the outer wall of the engine-house. The beam is formed of two parallel cast-iron plates of double L section, bolted together, the two plates being kept a fixed distance apart by wrought-iron pins. The two arms of the beam are of unequal length; the steam piston and mechanism for working the valves are attached to the longer arm, which works within the engine-house; the main pump-rod and rods of the air and feed pumps are attached to the shorter arm, which works in the open air, a gallery projecting from the wall of the engine-house gives access to the bearings on the outdoor side of the beam.

The engine has four valves for the distribution of the steam, three of these are placed near the top of the cylinder and the other one is at the bottom. One of them is a plain disc-valve, with a single conical beating face, and is independent of the engine; the other three are of the kind known as the double-beat or Hornblower's valve, a construction in which the bearing faces opposed to the pressure of the steam are reduced to a pair of narrow conical rings, the valve and its seat being so formed as to present a very large steam passage when open. Of the three upper valves, one is the governor or regulator valve; it is a plain disc-valve, which is maintained at a fixed opening by means of the setting screws on the rod attached to the right-hand pillar of the valve-gear framing. By this valve the steam is admitted from the main steam-pipe through the large hollow column on the right into the top steam-chest. The central valve is the admission valve; it commands the passage whereby the steam at full pressure enters and leaves the cylinder above the piston, and is governed by a system of levers attached to the uppermost of the three horizontal shafts, which are attached to the two vertical pillars or standards in front of the valve cases. The other upper valve is the equilibrium valve; it is placed at the top of a hollow column, through which the steam passes from the upper to the lower face of the piston, in order to establish an equality of pressure at the end of the steam stroke; the movement of this valve is effected by the central arbor. The bottom or exhaust valve, which controls the passage of the exhaust steam from the cylinder to the condenser, is attached to the lower horizontal arbor.

The valves are opened by falling weights, and closed by the action of tappits on the plug-rod, acting on curved handles projecting from the front of the horizontal shafts. The sector-shaped cams and catch levers outside the bearings of the horizontal arbors keep the valves locked in position during the repose of the engine.

The engine is intermittent in its action, a pause being made after the descent of the main rod in the shaft, varying in duration according to the amount of water to be lifted; this is effected by a simple hydráulic regulator, known as the cataract.

The cataract, which is placed in the well below the floor of the engine-house, is a square wooden plunger box, open above and closed at the bottom, with the exception of a small conical hole which can be stopped by a plug attached to a vertical rod; the plunger moves in a square cistern of water a little larger than itself, and is attached to a vertical rod passing through a collar projecting from the right-hand frame pillar; it is further attached by a chain rolling on a sector head, to a double-armed lever which oscillates about a horizontal axis; the shorter arm of this lever is pressed down by a roller at the lower end of the plug-rod, during the up stroke of the engine, a balance-weight being fixed to the end of the opposite arm, which raises the shorter arm when the pressure of the rod is taken off.

The action of the cataract is as follows:—When the indoor side of the beam makes its down stroke, during the lifting of the main rod in the shaft, the cataract plunger is driven down in its cistern, displacing the water in bottom of the latter, which consequently rises above the open top of the plunger box and fills it up; this water afterwards flows out through the small hole in the bottom of the box with more or less rapidity according to the position of the conical plug, and during this time the valves are closed, and locked by their catches, the steam piston is at the top of its stroke with a slightly compressed cushion of steam above it, and the expanded steam of the preceding stroke below it. As soon as sufficient water has flowed out of the cataract plunger to establish the preponderance of the balance-weight on the longer horizontal arm of the lever, the box rises and the rod attached to it opens the exhaust valve, by striking against the catch lever and releasing the balance-weight. The steam below the piston flows away to the condenser, and a vacuum is formed in the cylinder. The catch on the steam-valve is formed by the vertical arm of an angle lever, whose horizontal arm is parallel to the exhaust valve catch, and is connected to it by a parallel bar with a slotted link at the top, which works on a pin at the end of the horizontal arm of the upper catch. When the bottom of the link strikes the pin, the steam-valve is opened in a similar manner to that already described for the exhaust valve. The piston descends under the full pressure of the steam in the cylinder until the link-frame at the back of the plug-rod closes the valve, by pressing against the handle which projects from the top arbor; the sector on the arbor in turning gradually lifting the catch lever, which falls into its place as soon as the end of the cam has passed the notch. The steam is now cut off, and the remainder of the stroke is effected by the expansion of the steam already in the cylinder. The length of the full steam stroke is determined by the position of the link-frame on the plug-rod, the proportion of expansion is diminished or increased by raising or lowering the link by the setting screw on the front of the rod.

The exhaust valve is closed by the plug on the right-hand side of the rod shortly after the closing of the steam-valve; the equilibrium valve is opened at the end of the stroke by its balance-weight; this establishes a communication between the upper and lower faces of the piston, equalizing the pressure on both sides, when the piston is drawn up in the cylinder by the excess weight on the outer side of the beam. The equilibrium valve is closed by the left-hand plug during the rise of the rod; this confines a small quantity of steam above the piston, which forms a cushion by compression, and brings the moving mass to a state of rest.

The condenser and air-pump are connected with the outdoor side of the beam. The latter is surmounted by an open hot well of large capacity. The feed-pump draws its supply directly from the hot well, and forces the water through a double U tube, passing four times through the exhaust pipe, where it is heated by the waste steam on its passage from the cylinder to the condenser. The feed-water is further heated by circulation through a system of horizontal pipes in a flue at the back of the boilers. The steam from the six boilers is collected in a cylindrical steam-chest, with hemispherical ends, cast in two pieces, which are united by a wrought-iron expansion joint. The main steam-pipe passes from the chest, under the floor of the engine-house, and terminates in the right-hand vertical column, at the top of which the governor valve is placed. The main rod which works the pumps in the shaft, is formed of two square balks of timber placed side by side, and united by wrought-iron fish-plates and bolts. The excess weight of the rod, above that necessary to drive the water out of the pump-barrels, is balanced off by five balance-bobs, of which, three are placed underground, and two are at the surface. The latter are cast-iron beams, constructed in a similar manner to the beam of the engine, one end being connected by a wooden rod with the main rod on the shaft, the other carries a wooden box, which is loaded with masses of rock, acting as a counterbalance.

Catch pieces or stops are fixed to either side of the beam, to prevent it going beyond its proper distance in case of breakage on either side. The indoor catch is formed by an iron cross-piece fixed above the beam, which is received on a pair of spring beams, carried on horizontal balks crossing the upper part of the engine-house. The outdoor catch is formed by two pieces of timber strapped on to the front of the main rod; the lower ends of these beams, which are of the same size as the main rod, are caught by a mass of timber formed of horizontal balks piled one above another in the shaft.

The following are the dimensions of the more important parts of the engine:

Diameter of steam cylinder	85 inches.
Length of stroke of piston	132 "
Diameter of regulator valve	10·8 "
" admission valve	15·0 "
" equilibrium valve	18·5 "
" exhaust valve	25·0 "
" main steam-pipe	18·0 "
" exhaust pipe	24·0 "
" condenser	30·0 "
" air-pump piston	37·0 "
" " valve	30·0 "
" hot well	55·5 "
" feed-pump	6·0 "
Length of main beam	34 feet $2\frac{1}{2}$ "
Height of main beam at centre	7 feet $1\frac{1}{2}$ inches.
Length of beam, steam side	17 " $10\frac{1}{2}$ "
" " outdoor side	16 " 4 "
Length from centre of beam to point of attachment of air-pump rod ..	9 " $7\frac{1}{2}$ "
Length of feed-pump rod	6 " 8 "
" stroke of main rod	10 " 0 "
Section " "	24 inches broad. 12 " deep.
Diameter of piston rod	$7\frac{1}{2}$ "
" air-pump rod	$3\frac{1}{2}$ "
" feed-pump rod	$2\frac{1}{2}$ "
" axis of main beam	20 "
" journals	16 "

BOILERS.

4 of 30 feet length, 5 feet diameter of outer shell.	
3 feet 4 inches diameter of inner tube.	
2 of 34 " " 5 " 10 " external diameter.	
Steam-chest	30 inches diameter.
Feed-pipe	$5\frac{1}{2}$ " "

The engine was started in December 1840; its performance was continuously reported in 'Lean's Engine Reporter' up to the end of 1851. The most economical condition of working was reported in September 1842. The mine was then 201·2 fathoms deep; the load on the piston amounted to 75·362 lbs., or 12·05 lbs. per square inch of surface. The engine making five strokes per minute, developed a quantity of work equal to 114·2 horse-power. The quantity of fuel consumed showed an effect of 107,494,580 foot-pounds per bushel of coal of 94 lbs., equal to 1·74 lbs. per horse-power per hour.

The last return in December 1851 shows a duty of 62 millions of foot-pounds per bushel, or 2·9 lbs. per horse-power per hour. The depth had increased to 239 fathoms; the load per square inch to 15·8 lbs., giving a duty of 165 horse-power at a speed of 5·5 strokes per minute. The greatest working speed attained appears to have been in December 1849, when the engine made 7·5 strokes per minute, showing 221 horse-power, with a consumption of 2·4 lbs. per horse-power per hour. The method by which the above duties is computed consists in comparing the amount of coal burned with the theoretical volume of water discharged by the pumps during the period of observation. The actual volume is, however, somewhat smaller, the discharge of the best mining pumps being from $2\frac{1}{4}$ to $2\frac{1}{2}$ per cent. less than the theoretical amount for each lift.

Example of Cornish Pumping Engine.—The Cornish type of engine is illustrated in the drawings, Figs. 528 to 541. It is a compound engine of 150 horse-power, on Woolf's system, erected at the Royal Collieries near Saarbrücken, and is one of the best examples of recent construction. In the drawings the chief parts are denoted by letters as follows:

A, the large steam cylinder; A_1, the small steam cylinder; B, the beam; B_1, a smaller beam to work the steam-distributing valves; D, the steam-pipe; D, D_1, D_2, steam passages between the valve-chests and the cylinders; E, the valve-chest of the small cylinder; E_1, E_2, the upper and lower valve-boxes of the large cylinder; F, the catch-pin on the beam; G, the exhaust steam passage from the large cylinder to the condenser; H, the condenser cistern; I, the boiler feed-pump; K, the condenser; K_1, K_2, the two cataracts; K_0, K, the cataract box and pump; L, the connecting rod between the engine beam and the pump-rods; M, the piston rod of the large cylinder; M_1, the piston rod of the small cylinder; M_2, the air-pump rod; N_1, N_2, the supports for the engine beam; O_1, O_2, O_3, O_4, guides for the connecting rod; P_0, P_1, P_2, the parallel motion rods; P, the air-pump; P, P_1, the cataract weights; Q_0, the cross-head of the piston rod of the small cylinder; Q, the cross-head of the air-pump rod; Q_1, Q_2, Q_3, Q_4, cross-pieces to serve as guides to the pump-rods; R_0, R, columns connecting the cross-pieces Q_1—Q_4; R_1, R_2, longitudinal girders to support the latter; S_0, S, S_1, S_2, the steam-valve rods and connections; S_0, the cataract piston; T_1, T_2, T_3, the framing supporting the three valve rocking shafts; V_0, the cut-off valve; V, hand-valve for warming the large cylinder and for starting the engine; V_1, V_2, V_3, V_4, V_5, the distributing valves of the two cylinders; X, X_1, X_2, X_3, inlet and outlet passages of the condenser; Y, Y_1, balks of timber beneath the catch-pin of the engine beam. The lesser parts of the engine will be pointed out in describing the action of the engine.

Taking the engine in the position shown in the drawings, we find the piston at the top of its stroke, the rods S_1 and S_2 in their highest position, and all the valves closed. The engine is now at rest; only the cataract K_1 is in motion, the rod s being in the act of making its descent. This descending motion brings the tappets d_1 and d_2 into contact with the detents e_1 and e_2, and releases them; the quadrants c_1 and c_3 of the rocking spindles a_1 and a_3 are thereby liberated, and the weighted levers m_1 and m_3 turn the spindles and open the valves V_1, V_3, V_5. The inlet valve V_1 is actuated by the spindle a_1, through the medium of the rod t_1 and the lever o_1; the inlet valve V_3 of the large cylinder is actuated by the spindle a_3, through the rod t_3 and the lever o_3. The exhaust valve V_5 is connected to the same axis by the levers o_5 and p_5 and the axis l_3; the cold-water valve of the condenser is likewise connected with it through the lever o and the rods ff. The valves are raised quickly one after another and in such order that first the exhaust valve, together with the cold-water valve, is opened to create a vacuum, next the inlet valve of the large cylinder, through which the steam passes from the small to the large cylinder, and then the inlet valve of the small cylinder is opened. Fresh steam is now admitted below the small piston, and the down stroke begins.

With the piston, the rods S_1 and S_2 descend. The descent of these causes the tappet r_2 to quit the cataract lever h_2; the weight P_1 begins then to drop and actuates the cataract K_2. As the descent continues, the long tappets q_1, q_2, on the rod S_2 strike against the levers $u\,u$, and thereby turn the spindle a_1; this closes the inlet valve of the small cylinder, whereupon expansion begins in the latter. At the end of the stroke, the lever x is pressed down by the tappet q_3 on the rod S; this turns the axis or spindle a_3 and closes the inlet and exhaust valves V_3 and V_5 of the large cylinder, as well as the cold-water valve of the condenser. By the motion of the rocking spindles the weights m_1 and m_3 are again raised and the detents e_1 and e_2 fall again into the quadrant c_1 and c_3 to hold them. Finally, at the end of the down stroke, the cataract lever h_1 is pressed down by the tappet r_1 and the weight P raised, or the cataract K_1 lifted. The valves are now all closed, and the engine remains at rest, or makes a pause, during a length of time determined by the slow motion of the cataract K_2.

As soon as the cataract rod s_2 has been sufficiently raised by the weight P_1 to bring the tappet d_3 into contract with the detent e_3 and to slightly lift the latter, the quadrant c_2, being liberated, the spindle a_2 is turned by the weight m_2 and the two equilibrium valves V_2 and V_4 are opened, the valve of the small cylinder V_2 is moved by means of the lever o_2, the rods t_2, and a lever upon the spindle e_1, whilst the lifting of the equilibrium valve V_4 of the large cylinder is effected through the medium of a loose collar, having two arms or levers upon the spindle l_3, which is connected on one side with spindle a_2 by the rods t_4 and the lever o_4, and on the other side with the valve by the rods t_6 and the lever upon the spindle l_2. When the pressure above and below the piston has been equalized, the weight of the rods overcomes the resistance, and the up stroke of the engine begins.

When the rods S_1, S_2, begin to ascend, the tappet r_1 leaves the cataract lever h_1, and the cataract slowly descends. The motion of the engine now goes quietly on till near the end of the stroke, when the equilibrium valves have again to be closed. The tappet q_4 now strikes against the lever z, and thereby turns the spindle a_2, with which both the valves are connected. At the same time the weight m_2 is again raised, and the detent e_3 falls into the quadrant c_2 to prevent its return. Finally, at the end of the stroke, the cataract lever h_2, with the weight P_1, is raised by the tappet r_2 and the cataract K_2 drawn up. The steam which was above the two pistons has now passed beneath them; that which remained above, after the closing of the valve, however, is compressed by the continued ascent of the piston, which is thereby quickly brought to rest. A pause now ensues, and lasts till the cataract K_1 again loosens the detents of the inlet and the exhaust-valve mechanism, when the action of the engine already described is repeated.

In starting the engine, it is necessary to introduce fresh steam above the large piston, as the pressure upon the small piston is insufficient to lift the pump-rods. For this purpose there leads from the steam passage D_0, a little in front of the regulating valve V_0, a small pipe, which opens into the connecting pipe D_2, between the large and the small cylinders, and which may be closed by the hand-valve V. From this branch pipe the steam jackets are supplied through the little pipe y. Before starting the engine, steam is sent through both cylinders to warm them, by opening the five steam-valves and admitting steam through the hand-valve. When the cylinders have been sufficiently warmed to prevent any great condensation of steam, the exhausts are closed and steam is admitted above the small piston through the valve V_0, and above the large piston through the valve V. At the same time, for the condensation, the valve V_5 and the injection valve g_3 are opened, and the engine puts itself in motion. After two or three strokes, the flow of steam and of cold water becomes regular, and the engine is left to itself. The inefficiency of the first few strokes is due mainly to the presence of air in the condenser.

This single-acting pumping engine, which has shown a very high degree of efficiency, was manufactured by the firm of F. Wöhlert, in Berlin, from designs prepared by C. Kley, C.E., of Bonn.

A modification of the foregoing type has of late been introduced, and appears to be gaining favour, especially in Germany. It consists in the application of the fly-wheel to the engine. The arrangement usually adopted is to place the cylinders directly over the pump-rods, and to connect the other end of the beam to the fly-wheel. This arrangement is shown in Figs. 542 and 543. It will be unnecessary to describe this engine, the construction and action of which will be readily understood from an inspection of the drawings.

Horizontal Pumping Engines.—The advantages possessed by the horizontal type of engine have led to its adoption for pumping purposes, and recently some very efficient designs have been introduced. Of these, some are intended to run at a high speed, and to drive the pumps through the medium of gearing, while others are designed to act directly, and to run, consequently, at a slow speed. The latter are very suitable where the quantity of water to be raised is not great, nor the lift very high. For large quantities of water and high lifts, the most suitable engine yet introduced is that known as the "Differential" pumping engine of the Messrs. Hathorn Davis, Campbell, and Co., of Leeds, a distinctive feature of which engine is its differential valve-gear. The following description of one of these pumping engines is given by Mr. Davey in a paper read by him before the Institute of Mechanical Engineers in October, 1874:

"In Figs. 544 to 553 is shown the direct-acting differential pumping engine, in which a differential arrangement of valve-gear is employed for effecting the distribution of steam. The simplest form of this engine has a double-acting cylinder, with the power applied direct to the pumps. The compound engine, shown in Fig. 544, has a pair of horizontal cylinders, the back end of the high-pressure cylinder forming the front cover of the low-pressure cylinder, as shown in the plan, Fig. 545. There are two piston rods to the low-pressure piston, which pass through tubes cast on the sides of the jacket of the high-pressure cylinder; these two rods and that of the high-pressure cylinder between them are all fixed to one cross-head, to which is attached the connecting rod for working the pumps. The cylinders are bolted down upon a strong girder bed; and the condenser is carried on a separate bed behind the low-pressure cylinder, the air-pump being worked by a tail rod from the low-pressure piston.

"The differential valve-gear, which is the particular feature of the engine, is shown in Figs. 546 to 549, and its action is illustrated in the diagrams, Figs. 550 to 553. These diagrams are not drawn to scale, but are intended to show clearly the action of the gear, whilst Figs. 546 to 549 show a practical example of its application to a compound engine. The main slide-valve G, Fig. 550, is actuated by the piston rod through a lever H working on a fixed centre, which reduces the motion to the required extent, and reverses its direction. The valve spindle is not coupled direct to this lever, but to an intermediate lever L, which is jointed to the first lever H at one end; the other end, M, is jointed to the piston rod of a small subsidiary steam cylinder J, which has a motion independent of the engine cylinder, its slide-valve I being actuated by a third lever N, coupled at one end to the intermediate lever L, and moving on a fixed centre P at the other end. The motion of the piston in the subsidiary cylinder J is controlled by a cataract cylinder K on the same piston rod, by which the motion of this piston is made uniform throughout the stroke; and the regulating plug Q can be adjusted to give any desired time for the stroke.

"The intermediate lever L has not any fixed centre of motion, its outer end M being jointed to the piston rod of the subsidiary cylinder J; and the main valve G consequently receives a differential motion compounded of the separate motions given to the two ends of the lever L. If this lever had a fixed centre of motion at the outer end M, the steam would be cut off in the engine cylinder at a constant point in each stroke on the closing of the slide-valve by the motion derived from the engine piston rod; but inasmuch as the centre of motion at the outer end M of the lever shifts in the opposite direction with the movement of the subsidiary piston J, the position of the cut-off point is shifted, and depends upon the position of the subsidiary piston at the moment when the slide-valve closes. At the beginning of the engine stroke the subsidiary piston is moving in the same direction as the engine piston, as shown by the arrows; and in the instance of a light load, as illustrated in Fig. 551, the engine piston, having less resistance to encounter, moves off at a higher speed, and sooner overtakes the subsidiary piston moving at a constant speed under the control of the cataract; the closing of the main valve G is consequently accelerated, causing an earlier cut-off. But with a heavy load, as in Fig. 552, the engine piston, encountering greater resistance, moves off more slowly, and the subsidiary piston has time consequently to advance farther in its stroke before it is overtaken, thus retarding the closing of the main valve G and causing it to cut off later. At the end of the engine stroke, Fig. 553, the relative positions become reversed from Fig. 550 in readiness for the commencement of the return stroke. The subsidiary piston, Fig. 548, being made to move at a uniform velocity by means of the cataract, the cut-off consequently takes place at the same point at each stroke, as long as the engine continues to work at a uniform speed; but if the speed of the engine become changed in consequence of a variation in the load—if, for instance, the load be reduced, causing the engine to make its stroke quicker—the subsidiary piston has not time to advance so far in its stroke before the cut-off takes place, and the cut-off is therefore effected sooner, as in Fig. 551. On the contrary, if the load be increased, causing the engine stroke to be slower, the additional time allows the subsidiary piston to advance the farther before the cut-off takes place, and the cut-off is consequently later, as in Fig. 552. This adjustment of the cut-off point, in accordance with each variation in the load, is entirely self-acting, and takes place instantly, however sudden or extensive the variation in the load on the engine may be, consequently the engine is rendered safe in working against variable loads, as it automatically and instantly varies the distribution of steam with every increase or decrease of the resistance. The action of the differential valve-gear is so sensitive and perfect that the load on the engine may be greatly varied whilst in full work without requiring hand control by the stop-valve; engines on this plan may accordingly be employed to pump direct into town mains without the use of stand-pipes or balance-valves.

"The force acting on the subsidiary piston is much greater than that required for moving the slide-valve, the excess being absorbed in driving the fluid in the cataract cylinder through the small adjustable aperture; and as the resistance of the fluid increases as the square of the velocity, a very small variation only in the speed of the subsidiary piston can be effected by a considerable variation in the force upon it; so that the speed is maintained practically constant for a given adjustment of the cataract plug, although the boiler pressure of the steam may vary. The main slide-valve is opened at the beginning of each stroke by the motion of the subsidiary piston, which is controlled by the cataract; and a pause is consequently given at the completion of each stroke of the engine, which allows time for the pump-valves to fall to their seats. Slip in the water is by this means prevented, as well as the shock which occurs when pump-valves close under the pressure from a moving plunger. This freedom from shocks in the pumps is an important point, giving safety from accidents, such as the bursting of pipes; and at the same time the durability of the valves and their seats is materially increased.

"In Figs. 544 and 545 are shown the details of the arrangements for communicating the motion of the engine piston to the intermediate lever of the valve-gear by means of the long lever and the connecting rod, the lever itself being actuated by a connecting rod from the engine cross-head, as shown in the drawing. An independent steam starting or pausing cylinder is provided, the piston rod of which carries a rack gearing into a pinion on one end of a tubular shaft; the other end of the shaft being made with a screw-thread, its rotation traverses the outer end of the lever of the valve-gear, and thereby opens the small slide-valve of the subsidiary cylinder. The slide-valve of the pausing cylinder is moved by tappets by means of a lever actuated by the same lever that works the inner end of the intermediate lever of the valve-gear. The pausing cylinder is itself also controlled by a cataract cylinder on the same piston rod, and the length of pause after each stroke of the engine is consequently determined jointly by the two cataracts; the first regulates the time of opening the small slide-valve for starting the subsidiary piston; after which this piston, under the control of the other cataract, has to travel a sufficient distance for opening the main slide-valve of the engine. The adjustment of the latter cataract also determines the mean piston speed of the engine under the normal conditions of load and steam pressure.

"In Fig. 546 is shown a longitudinal section through the steam-chests and slide-valves of the two cylinders; and Figs. 547 and 549 are transverse sections of the valves. The slide-valve of the high-pressure cylinder has a couple of narrow ports through the thickness of the metal from end to end, as shown in the drawings, the effect of which is that while the engine is pausing at the end of its stroke for the valve to be moved from mid position through the extent of the lap, a communication is established from one side of the piston to the other, so that whatever the amount of clearance space left in front of the piston at the end of the stroke, it becomes all filled with steam that has just done its work behind the piston. This prevents the slight loss that would occur in having to fill the whole clearance with full boiler steam at the commencement of the return stroke; the initial steam has now only to raise the pressure in the clearance from the terminal pressure in the high-pressure cylinder. A double-beat valve is provided in the steam-pipe, and is worked off the main valve spindle by means of a bell-crank lever and a pair of slotted connecting rods; these are fitted with right-and-left-handed screws, so as to afford a ready means of adjusting the degree of expansion in the high-pressure cylinder under the normal conditions of the engine, without the use of a back cut-off slide; the main slide-valve is also relieved from working under the full boiler pressure after the steam has been cut off by the double-beat valve. The slide-valve of the low-pressure cylinder is balanced by means of a steel ring inserted in an annular groove on the back of the valve; this ring is pressed outwards against the steam-chest cover by an indiarubber packing ring compressed beneath it in the groove; and there are also a series of small holes in the bottom of the groove for the admission of the steam pressure behind the packing.

"To avoid the heavy cost of the rods and the incumbrance which they occasion in the shaft, the system of placing the engine underground is sometimes adopted. Of course with such an arrangement the engine must be of the horizontal type. The differential engine is very suitable for this system of pumping, and it has been adopted for raising water in this way in numerous instances. The pumps used are of the forcing class; they draw water from the pump immediately above which they are placed, and force it to the surface at one lift, thus removing the necessity for tanks in the shaft. It is obvious that this system possesses great advantages, but it also possesses some defects. The great height of the lift necessitates the adoption of pipes of considerable thickness to withstand the pressure; any disarrangement of these pipes, or of the pumps, is difficult to remedy; and the engine is liable to be drowned while standing. If steam has to be conveyed to the engine from boilers at the surface a great loss from condensation will occur; but in some instances this objection has been removed by placing the boilers underground. This arrangement, however, does not remove the danger of drowning. Notwithstanding these somewhat serious defects, the advantages offered by the system are so great, that it is probably destined to supersede, in very many cases where the conditions are favourable, the Cornish system with its cumbrous pit-work. In Fig. 554 we have shown this arrangement of the differential pump. The engine is erected at a convenient level in the shaft, and the water is forced up from this level to the surface in one lift. To pump from the bottom level a hydraulic engine is used, as shown in the drawing. This engine is worked by the head of water in the rising main from the steam engine situate above."

An underground pumping engine of good design erected at one of the mines in Germany belonging to the Silesian Kohlenwerks-actien Gesellschaft, is shown in Figs. 555 to 557. It is strongly built and very compact—qualities of the highest importance in an underground engine. The greatest quantity of water to be dealt with was found by observation to be 1·31 cubic mètre a minute; but it was deemed prudent to design the engine for a maximum quantity of 2 cubic mètres. It is a single-cylinder engine, having a fly-wheel and working with expansion and complete condensation. The diameter of the steam cylinder is 0·60 mètre; the stroke is 0·70 mètre; the diameter of the piston rod is 0·075 mètre, and that of the pump piston is 0·190 mètre. The lift is 113 mètres, the suction being 3·75 mètres. The maximum speed is about sixty-five revolutions a minute, and the grade of expansion about fourfold. The pressure of steam is 60 lbs. to the square inch. It has been remarked that when moving at a high speed the friction of the water in the pumps and the rising main is about equal to a head of 7 mètres; thus the total resistance upon the pump piston is that given by a head of 120 mètres.

The pump, as will be seen in the drawings, consists of two separate pump cylinders *a*, *a*, in which wroks a common plunger *b*. Each cylinder is provided with a suction and a force valve, so that the pump may be regarded as double acting. The valves are contained in the chambers *c*, *c*; over the force-valves stand the air-vessels *d*, *d*, and immediately below the two suction valves is a common air-vessel *e*, from which the suction pipe leads into the pump. Originally it was intended to take the injection water for the condenser from the suction pipe, and to lead the water thrown out by the air-pump directly to the suction air-vessel. This intention was, however, ultimately abandoned, because in another instance where the method had been adopted the warm water caused incrustation to take place in the pipe, and after a time portions of the incrusted matter became detached and interfered with the proper action of the valves. In this case, therefore, the condenser draws its water through a special pipe *f*, and the air-pump discharges it into the sump through the pipe *g*. Above the engine is a kind of travelling crane, constructed of tram-rails, for the purpose of readily removing the force-valve air-vessel, and thereby to give access to the valves in case of derangement.

The pipes of the rising main are 0·17 mètre in diameter, and 20 millimètres thick at bottom and 15 millimètres thick at top. The steam-pipe through which the steam is brought from the boilers at surface is about 120 mètres in length, 0·15 mètre in diameter, and 13 millimètres thick. This pipe is covered throughout with felt to prevent condensation. At two points in its length, stuffing boxes are introduced to allow for the expansion caused by the heat of the steam. The loss of steam from condensation is very small.

The engine is fitted with Myer's expansion gear. The condenser is placed beneath the cross-head girder, and by the side of this is the double-acting air-pump, the valves of which are composed of discs of indiarubber. The engine is provided with a stout bent crank-shaft, upon one end of which is the fly-wheel, and on the other end the crank for working the air-pump and the eccentrics for driving the slide-valves. The whole rests upon a strong cast-iron foundation.

The stuffing boxes of the pump are not packed with hemp, but with a packing composed of plates of metal and leather. These boxes are perfectly tight, and wear slowly, while the plunger keeps clean and bright. Each pump-valve consists of a large bronze plate in which are set eighteen small valve seatings having a peculiarly constructed guide over them for the valves. The valves are flat, and have conical edges; the lift is very low. Each single valve with its seating and guide may be easily taken out and replaced by another. An air-vessel feed-apparatus, invented by Riehn, Meinicke, and Wolf, is provided for each vessel. The use of this apparatus is to keep the vessel supplied with air, which, as is well known, gradually diminishes in quantity. The apparatus, which has been found to work admirably, is fixed upon the pump cylinder, from which it may be cut off by an ordinary cock.

The system of erecting the engine underground, and thereby avoiding the ponderous pump-rods required in the Cornish pump, has of late years received a good deal of attention. Where the quantity of water to be dealt with is not great, some of these small direct-acting engines work very effectively, and lead to a notable economy, both in the first outlay and in the cost of maintenance. In shaft sinking they often do good service; in such a case the steam is taken down through a felted pipe from a boiler at surface. Being self-contained, they may be slung in the shaft, and as no rods are required, they occupy but little space. Already these engines are commonly employed, and it may be confidently anticipated that their application to all but heavy pumping work will soon become general. Various designs of these engines are in use; the following may be taken as good types of their class.

Tangye's "Special" pump is represented in section in Fig. 558. A represents an ordinary steam cylinder, provided with a piston, B. Steam is admitted to this cylinder through parts *a a*, and it exhausts through the part *b*; and these parts are opened and closed by the action of the slide-valve *c*, which is of the ordinary construction, and which may be so arranged as to admit steam under the valve, as in the figure, or which may be constructed in any other suitable manner. This slide-valve is seated on the bottom of the steam-chest, D, the ends of which form small cylinders, E E′, bored out to receive small pistons, F F, which are connected to each other by a rod, G, and this rod is provided with two collars to straddle a standard, *c*, which rises from the back of the valve. Small channels, *d d′*, passing through the pistons, F F, form a communication between the interior of the steam-chest and the outer ends of the supplementary cylinders, E E, so that the small pistons are exposed to a uniform pressure of steam from all sides. The supplementary cylinders, E E, communicate through channels, *e e*, with chambers, H H, in the cylinder heads, and communicate with the interior of the main cylinder, A, by means of openings, *f f*; these chambers are bored out to receive piston valves, I I, the stems of which project through the openings, *f f*, into the main cylinder, A, and they communicate by means of channels, *h h*, with the interior of the steam-chest, D; the channels being so situate that the outer ends or heads of the piston valves, I I, are continually exposed to the pressure of steam, which fills the valve-chest. By this pressure the piston valves are forced towards the inner ends of the chambers, H H, whenever the inner ends of these chambers communicate with the exhaust end of the cylinder, and in this position the piston valves close the channels *e e*, leading to the supplementary cylinders, F F, as shown in the figure, where the valve I is represented in position to close the channel *e*, the main cylinder being represented to take steam through the port *a*, and to exhaust through ports *a b*. As the piston reaches the end of its stroke it comes in contact with the end of the stem of the valve I′, which it pushes out into the chamber H, the channel *e* is thrown open, and the outer end of the supplementary cylinder E is brought into communication with the exhaust port *b*. By these means the equilibrium of the small pistons F F is disturbed, and the steam acting on the outer head of piston F causes these pistons, together with the valve, to change their position. The motion of the main piston is reversed, and as soon as that end of the main cylinder containing the piston valve I is brought into communication with the exhaust port *b*, the live steam pressing on the outer head of that piston valve causes the same to fly in and close the channel *e*. In the meantime the steam, passing through the small channels *d d* in the supplementary pistons F F, restores the equilibrium of the small pistons until the main piston, by coming in contact with the stem of the valve I, produces the subsequent change.

The steam piston B connects by a rod J with the pump piston, which works in the cylinder K. By placing the mechanism for changing the steam-valve in the interior of the steam cylinder the piston rod J can be made very short and the two cylinders A and K can be brought close together. The pump cylinder K is provided with a valve chamber L, containing four valves, *j*, *j*, *k*, *k*, and communicating with the ends of the cylinder through channels, with the suction pipe through an aperture *m*, and with the delivery pipe through an aperture *n*. All these channels and openings are exposed by removing the bonnet, so that they can be readily kept clean, and the correct operation of the pump ensured with little trouble.

The valves *j j*, *k k*, are constructed of discs, which are provided with annular recesses to receive a packing of indiarubber or other elastic material; this packing projects beyond the face of the valve, as shown in the figure, and if the valve comes down on its seat the packing forms a tight joint, and the valve is prevented from coming in metallic contact with its seat on account of the incompressibility of the rubber or other packing confined in its recess. The seats *o* are cast of brass or other suitable material, independent of the pump, and they are faced off and then cast into the lining, so that they require no further attention when the pump casting is received from the foundry. In order to retain the seats firmly in their places, they are provided with grooves P P in their peripheries. The cast iron which composes the pump runs into these grooves and retains the seats. The valves *j j*, *k k*, are held in the proper position in relation to their seats by pins *q*, *q′*, which screw into the centres of the seats; and, if desired, springs *r* may be applied to hold the valves down upon their seats. The play of the pump is very simple, and will be readily understood. When the steam piston moves in the direction of the arrow, the valve *j* opens to admit water from the suction pipe, and the water in front of the pump piston is forced out through the valve *k* and through the delivery pipe. When the steam piston moves in the contrary direction, the vales *j* and *k* open, and the valves *j* and *k* close. A pump, constructed for the Adelaide Collieries at Bishop Auckland, has a steam-cylinder 26 inches diameter, and the pump, which is double acting, is $6\frac{1}{4}$ inches diameter, with a 6-foot stroke. The engine-room is situate at a depth of 1040 feet beneath the surface. It is an arched chamber, 100 feet long by 20 feet broad, and 10 feet high at the centre. The boiler, which is double flued, 27 feet long and 7 feet in diameter, is erected at the far end of this chamber, and the pump is placed between the boiler and the shaft. Thus the height to which the water has to be raised is 1040 feet, and this is done in one lift at the rate of 130 gallons a minute.

The "Universal" pump, manufactured by Hayward Tyler and Co., is shown in elevation in Fig. 559. It is remarkable for the simplicity of its parts. As in the special, the only portion of the mechanism exposed to view is a few inches of the piston rod between the steam and pump cylinders, and this portion is protected from blows by a half cylindrical casing. Another remarkable feature is its compactness. A pump with a 15-inch steam cylinder and a 12-inch pump cylinder, capable of raising 28,000 gallons an hour, occupies a space of only 8 feet 4 inches by 3 feet 1 inch, the weight of such a pump being only two tons. This is a great advantage in all cases, but especially in mining operations, and as they are self-contained they require little foundation. These qualities render them peculiarly suitable for placing in the workings, as they occupy little space, and may be easily moved forward as the heading advances.

The essential feature of the Universal pumping engine consists in having a cylinder and piston so suited to each other that the piston will perform the functions of a valve in opening and closing the ports of the inlet and exhaust passages. This is accomplished by making the piston as much longer than the stroke as is required to cover the steam-ports at each end and exhaust apertures in the centre of the cylinder lengthwise alternately at the same time when in operation. Besides this there is an arrangement of steam passages to the interior of the piston, in which a piston valve is so arranged with its steam passages and cavities, as to properly communicate with the passages in the piston to change and direct the flow of steam alternately to each end of the cylinder for the purpose of producing the reciprocating movement of the piston without external valve-gear. The nature and construction of the various parts will be better understood by reference to the accompanying drawings.

Fig. 560 is a longitudinal sectional view through the steam cylinder and pump; Fig. 561 is a plan showing the steam cylinder and piston in section, and the pump with air-vessel removed; Fig. 562 is a transverse section of the steam cylinder, piston, and valve. A A is the steam cylinder, B the piston, and C the piston valve within it. G is the steam inlet pipe, and H the exnaust pipe; *m*, *m*, are rods connecting the covers I, I, of the piston; *k*,*k*, springs surrounding the ends of the piston; *a*, is a lubricating cock, and *b*, *b*, are drain cocks; *o* and *n* are guide-pins for preventing rotary motion in the piston valve and piston. The action of the steam in the cylinder and the working of the piston are as follows:—Steam enters through the inlet pipe G, Fig. 562, and has constant access to the interior of the piston through the aperture *d* and the elongated slot *g* in the side of the piston. It also enters the interior of the piston valve through the rectangular opening *h*, which is in constant communication with the inlet pipe. It should be remarked that this aperture is made above the centre of the piston valve in order that the steam may exert a pressure downwards greater than in any other direction, and thereby causes the bottom surface of the piston valve to slide steam-tight. The steam passes down the ports and passages, as shown by the arrow, and thereby has access to one end of the piston, causing it to make a stroke. On or near the termination of the stroke, the piston causes the elongated slot *g* in its side to pass over the opening *d* in the side of the cylinder, communicating by a passage with the opening *e*, over which passes, simultaneously with the latter, an orifice and passage *a* in the piston leading directly to the inner chamber wherein the piston valve works. Hence the steam gets access to the back of the piston valve, and forces it to the opposite end of its traverse; the steam on the opposite side having at the same time free access to the exhaust pipe through the passage *b*, *b*, in the piston similar to the passage *a* before mentioned, which passage *b*, *b*, passes over a corresponding aperture *c′* in the centre of the length of the cylinder. Thus the piston valve, on the principle of the D slide, changes the direction of the steam, at the same time opening the exhaust communication, and causing the piston to make a return stroke, the steam escaping, as shown by the arrows, down through the aperture and the exit pipe H. A certain amount of lead is given to allow the steam to exhaust before steam enters on the other side. This is accomplished by permitting the passage *c* to communicate with each exhaust passage leading to the back of the piston valve, a little before the slot *g* covers the aperture *d*.

Fig. 563 is a transverse section of the pump, a longitudinal section of which is shown in Fig. 560. A suction pipe W, is affixed either side of the chamber W as may be necessary, a portion of which chamber is below the barrel of the pump, and communicates by passages outside and surrounding both sides of the barrel with the suction valves P P, from where it has access to either end of the pump. The water is thence forced up the passage R′ and through the passage R, the latter of which has a diagonal and horizontal direction leading to the delivery valves *y*, *y*, whence it enters the chamber S. To this chamber a discharge pipe T is affixed, capable of being used on either side to suit convenience. This arrangement of the water passages and valves, so that the suction and delivery pipes can be attached to either side of the pump, allows the valves to be got at for repairs or other purposes without breaking and renewing pipe-joints. This pump works with remarkable ease on account of there always being a cushion of steam at the instant of reversal, both in the case of the valve and the main piston. It is readily erected and as readily removed ; it occupies but little space, does not easily get out of order, and altogether may be taken as a good example of the system of underground pumping engine at present existing.

In Parker and Weston's steam-pump, shown in Figs. 564 to 576, the distinguishing feature, as in all others of the direct-acting class, consists mainly in the valve movement in the steam cylinder. In designing this valve motion the patentees had two objects in view, first, to get a positive motion by means of a simple valve moved by the steam alone without the use of tappets and other extraneous gear, and, second, to use the steam expansively in the cylinder. How this is accomplished will be readily understood from the accompanying illustrations. Two forms of main steam-valve are used, one being an adaptation of the old Cornish valve, and the second being a common slide-valve moved by two pistons in exactly the same way as the preceding.

In the drawings, Fig. 564 is a longitudinal section of the steam cylinder and valve-chest. A is the steam space in the centre of the chest, B B are the steam-valves; these are in one piece, and fixed to the steel spindle *b*; C C′ are the exhaust valves; D D′ are the valve pistons, which are cast in one piece with the exhaust valves. The valve-chest is semicircular in form, and has four diaphragms cast across it; these have circular seats formed upon them, against which the valves work, the steam-valves opening towards the centre, and the exhaust valves opening outwards. The valves are made of cast iron, and owing to the short travel and the ease with which they come against their seats, they are found to work a long time without any appreciable wear.

Fig. 565 is a plan of the cylinder with steam-chest removed. The steam and exhaust branches are cast on the cylinder, and the steam-chest can, therefore, be removed without disturbing the pipes. E E′ are the main ports to cylinder, and F F′ the exhaust passages; G G′ are passages leading from the cylinder to the spaces behind the valve pistons D D′; in these passages are inserted the ball-valves H H′. These work in brass cages, and are accessible from the outside by unscrewing the brass plugs shown on Fig. 566. The use of these ball-valves will be seen as we proceed.

The motion of the valve is as follows:—Suppose the space A to be filled with steam and the main piston to be travelling in the direction indicated by the arrow, as shown on Fig. 564, steam would then pass through the valve B and fill the Z end of the cylinder. The series of valves would remain as shown until the main piston passed over the reversing port G′, when the live steam rushes up the opening and blows the ball H′ against the passage into the main steam-port and fills the space behind the valve piston D′. As the opposite end D is at the same time exposed to the pressure of the live steam from being in communication with the Z end of cylinders the two-valve piston D D′ are thus placed in equilibrium. The surface of the exhaust valve C′ has only the exhaust pressure upon it, whilst C has the full pressure of the steam; this preponderance of pressure on C causes the whole series of valves to be instantly shot over and the Z end of cylinder put in communication with the exhaust. The steam then fills the opposite end of the cylinder and the main piston moves in the opposite direction, when the piston uncovers the hole G, and the same motion of the valves takes place at the other end.

The ball-valves play an important part in ensuring the certainty of action of the main steam-valve. It has already been stated that when the piston passes the reversing hole G′, the entering steam blows over the ball, closes the opening to steam-port at P, Fig. 566, and allows the steam to get behind the valve piston D′. The instant the valve is reversed the port E is filled with steam, and the end of the cylinder Z placed in communication with the exhaust; but by this time the piston has not moved sufficiently far on the return stroke to cover the reversing port G′; this is now also open to the exhaust, which would have the effect of releasing the pressure from behind the piston D′, and thus destroy the stability of the valve movement. But the steam from the port E at this distance blows the ball over and closes the connection with the cylinder through the passage G′, and allows the full pressure of steam from the port E to be kept on the piston D′, thus holding all the valves on their seats during the stroke of the engine. The motion of the valves is absolutely certain, even at a crawling speed, and must give a full opening for steam and exhaust at every stroke, thus differing from those steam-moved valves whose steam admission depends upon the use of tappets, the main valves of which cannot be insured to move the full travel when the engine is working at a slow speed.

The expansion of the steam in the cylinder is effected by means of a valve entirely distinct in its action from those which control the main piston. The steam is admitted through a branch on the side of the cylinder, and then passes by an oblong-shaped port to the centre of the steam-chest through the expansion valve. The time of the admission of the steam to the upper part of the chest is regulated by a circular valve M, which can be raised at any desired point of the stroke by the admission of the steam under its lower surface. This under surface being of greater area than the top, the pressure of steam upon it overcomes the resistance of the incoming steam by raising the valve, and cuts that steam off from the steam-chest. The construction and action of this valve will be readily understood by reference to the Figs. 567 and 571. K is a hole running parallel with the cylinder, and bored throughout its entire length, and in this hole is fitted a brass tube *s*; this tube is turned round by means of the spindle and hand-wheel, and is kept steam-tight by the stuffing box at the end. Holes are drilled at intervals along the cylinder corresponding to the various points of cut-off. The tube is also perforated, but not in the same horizontal line as the steam cylinder. By turning the tube round, one of the holes at each end is brought opposite a corresponding hole in the cylinder. When the piston passes those holes the steam rushes along the tube, opens the valve L, and raises the expansion valve M, shutting off the further supply of steam to the chest, and allowing the steam already in the cylinder to expand to the end of the stroke.

The use of the valve *r* in the tube is to prevent the cut-off taking place before half stroke. The valve between its faces is longer than the distance between the seats; one or both ends of this valve can thus be open at one time. It is obvious, therefore, that as the piston travels over the holes *o*, *p*, *q*, the steam would find its way along the tube and raise the expansion valve, but the steam shuts the valve *r* until the piston has uncovered the required hole on the other side of the centre, when the valve being thus put into equilibrium the steam finds its way below the expansion valve and produces the desired result. By an exceedingly simple arrangement the expansion valve is made to serve the purpose of a cataract governor, and causes the engine to pause at each end of the stroke. This is effected by placing a small valve, marked L in Fig. 567, and *l* in Fig. 571, in the passage leading to the expansion valve; this valve opens upwards only for the admission of steam, the exhaust from the under side of expansion valve takes place through a small orifice, the area of which is regulated by a screw not shown in the drawing; by this means the engine can be made to pause at the end of the stroke, as no new steam can be admitted to the chest until the expansion valve is allowed to open.

The drawings numbered 564 to 571 show the valve-gear as applied to a direct-acting pumping engine with an 18-inch steam cylinder, and 8-inch pump with 36-inch stroke, now at work in a colliery in South Wales, and forcing 1300 gallons per hour to a height of 252 feet.

From diagrams which have been taken from some of these engines the saving in steam is seen to be very marked, and this fact removes the objection commonly urged against this class of pumping engine on the score of a comparatively great expenditure of steam.

Figs. 572 to 576 show another form of steam-moved valve, consisting of a semicircular slide-valve moved by two pistons. Fig. 572 is a section through steam-chest. The slide-valve is made in a separate piece from that forming the piston *l'* and the centre *c*, and has merely end contact with them; the pressure of steam acting on the back of the valve keeps it tight to the face as in a common slide-valve.

The steam is admitted to the chest through an expansion valve *d*. The cut-off is not made variable in the smaller sizes of pumping engines, the steam being generally cut off at two-thirds of the stroke; one hole, *n*, is drilled into the cylinder immediately under the expansion valve, the valve is thus raised each time the piston passes the hole. When it is desired to give the valve steam during the whole of the stroke the stop *e* is screwed down and thus prevents the valve from rising. The movement of the valves will be readily understood from the following description and an examination of the drawings.

In Figs. 574, 575, and 576, *f f'* are passages communicating with the main steam cylinder and the small cylinder in which the valve pistons *l l'* work. In these pistons small ports are formed having certain relative positions to the aforesaid passages *f f'*. Other passages, *g g'*, lead directly from the main steam-ports to the outer end of valve cylinder, and *h h'* are passages from the steam-ports to the inner end of valve cylinders. Suppose the piston to be travelling in the direction of the arrow, the slide-valve would be in a position shown in Figs. 572, 573, and 574, and steam would be passing through the steam-port *k*, and filling the end of the cylinder *z*. Under these conditions live steam is also filling the passages *g* and *h*, and acting on both sides of the piston *l*, at the same time the exhaust is passing out from the end of the cylinder *y* through the main port under the slide-valve, and thence to the atmosphere or condenser; both sides of the piston *l'* are also open to the exhaust. The valve is retained in this position until the completion of the stroke of the engine by the pressure on the outer or larger side of the piston *l*. When the main piston uncovers the hole *f'* the steam rushes through and fills the space behind the valve piston *l'*, and thus the outer sides of both the valve pistons are subjected to equal steam pressures, but the inner surface of *l* has the live steam on it whilst the inner surface of l' has only the exhaust pressure, the extra pressure on l therefore shoots the valve over to the opposite end.

As the main piston in reversing has to pass back over the passage f' there might be a slight tendency of the valve to falter, or not to travel the whole distance, owing to the slight loss of pressure which would occur behind the piston l' when the main piston was passing the hole. This is prevented by the following means :—Let the slide-valve open only the smallest amount, the main steam-port will be filled with steam at the same time the outer end of the valve piston l' will have uncovered the passage g', and admitted a second supply of steam behind the piston l'. By this time also both sides of l will be open to the exhaust which has taken place in the z end of cylinder, and the valve is thus carried the full stroke by the pressure acting on the outer end of piston l'. It will thus be seen that there are two distinct causes at work to move this slide-valve, following each other with rapidity and apparently with certainty. The motion can be perfectly cushioned by the small quantity of steam squeezed up on the inner side of the piston l' when it crosses the opening h'. Altogether the arrangements of valve-gear we have described have been very ingeniously and carefully worked out.

A pump of the same class as the foregoing is much used in mining operations in America. This pump, which is known as the "Niagara" pump, is shown in Fig. 577. It is well adapted for mining work, being strong, simple, and efficient. As there are neither piston rings nor interior packing, there is no necessity for removing the cylinder heads. The pump is double acting, there being one plunger to the two cylinders. To pack this plunger, all that is required to be done is to unscrew the nuts shown at the centre of the pump cylinder, slip back the caps of the stuffing box, insert the packing in the stuffing boxes, and replace the caps. One of the advantages of this pump lies in the fact that, as far as is consistent with durability, it is cast in separate parts, so that, in case of breakage, only the part immediately affected need be replaced; the cylinders are separate from bed-plate, water-valve chest, discharge and air-chamber.

The arrangement of water valves in this pump is such that in case of obstructions entering the valve chamber through the suction pipe, the valves may be readily taken out, and cleaned and replaced in a short time. One minute is sometimes sufficient. To take out those water valves, it is necessary to remove only one nut, no further fastening being required, as the valves consist of four square pieces of metal kept in place by a bonnet. The valves present on each face an accurately fitting surface to the valve seat in the chest, so that each of the four surfaces may be used successively. When these surfaces are worn irregular, they may be replaced by blocks of hard wood of a similar form. These valves are usually made of a special composition, and for mining purposes are faced with leather; vulcanized rubber valves are sometimes adopted.

The steam-valves used in this pump enable it to start whenever the steam is turned on, no matter at what point of the stroke the piston may be. The general design will be understood from the drawing.

A pumping engine, differing essentially and widely in principle from the foregoing, but applicable to some of the conditions to which these are suitable, is that known as the "Pulsometer." Its action is limited to a lift of about 60 feet; but the extreme simplicity of its construction, and the readiness with which it may be suspended in an excavation, render it a very useful engine for pumping under certain conditions occurring in mining operations. This engine is illustrated in Figs. 578 and 579.

The pulsometer consists of a single casting, called the body, which is composed of two chambers A A, joined side by side, with tapering necks, bent towards each other, and surmounted by another casting, called the neck J, accurately fitted and bolted to it, in which the two passages terminate in a common steam chamber, wherein the ball-valve I is fitted so as to be capable of oscillation between seats formed in the junction. Downwards, the chambers A A are connected with the induction passage C, wherein the inlet valves E E are arranged. A discharge chamber, common to both chambers, and leading to the discharge pipe D, is also provided, and this also contains one or two valves, F F, according to the purpose to be fulfilled by the pump. The air-chamber B is made in the same casting as the chambers, and communicates with the suction. In some instances it is divided by a diaphragm, and one portion communicates with the suction and the other with the delivery. The induction and discharge chambers are closed by covers H H, accurately fitted to the outlets by planed joints, and readily removed when access to the valves is required. G G are guards which control the amount of opening of the valves E E. Small air-cocks are screwed into the cylinders and air-chamber for use, as will be hereafter described. These are the general outlines of the construction of the apparatus, and they are sufficient for the understanding of the nature of its operations. The pump, after being filled with water, either by pouring water through the opening in the chamber, or by drawing the charge, which may very readily be done, is ready for work. Steam being admitted through the steam-pipe *k* by opening to a small extent the stop-valve, it passes down that side of the steam-neck, which is left open to it by the position of the steam-ball, and presses upon the small surface of water in the chamber which is exposed to it, thereby depressing the water without any agitation, and, consequently, with but very slight condensation, and driving it through the discharge opening and valve into the rising main.

It should here be noted that the success of the pulsometer is in great measure due to the arrangements for preventing the steam from being largely condensed by contact with the water or other liquid which is to be pumped during the emptying of the chamber. To this end, the peculiar form of the chambers greatly contributes, but it is also believed that the admission of air through the air-cocks, which is afterward somewhat condensed by the rising of the water, tends to prevent the intimate contact of the steam and water. That a successful result is produced is easily shown by the very small amount of heat which is imparted to the discharged water by the steam which has raised it.

The moment that the level of water is as low as the orifice which leads to the discharge, the steam blows through with a certain amount of violence, and being brought into intimate contact with the water, an instantaneous condensation takes place and a vacuum is in consequence so rapidly formed in the just emptied chamber that the steam-ball is pulled over into the seat opposite to that which it had occupied during the emptying of the chamber, closing the upper orifice and preventing further admission of steam, and allowing the vacuum to be completed; water immediately rushes through the suction pipe, lifting the inlet valve E, and rapidly fills the chamber A again. Matters are now in exactly the same state in the second chamber as they previously were in the first chamber, and the results already described are repeated. The change is so rapid that even, without an air-vessel on the delivery, but little pause is visible at the discharge opening, and the flow of steam is, under favourable circumstances, very nearly continuous. The air-cocks are introduced to prevent the too rapid filling of the chambers on low lifts and for other purposes, and a very little practice will enable any unskilled workman to set them by means of the little milled nut, so that the best effect may be produced. The action of the steam ball is certain, and no matter how long the pump may have been standing, it will start as soon as steam is admitted.

The steam-ball, if not at once made true, wears itself and its seat true, as it turns in its bed at every stroke, so that no part of its surface falls twice in succession upon the seat. In the larger sizes, instead of the balls, valves are used, having faces fitted into shoes of iron or other metal. The faces are of hickory, boiled in oil, the end of the grain being exposed to the wear. An important feature in the pulsometer is the facility afforded for quickly replacing the few wearing parts.

As the pulsometer is capable of raising large quantities of sand and small gravel, it may often beused with advantage for well-sinking, and sometimes even for shaft-sinking, purposes. In quarries it may be applied very successfully.

Pumps for Oil-Wells.—It is desirable to describe here the pump ordinarily used for raising petroleum oil from the bore-holes treated of in a former chapter. These machines are of an exceedingly simple character: but they possess some feature worthy of note. It was pointed out, when describing the process of boring an oil-well, that the rocking lever, or "working beam" as it is usually called, is made sufficiently strong to bear the strain of pumping after the boring has been completed. It is, moreover, constructed and erected with the view of being thus used subsequently, so that all is in readiness to receive the pump as soon as the boring tools have been removed.

The pumps are always of the lifting class, the force-pump being altogether unsuited to the requirements of the case. The pipes used are of wrought iron, two inches in diameter, and are thoroughly tested by hydraulic power before being let down into the well. This tubing is in joints or lengths of twelve or fifteen feet, and these lengths are screwed together by means of a thread on each of its ends, with a close-fitting thimble, or union. The working or pump barrel is usually from five to six feet in length and is of brass, the diameter being from $1\frac{3}{4}$ to $1\frac{7}{8}$ inch, always less than that of the pipes. In the lower end of this is placed the lower valve, or, as it is often termed, "the standing box." The working barrel is then screwed on to the first length of pipe by means of a sleeve or thimble, in the same way as the different lengths are jointed together. The tackle blocks being suspended from the derrick, the swivel is screwed into the other end of the length of tubing. The hook of the lower block is attached to the swivel, and by means of the rope the whole is suspended over the well and let down into it as far as the level of the derrick floor. Clamps are placed across the mouth of the driving pipe under the thimble at the end of the joint and secured by a ring on the end of the handles. The swivel is then taken out with the pipe-tongs, and another length of tubing attached, and the whole is lowered to the floor level as before. The pump is lowered in this way to the depth required, which is usually near the bottom of the well, but may be anything short of that.

The pump-rods, called "sucker rods," are of ash or hickory, $1\frac{1}{4}$ inch to $1\frac{1}{2}$ inch in diameter, and from 24 to 28 feet in length. The sucker or working valve is fixed to the end of one of these lengths of rod, each end being provided with a screw-thread and thimble alternately. The first length of rod with the valve is lowered into the tubing, and another length screwed on. The lowering and attaching is continued until the valve goes into the working barrel. The attachment is then made with the working beam by means of a rod passing through a stuffing box. The work of pumping is then commenced and carried on in the same manner and by the same means as the boring, the sucker at the end of the rods acting upon the standing valve in the working barrel. This sucker is packed with heavy sole leather compressed into rings that fit closely around it. These wear away rapidly, as the oil is very destructive to the leather.

A section through an oil-well pump is shown in Fig. 580. An enlarged view of the upper pump-box is shown in Fig. 581, and one of the lower box, in Fig. 582. The stuffing box is shown in elevation in Fig. 583.

WATER-PRESSURE ENGINES.—In mountainous regions, where water under a considerable head or pressure can be had, it may be advantageously utilized for pumping, hoisting, or other mining operations requiring power, by means of hydraulic engines and surface or underground wheels. There are many places where such engines might be introduced with advantage. They are usually constructed for pumping only, and are single acting, with long cylinders placed vertically over the pump-shaft, the pump-rod being simply a prolongation of the piston rod. The water is admitted to the under side of the piston, and when it has run its upward stroke the water is allowed to flow out and the piston descends.

The absence of any sensible elasticity in water renders the motions resulting from its use under pressure in engines susceptible of perfect control; but the same inelasticity causes sudden shocks and blows to the moving parts if the inlets and outlets are made as in engines actuated by the elastic fluids, steam or air. It is therefore necessary to use valves of peculiar construction, by which the flow of the water may be gradually increased or slackened, and to provide other means for preventing impact and securing smoothness of action.

Many such engines have been constructed for pumping mines abroad, and have worked successfully for long periods with very little expense or attention. One was erected by the engineer Trevithick at the Alport mines, in the year 1803, and worked continuously for forty-seven years, until 1850, when work upon the mines ceased. In this engine the water was admitted first upon one face of the piston and then upon the other, alternately, and the inlets and outlets were opened and closed by two pistons at the side.

An engine was erected by Mr. Darlington at these mines in the year 1842, and worked till 1852, when on the opening of the mine it was removed and re-erected at Talargoch mine. It is remarkable for simplicity of construction as well as for its unusual dimensions. The piston rod passes through the bottom of the cylinder, and is attached directly to the pump plunger by a wooden rod in the shaft; the distribution gear consists of a pair of cylindrical valves, with feather-edged beating faces, the inner one serving for the admission, and the outer one for the discharge of the driving water; a pair of sluice valves or slides are placed, one in front of the admission valve, and the other behind the discharge valve, for regulating the speed of the engine by checking the velocity of the water. The pair of small pistons placed between the main valve-boxes and the cylinder are auxiliary valves for continuing the admission and exhaust through reduced apertures after the main valves are closed, in order to prevent the shock caused by the sudden closing of the large valves. These relief valves are worked by enlarged gearing placed below the valve nozzles. The pump plunger is loaded at the top, the weight of the rod not being sufficient to press the water out of the pump cylinder. The pump-valves are tubular beat-valves, similar to those used in town waterworks engines. The following are the principal dimensions :—

Diameter of cylinder, 50″; diameter of pump plunger, 42″; stroke of piston and pump, 120″ = 13 feet.
Height of driving column, 132 feet; height of pump lift, 140 feet.
Pressure on the piston, 112,500 lbs., or about 60 lbs. per square inch.
Average working speed, 4 strokes per minute; with a maximum speed, 7 strokes per minute.
Effective horse-power, 168 H.P.
The volume of driving water per stroke, 852 gallons; discharged by the pump per stroke, 600 gallons.

WATER WHEELS.—Water wheels are very commonly used for pumping, and they constitute very economical motors. It is to be regretted that they are not more frequently adopted in places where water power is available. The kind of wheel generally in use is the vertical over-shot or breast wheels; but of late the horizontal wheel or turbine has been rapidly growing into favour.

Horizontal Wheels.—In Figs. 584 and 585 is shown one of the vertical water-wheels used for pumping at the Devon Great Consols mine, near Tavistock.

These wheels, which are driven by the water of the river Tamar, work the pumping machinery in three shafts placed at a considerable distance from the river, by lines of rods carried on guide-rollers over the side of the hill. Each wheel has 112 buckets, each formed of two deal boards, whose ends rest in sockets formed on the cast-iron rings or shroudings. The inner platforms or backing of the buckets are also formed of deal boards. The axles are made of oak, tired in the centre with a cast-iron ring, and terminated on each side by cast-iron cylinders carrying the "bosses" or radial sockets for the arms. The outer sides of these castings are flanged, and to the flanges, covering plates carrying the journals are secured by screw-bolts. The ring of the wheel is supported by arms arranged in four series; those forming the two outer series are socketed at their outer ends into seatings on the shroudings, and at their opposite extremities they rest in sockets on the axles. The arms of the other two series incline inwards from the seatings on the axle, and unite midway below the centre of the backing, where they are bolted to a cast-iron ring, so as to form a support for the ring of the wheel equidistant from both shroudings. The power is transmitted from a crank at each end of the axle by a wooden connecting rod. These connecting rods are kept at their proper distance apart by a cast-iron transverse beam. The forked ends of a line of round wrought-iron rods, $3\frac{1}{4}$ inches in diameter, are carried upon guide-rollers. The water is laid on to the wheels at a point about 20° below the summit.

Principal dimensions:—Height of wheels, 40 feet; breadth of face, 12 feet; breadth of feed launder, 10 feet; diameter of oak axle, 5 feet; diameter of journals, 15 inches; length of crank-arm, 3 feet 6 inches and 4 feet (each crank has two sockets for varying the length of the stroke). The actual lengths of the lines of rods are 360 fathoms for one wheel and 396 fathoms for the other. The usual working speed is four revolutions per minute, or a velocity of rather less than $8\frac{1}{2}$ feet per second at the circumference. The weight of the cranks and connecting rods are balanced by a pair of balance-bobs placed behind each wheel.

Turbines.—The turbine, or wheel with a vertical axis, offers some important advantages over that with a horizontal axis, such as the kind described in the preceding paragraphs. The latter are necessarily of large dimensions, and turn with a low velocity. This low velocity may be an advantage when pumping is the work to be done, but in other cases, it often necessitates the intervention of multiplying gear. The turbine, on the contrary, is of comparatively very small dimensions, and revolves with a very high velocity. A wheel of this kind, only 27 inches in diameter, erected at St. Blazien, in Baden, under a head of 354 feet, works at the enormous speed of 2300 revolutions a minute. For high falls, the turbine is particularly suitable. It should also be remarked that this wheel will work when wholly submerged.

The turbine since its introduction by the inventor, M. Fourneyron, has undergone some modification in the details of its construction. But wheels are even now frequently erected according to his original designs, and these give very satisfactory results. One of these wheels, erected at St. Maure, is shown in Figs. 586 and 587. The former of these exhibits the wheel in outside and in sectional elevation, and the latter shows in plan the relative positions of the directing curves and the buckets. The direction in which the wheel revolves is indicated by the arrows.

In the drawings, *a a a a* is the shrouding of the wheel, between which are three rows of buckets; *b b* is the dish-shaped plate, on the rim of which the buckets are fixed; this plate is keyed on the upright shaft *c c*, on which is a large spur-wheel gearing into pinions which give motion to the machines; *e e* is a pipe, suspended from the top framing, serving the double purpose of keeping the shaft from the water, and of being a fixture to which the inside plate *d* is keyed; this plate prevents the water from pressing on the foot of the upright shaft, and serves as a floor on which the directing curves *s s* are secured; *l l* are stays for keeping this plate concentric with the wheel that surrounds it; *g g* is a strong frame of wood, to which is bolted the outer cylinder *h h*; this cylinder is truly bored to receive the sluice *i i*, which is made water-tight by a ring of strong leather *j*; *k k* are wooden blocks, stationed all round the inside of the cylinder sluice, which are made to fit between the directing curves *s s* so as to move between them with the sluice; the blocks are intended to cause the water to flow on to the wheel in small streams, as if injected from horizontal bent pipes; *n*, the pivot and foot-step are oiled by means of the tube *m*, which conveys the oil into grooves cut on the upper surface of pivot and oil-box, thereby keeping the foot constantly lubricated; *o* is the lever for raising the footstep when worn; the sluice *i i* in this section is raised as high as the lowest row of buckets. The arrows show the direction in which the water flows from the river on to all the buckets opposite the opening. The sluice is regulated as follows: *q q* are iron rods having their lower ends secured to three brackets *p*, cast on the inside of the sluice; screws are formed on the upper end of these rods, and pass through the eyes of three pinions *t*, having corresponding female screws inserted in them; these pinions gear into the centre wheel *u u*, which revolves freely round the short tube secured on the top of the framing *v v*; the wheel also gears into the pinion *w*. To the shaft of this wheel are connected worm-wheels; by the action of a hand-wheel on them, motion is transmitted to the pinions and screw-rods, thereby causing the sluice to have a vertical movement at the command of the person who attends it; when the sluice is lowered till it meets the margin of the plate *a*, it encloses the directing curves, and prevents the impelling water from entering the wheel, but when the sluice is raised, the water passes through the channels upon the passing buckets with a velocity proportional to the height of the water over it, thus giving motion to the turbine and all the gearing connected to its upright shaft. The reservoir for conducting the water to the wheel is composed of carefully executed masonry, in which are inserted wooden beams *g g*, sheeted with plank, for the purpose of supporting and securing in its place the large outside cylinder *h*; this sheeting forms that part of the watercourse which surrounds the cylinder.

A modification of Fourneyron's wheel, known as the "Leffel" wheel, is much used in America, where several thousands have been erected during the last ten years. In this wheel, the water is taken in on the outside and discharged from the centre. The construction is that called the double system, that is, a combination of two independent sets of buckets, one set having a central, and the other a vertical discharge. Each of these sets receives its water from the same guides. As one set of buckets is placed directly under the other, the combination is effected without increasing the diameter of the wheel. This arrangement allows the admission of the greatest quantity of water to a wheel of a given size, and at the same time gives the greatest area for its escape.

The Leffel wheel is illustrated in Figs. 588 to 593; Fig. 588 is a perspective view of the wheel and Fig. 589 is an elevation of the iron casing or "flume" in which the wheel is usually enclosed.

This casing is composed of two hemispheres bolted together. On the top, is a bridge-tree, firmly bolted on, carrying a broad oil bearing for the support of the upper end of the wheel-shaft. On each side, there is a hand-hole to give access to the wheel. The gate-rod passes out through a stuffing box in the upper portion of the casing, through the centre of which, also through a stuffing box, passes the wheel-shaft. A short tube or cylinder is fixed to the lower portion of the casing, which is intended to be slightly submerged in the tail-water. It will be observed that the water is led into the casing through a pipe at the side, and discharged from it through the short tube or cylinder at the bottom. The internal construction of the Leffel wheel is shown in Figs. 590 to 593.

CHAPTER V.

VENTILATING MACHINERY.

The machines used for ventilative purposes in mining operations consist of boxes or bells, fans, and blowing apparatus. These machines operate either by exhausting the air from the upcast shaft, or by forcing air into the downcast shaft. The former method is by far the more commonly adopted. The fan has of late years been growing rapidly in favour, and is now applied in a great number of mines at home and abroad. There are many varieties of this machine, differing in the details of their construction mainly, but some in the mode of applying the force communicated to the vane. The most important of these varieties will be found illustrated on the accompanying plates.

Bells.—In the cases where small volumes of air have to be dealt with, the simple contrivance known as the "box" or "bell" is often sufficient, and the readiness with which it may be applied leads to its frequent adoption in headings. In such situations, it gives a good ventilative current, with an expenditure of a small amount of force. At the St. Gothard tunnel, the ventilation is effected by bells of large dimensions.

In Germany and in Cornwall, the box is commonly employed for ventilating the ends of levels; being usually of small size, and requiring but little power, it is generally attached to the end of the pumping engine. One of these boxes is shown in Fig. 594. It consists of a wooden box of square section, open below and closed at the top, and connected by a wrought-iron rod to a cross arm projecting at right angles from the main pump-rod, by which it is moved up and down in another box or outer case of a similar shape, partly filled with water. A pipe, in communication with the level to be ventilated, passes up through the bottom of the outer box to within a short distance of the top; it is covered with an ordinary clack-valve opening outwards; two similar valves are fixed to the top cover of the inner box. As the rod ascends a partial vacuum is established within the box, as communication with the outer air is prevented by the water joint, and the top valves are kept closed by the pressure of the external air; the valve on the pipe inside therefore opens, and the air from the workings flows in until the change of stroke, when by the descent of the box the air is compressed and opens the two top valves, through which it passes freely into the atmosphere.

The same principle has been applied in Belgium to the construction of large ventilating machines for collieries. At Marihaye, near Liége, a pair of wrought-iron bells or cylinders are employed, each of 144 inches diameter and about 9 feet stroke; they are suspended by chains over guide-rollers, and are driven by a direct-acting horizontal steam engine. There are sixteen suction and an equal number of exhaust valves, which, owing to the small difference of pressure produced, require to be counterbalanced with weights, in order that they may open and shut freely at the change of the stroke. The amount of air drawn by this machine is about 11,500 cubic feet per minute.

The bells used to ventilate the headings at the St. Gothard tunnel are of wrought iron, and are cylindrical in shape. They are placed in a special building at the entrance of the headings. The cylinders are 5 mètres, nearly 16 feet 6 inches in diameter; they are connected by a beam which oscillates about a horizontal axis placed in the middle of its length, and supported upon strong wooden bearings. Motion is communicated to the beam by a water-pressure engine. The two upper or movable cylinders are provided on their upper surface with ordinary force valves. These move in two lower fixed cylinders provided at the bottom with suction valves, and communicating with the heading through a wrought-iron pipe. The oscillating motion of the beam causes one of the bells to suck the air while the other is forcing it out, so that the current is kept practically continuous, there being always one bell withdrawing the vitiated air from the workings, and one discharging it into the outer atmosphere. The construction of these bells is shown in Fig. 595, in which the means of communication with the tunnel will be seen, and the action of the apparatus clearly perceived. Bells of a similar construction were used to ventilate the workings of the Mont Cenis tunnel.

Hand Fans.—Not unfrequently, in metalliferous mines, when a small volume of air has to be put in motion, a fan driven by hand is used. This fan, which is shown in Fig. 596, is of the same kind of construction as that employed for blowing ironfounders' cupolas. It has five radial arms with flat rectangular blades, which revolve about a horizontal axis within a cylindrical case or drum, having a circular aperture about 20 inches in diameter in the centre of each of the sides; the outside diameter of the fan is about 4 feet. The air taken in at the centre is discharged through a rectangular tube of 15 inches in breadth and 10 inches in height at the bottom of the drum, and is conveyed through pipes of a similar section, made of wooden planks or sheet zinc, into the forward end of the level to be ventilated. The fan is driven by a wheel 64 inches in diameter, connected by a strap with a spindle of 4 inches, giving sixteen revolutions of the blades for one of the driving wheel. The strap is kept at a proper tension by a friction roller attached to a board, which slides on a pair of horizontal cross timbers, an arrangement which allows the machine to be put out of work without stopping the driving wheel or disconnecting the strap in cases where it is required to be used only intermittently. By putting the central apertures in communication with the air-tubes, the fan can be used for establishing a circulation by exhausting the vitiated air. By surrounding the fan with spiral guide-plates or diffusers, the air, instead of being discharged at a useless velocity against the walls of the drum, may be led off to the discharge pipe more conveniently and more economically. Small ventilators on this principle are now commonly used in the Saxon mines; they have six arms, with blades $8\frac{1}{2}$ inches square and 30 inches in diameter. These fans can be worked by one man at a maximum speed of 400 to 450 revolutions a minute, with a pipe 6 inches square; 60 cubic feet of air can be drawn in that time from a distance not exceeding a quarter of a mile. The quantity of fresh air required by a man at work in the end of a level is estimated at 6 cubic feet a minute.

Fabry's Wheel.—Fabry's ventilator or pneumatic wheel, illustrated in Figs. 597 and 598, is employed to a considerable extent in the Belgian collieries, and in some other localities. It consists of two fans, each of which has three broad rectangular blades, arranged radially and at equal distances apart, around a horizontal axis, connected together by spur gearing wheels, so as to revolve at equal velocities in opposite directions. The fans are hung in a chamber of masonry, which covers about two-thirds of their circumference, the remaining parts moving in the open air. The chamber is rectangular in plan, with vertical side walls; the end walls are segments of horizontal cylinders, whose centre lines coincide with the axis of the fans. These cylindrical walls correspond to the drum in the ordinary fan-blower; they are coated with cement dressed up to a smooth face, so as to give the smallest possible interval between the ends of the blades, without actually touching. The foul air from the mine is brought in through an arched passage in one of the side walls. The space intermediate between the two axes is kept isolated from the external air by a peculiar contrivance, each of the blades has a shorter blade projecting from either face at right angles, which carries a plate curved to an epicycloidal form; these cross arms are fixed at about two-thirds of the distance from the centre of the blades towards the circumference. As the two fans turn towards each other on the inner side (between the axes), a pair of the curved heads, one on each wheel, are continually in contact, preventing any communication between the interior of the chamber and the outer atmosphere. The blades, as they rise, scoop up a quantity of air and deliver it at the outer edges of the chamber, the volume included between two contiguous blades being somewhat less than that contained in a segment of 120° of the cylinder bounded by the curved wall. A quantity of air is, however, carried in by the cross arms from without; this is in form, an irregular five-sided prism, whose bases are enclosed by those parts of two of the blades that lie between the centre and the intersection of the cross arms, the cross pieces on one side of these blades and the cross arms on the intermediate blade of the opposite fan. The volume of this prism is, however, but little greater than that of a cylinder whose radius is equal to the length of the blade between the centre of the axis and the intersection of the cross arms with the blades of the fan. The effective volume removed by each fan, per revolution, therefore, is nearly equal to that of a hollow cylinder whose longer radius is equal to the length of the blade, the smaller one being the point of intersection of the cross arms. These machines are usually made with arms 46 to 48 inches long and about 115 to 120 inches broad. The effective volume removed per minute is equal to rather more than 25,000 cubic feet, at a pressure of from $1\frac{3}{4}$ to 2 inches of water, the wheels making from 36 to 40 revolutions during that time; this requires a disposable effect of 14 steam horse-power, about one-half of which represents the useful mechanical effect.

Lemielle's Ventilator.—Lemielle's ventilator, illustrated in Figs. 599 and 600, is in use at many of the continental mines. This machine has a vertical cylinder, within which revolves a second cylinder or drum, also vertical, the axis of which is placed eccentrically to the outer one. Two portions of the circumference of the inner drum are truncated and replaced by flat sides, to which a pair of hinged doors are articulated. The section of the inner cylinder approximates to that of a barrel, the heads representing the flat surfaces to which the doors are fixed. These doors are kept in constant contact with the inner surface of the outer cylinder by means of rods attached to an elbow or crank formed on the vertical shaft on which the drum revolves, the arrangement being similar to that of the feathering float-boards adopted in paddle-wheel steamers. The central line of the aperture by which the air is introduced makes an angle of about 150° with that of the discharging orifice. The folding door as it advances pushes the air taken in at the feed aperture before it, the contact with the cylinder wall being kept up by the eccentric rod, which causes the door to open out farther, making a constantly increasing angle with the side of the drum, as the distance between the inner and outer cylinders increases; this goes on until the crank has passed its centre, when the door is again gradually drawn in, as necessitated by the diminishing distance between the cylinders, until it reaches the discharging aperture, where it occupies the same angular position with respect to the side of the drum that it did at starting. The volume of the air carried through the machine by each door, as it revolves, is equal to that of a crescent-shaped solid, with truncated points, whose horizontal section is equal to that part of the base of the outer cylinder, that is truncated by a chord, joining the admission and discharging passages, diminished by half the area of the base of the drum.

Cooke's Ventilator.—A ventilator of the same class has recently been introduced by Mr. Cooke. This machine, which is illustrated in principle, though not in the details of construction, in Fig. 601, appears to have given good results. The one shown in the drawing, of which the following is a description, was designed to deliver 180,000 cubic feet of air a minute, with an exhaustion equal to 3 inches of water; or 150,000 cubic feet, with an exhaustion of 4 inches; or 120,000 cubic feet, if the drag of the air is increased to 5 inches.

The machine consists of two drums *a*, each 8 feet in diameter and 16 feet in length, mounted eccentrically on the shaft *l*. The amount of eccentricity of each drum is 2 feet, and each as it revolves moves almost in contact with a cylindrical casing *c*, of 6 feet radius. This casing is closed at the ends by the brick walls which form the sides of the apparatus; they are coated with plaster over those portions against which the ends of the drums work, and are connected at the top of the covering. The casings are not complete cylinders, but are open throughout a portion *d e* of the circumference. The air from the mine is led to the apparatus through the shaft, which is in communication with the space surrounding the casings, and it is drawn into these casings, and finally discharged at openings by the action of the revolving drums *a*, in a manner which we shall now proceed to explain.

The portion of the casing left open is closed by a vibrating arm or "shutter" *s*, hung by the upper edge at *j*, and the lower edge of which is kept closely in contact with the surface of the revolving eccentric cylinder by means of an arm keyed upon a prolongation of the shaft *j*, beyond the side of the machine.

Each arm is 6 feet long between centres, this length corresponding to the distance between the centre of the shaft *j* and the centre *m*, from which the curve of the lower part of the shutter *j k* is struck. In fact, the centre of each arm agrees exactly in position with the centre *m*, to which it corresponds. On one end of each of the main axles *b* is fixed a crank, each crank having a 2-foot throw, and the centre of its crank-pin exactly corresponding in position with the centre of the eccentric drum on the same shaft. Each of these cranks is connected by a link to the end of the corresponding rocking arm, and as the length of this link is equal to the radius of the drum *a* added to the radius *m o* of the lower part of the corresponding shutter *j k'*, it follows that each shutter is kept in constant contact with the drum to which it belongs. The lower edge *k* of each shutter sweeps over a curved surface of plaster *e f*, this plaster, which is held in a hollow casting as shown, enabling a sufficiently tight joint to be made very readily.

The action of the apparatus, which we can best describe by considering the motion of one drum only, is as follows: When the moving parts are in the position directly opposite to that shown in the section, the communication between the interior of the casing *c* and the space surrounding it is closed by the shutter *j k'*; but as the drum *a* moves round in the direction of the arrows, the lower end of the shutter *j k* gradually approaches the shaft *b*, and a space is thus opened between its lower edge *k* and the edge *e*, through which the air can enter the casing *c*, this opening reaching its maximum area when the parts are in the positions shown. As the drum continues its motion, the shutter *j k* returns again toward the position *j k'*, and the air which has entered the casing is swept round to the discharge opening *g*. The curved surface *e f* is made of such length that the lower edge *k* of the shutter keeps in contact with it during the time that the point *p* of the drum *a*, the point of greatest eccentricity, is passing between the points *d* and *e* of the circumference of the casing—and in fact somewhat longer—thus preventing any back leakage.

The two drums *a* are so connected to the engine as to be moving always in contrary directions. One reason for this is, that the air contained between each drum and the interior of its cylinder is nearly a complete crescent, and consequently much smaller at the horns than in the middle. By having a second drum working at the horns when the first is working at the middle of its crescent of air, the two drums are made together to give an equable stream of air in the shaft. A second reason for adopting this plan is, that convenient sizes for mine ventilators are apt to be too long, and if the weight is to be divided this plan admits of the convenient disposition of the engine, while, at the same time, doubling the bearings of the machine. A third reason is, that although the drums are perfectly balanced as respects their own rotation, there remains the reciprocation of the shutters and their levers and connecting rods, which, instead of introducing vibration into the machine, are by this means made to compensate each other through the girders upon which they respectively act. A fourth reason, not unimportant in large machines, is, that the shutter as adopted in the plan (the small weight of this shutter being as much as possible concentrated near the axis, so as to assist its pendulous action, and diminish as much as possible the travel of its centre of oscillation) has the pressure of the air on one side only, and consequently puts a certain strain upon its connecting rod, which, by this duplicate arrangement, exactly counterbalances that upon the connecting rod of the other machine, the strain of course passing through the side rods from one drum to the other. When the machine is not duplicated it is proposed to place a balance weight near the axis of the shutter, at the same time partially balancing the pressure of the air, and making the shutter vibrate more in harmony with the revolutions of the drum. The next thing to be observed is that the opening on the top of each machine is equal to the extreme opening of the shutter into the cylinder internally. The machine whose shutter is in this position is at its greatest work while the shutter of the other machine is closed, and consequently no work is for a moment going on there. It will also be noticed that the openings which have been spoken of are much greater than half the area of the shaft to which the machine is applied. This is to avoid giving the air a higher average velocity in any part of its passage through the machine than that prevailing in the shaft. The machine acting on the thick part of the crescent doing much more than half the whole work then going on, the opening has been proportioned, so as to realize the required velocity.

The shafts *b* are provided at one end with cranks, which are coupled to a crank of equal throw fixed at the end of the crank-shaft of a horizontal engine placed by the side of the apparatus. The motion is thus communicated from the engine to the drums in the same manner as the coupled wheels of a locomotive are driven, a simple arrangement, which will no doubt be found to work well. The arrangement also allows either drum to be disconnected, when it requires to be stopped, without necessitating the continued stoppage of the other. This advantage is sufficient in fiery mines, at least, to justify the precaution.

It will be seen that the machine possesses many features that render it entitled to the careful attention of those interested in mine ventilation. The apparatus consists of but few parts, and those are all of simple construction, and are subjected to nothing more than very ordinary wear and tear. The eccentric drums are of sheet iron, $\frac{3}{32}$ inch thick, supported by cast-iron eccentrics, which also form the balance weights. The casings in which the drums work are also of sheet iron $\frac{1}{8}$ inch thick, stiffened by ribs; while the side walls of the apparatus are of brick, and have cast-iron columns built into them to support the plummer blocks. As the drums revolve barely in contact with the casing and flaps, they will be subjected to little or no wear so long as the bearings of the shafts are kept properly adjusted, and these bearings being all fully exposed to view, there is no reason why they should be neglected. Indeed, one of the great practical advantages of the arrangement is that all the wearing parts are completely open for inspection.

Guibal's Fan.—The most efficient fan yet introduced is that known as Guibal's. This fan is coming very rapidly into favour; many have been erected in England and in France and Belgium, and the good results that have in all cases been attained are likely to induce practical men to give the preference to this form. In the Guibal fan, the circular casing first used by M. Letoret is adopted, but it is improved in construction. A sliding shutter is provided whereby the outlet may be enlarged or diminished at pleasure. The degree of opening which gives the best effect for a given case is determined by experiment. The covering enclosing the upper portion of the fan for about five-eighths of its circumference allows a clearance to the vanes of about 2 inches; from this point, the casing slopes away below the fan till it ends in the side of the chimney. This gradually enlarging outlet passage constitutes an important improvement. In consequence of the increasing sectional area of the passage, the velocity of the air is reduced, by the time it reaches the outer atmosphere into which it is discharged, to one-fourth or one-fifth, and the *vis viva* to one-sixteenth or one-twenty-fifth of their original values. These conditions are obviously favourable to the utilization of the force applied. The vanes of the Guibal fan have also been improved in some of the details of their construction. By a system of interlacing the arms, a very strong structure is obtained. Some of these details of construction and the general design of the fan are shown in the drawings, Figs. 602 and 603.

Some Guibal fans of large dimensions have been erected. In a few cases, the diameter has been 30 feet and the breadth about 13 feet. With these dimensions, and a velocity of 100 revolutions a minute, they discharge from 100 to 120 cubic yards of air a second, where a depression of the water gauge of $1\frac{1}{4}$ to $1\frac{1}{2}$ inch is sufficient. It has been ascertained from experience that when the machine works under favourable conditions, the ratio between the volume generated by the vanes and that actually discharged from the apparatus varies but slightly. This ratio may be taken as having a mean value of 2·75, with a tendency to vary, within narrow limits, inversely as the speed of the fan.

Not unfrequently the Guibal fan is erected in such a manner that it may be used to force air into the mine by reversing the current. Cases may occur when this mode of ventilating the workings is preferable to that of exhausting the air usually adopted. When so erected, two chimneys are needed, one for delivering the air from the mine upward, the other for the reverse current when the air is taken from the surface and forced down the shaft. One of these chimneys must of course be kept closed by means of a kind of door or valve. Fans of this character have been erected at the Blanzy mines in France.

The following results have been ascertained concerning fan ventilation, and tabulated by Mr. D. P. Morison:—

RESULTS OF FAN VENTILATION.

Date of Experiment.	Name of Mine.	System of Ventilation.	Indicated effective Horse-power of Engine.	Cubic Feet of Air a Minute.	Water Gauge at Top of Shaft.	Horse-power in the Air at Top of Shaft.	Percentage of Power Utilized.	Revolutions of Fan a Minute.	Coal Consumed per Utilized Horse-power per Hour (taken at 7 lbs. under Boilers per Foot).
					inches.				lbs.
1859	Sacré Madame, Belgium	Fan, Guibal	88·96	58·9	5·31	50·38	56·60	..	12·3
1869	Pelton, Durham	„ „ (30 ft. diam.)	67·75	107·5	2·60	44·05	65·02	60	10·8
1869	„ „	„ „ „ „	70·79	102·8	2·90	46·87	66·21	60	10·6
1869	Staveley, Derbyshire ..	„ „ „ „	74·73	104·2	2·95	48·48	65·24	60	10·7
1870	„ „ ..	„ „ „ „	71·91	104·1	2·85	46·74	65·00	60	10·8
1867	Swindon, Durham ..	„ „ 23 ft. „	22·45	57·8	1·60	14·57	64·89	64	10·8
1864	Elswick, Newcastle ..	„ „ „ „	19·73	60·4	1·40	13·33	67·56	57	10·4
1870	Whitehaven	„ „ 36 ft. „	88·14	128·5	2·80	56·71	64·34	51	10·8
1870	„	„ „ „ „	215·91	182·0	5·00	143·59	66·41	72	10·6
1870	Eaton Mines	„ „ 37 ft. „	..	116·5	1·95	..	..	40	..
1870	„ „	„ „ „ „	..	212·2	3·50	..	..	60	..
1867	Homer Hill, Staffordshire	„ „ 16 ft. „	..	37·5	1·05	..	75·00	..	9·3
1867	„ „ „	„ „ „ „	..	51·7	1·75	..	75·00	..	2·3

COST.

Quantity of air per minute, 50,000 cubic feet; Water gauge, 1 inch = 7·875 horse-power; Coals at 2*s.* 6*d.* a ton.

Name of Mine (see preceding Table).	System of Ventilation.	Coal per Horse-power in Air per Hour.	Cost per Horse-power in Air per Hour.	Coal required per 24 Hours to perform the above Duty.	Cost of Coal per Annum. £	s.	d.
Sacré Madame	Fan, Guibal	12·30	0·165	1·03	47	0	0
Pelton	„ „	10·70	0·143	0·89	40	17	6
Staveley	„ „	10·75	0·144	0·90	41	2	6
Swindon	„ „	10·80	0·145	0·91	41	7	6
Whitehaven	„ „	10·70	0·143	0·89	40	17	6
Elswick	„ „	10·40	0·135	0·87	39	17	6
Homer Hill	„ „	9·30	0·125	0·78	·35	12	6

Schiele's Fan.—Schiele's fan is used in many places in the north of England to ventilate workings that are not very extensive. In such circumstances, it gives very good results. The air is taken in through openings at the centre around the shaft, and discharged between the partitions of the casing at the circumference. There are two fans which act successively upon the same air. The first fan drives it into an intermediate chamber at a pressure of about 6 ounces; the second compresses the air still more, so that at the delivery pipe it has a pressure of about 12 ounces to the square inch. One of these fans was used to ventilate the Exhibition building at Paris in 1867.

Root's Blower.—A blowing machine much used of late years for various purposes, and applied in numerous instances to mine ventilation, is that known as "Root's Blower." The design is similar in principle to Fabry's wheel, but the details of the construction are very considerably modified. It occupies but a small space, is self-contained, and gives a powerful blast. This machine is much used for mine ventilation on the Pacific coast, whence many favourable reports of its performance have been received. In most cases, it is applied to give what is called the "positive" or force-blast, that is, it is used to force air into the downcast shaft; in some instances, however, it has been applied to exhaust air from the upcast shaft, with, it is said, better effect.

The construction of Root's blower is shown in Figs. 604 and 605; the former of these shows the external form of the casing and the pulleys at each end for the driving belts. The latter is a cross section, and shows the inlet and the outlet passages, and the vanes or wings. The similarity of these wings to the vanes of Fabry's wheel will be easily recognized. The casing is usually made of cast iron, with the cylindrical parts bored out, and the head plates faced off truly upon a boring mill arranged for the purpose. The friction is limited to the journals and the toothed wheels. The wings do not touch in running, but move as closely together as possible without coming into actual contact. These wings are about 2 feet in length, and they make from 200 to 300 revolutions a minute; at a speed of 250 turns a minute, it is said to produce a pressure of about 5 lbs. to the square inch.

It is obvious that this machine is inadequate to the requirements of extensive workings. But in many cases, particularly in exploring-drifts and other preliminary excavations, it will be found to be sufficient. For these cases it is very suitable, by reason of the facility it affords for erection and driving, and the lowness of its first cost. On the Comstock lode, it has done, and indeed is still doing, good service. In tunnelling, it may be applied with advantage.

The ventilating machines employed on the Pacific coast are worthy of attention.—During the earlier years of work on the Comstock lode, little or no difficulty was experienced in effecting free ventilation of the mines,—the underground works, even to considerable depths, being in communication with the surface, either by adits or connected shafts in such manner as to ensure an easy circulation of air.

As the depth increased, and work had to be done at points not reached by the ordinary circulating currents of air in the mine, various simple and well-known means were employed to supply fresh air to the miners. One of the simplest and most efficient appliances for that purpose, formerly used in the Gould and Curry mine, was the water blast, which consisted of a wooden box-pipe, P, Fig. 606, standing in the shaft some 200 feet high, and connected at the bottom with an air-pipe A. In the case illustrated, the standing pipe extended from the fourth station down to the sixth, at which point an exploring drift was being carried eastward several hundred feet. The object of the blast was to supply air to the men in the end of this drift. The top of the box-pipe P is open, and a finely divided stream or shower of water being caused to fall into the box carries down with it a volume of air. The bottom of a pipe P dips in a box B, 2 or 3 feet long and 15 inches deep, in which the water is allowed to stand above the bottom of the pipe, and from which the excess escapes through a sliding gate or valve *v*. Connected with the water-pipe just above the box B, is the air-pipe A, leading to the point to which fresh air is to be forced. The air coming down the standing pipe P with the water, having no other means of escape, is driven along the horizontal air-pipe A and delivered at the desired point.

Latterly the deeper mines have found the lack of good air and the greatly increased heat sources of much trouble, and some of them have been forced to resort to more costly means of ventilation. For this purpose, the method generally in use at present is that of forcing air down the mine, and into the several levels or tunnels where it is most needed, by means of a Root's blower. This machine has been found very efficient, and has given much satisfaction to the mining companies that employ it on the Comstock. It is made of various sizes. At the Ophir works, a number 5 is used, the drum being 4 feet long. It is driven by a small engine provided specially for the purpose, but capable of doing additional work. The machine is calculated to run at 300 revolutions per minute; but when running at 130 revolutions it fully performs the duty at present required, forcing the air down 700 feet in the shaft and thence to the end of the drift several hundred feet more.

For conveying the air down the shaft and along the drift, a square wooden box-pipe is used. When these blowers were first introduced, the conveying pipes were made of galvanized iron; but this material was not proof against the corroding influences of the water in the shafts, and very soon became useless in that part of the work, though better adapted to the drier levels. Air-boxes of common pine wood were used next, but the tendency of this wood to split and crack caused them to leak very badly. The best and most satisfactory material now in use for this purpose is the red wood of California, which seems to be less affected than any other by the changes of temperature and different degrees of moisture in the mine. The air-box, or conveying pipe, is made of dressed lumber $1\frac{1}{2}$ inch thick, and is about 12 inches square in horizontal section. The four sides of the box are tightly joined together with a tongue and groove, as shown in Fig. 607 at *a*, and the ends of the sections of pipe are connected by letting the lower end of the upper section into the upper end of the lower section, as shown in same figure at *b*. An iron band is put round this joint, which is well packed and then covered with a thick coat of paint. The pipe is supported in the shaft by clamps *c*, *c*, Fig. 608, which secure it to the timber-sets. It is fixed in the corner usually of the pump compartment, the clamps securing it as shown in the figure. The cost of this air-pipe finished and placed in the shaft is about 1·50 dollar per foot. The cost of the blower of the size used at the Ophir, which is the largest made, is 150*l*. It may of course be driven by the same power that is employed for hoisting or pumping, but as the work is continuous and cannot be interrupted while men are working in the mine, a small engine devoted exclusively to this duty is preferred and generally provided at the Comstock mines.

Anemometers.—Anemometers, or wind-measures, are required to ascertain the quantity of air passing along a given way in a given time. In mine ventilation, the anemometer is a very important instrument, for without it there would be a good deal of uncertainty concerning the actual quantities of air circulating through the various districts of the underground workings. In collieries, the instrument becomes a necessity.

Various forms of anemometers have from time to time been introduced; but of these, only one, that known as Biram's, has been extensively adopted. Biram's instrument is now generally employed. It consists essentially of a set of vanes enclosed in a cylindrical case, and supported upon its axis in such a way as to give but little friction. The revolution of the vane-wheel gives motion, by means of endless screws, to pointers, which move over the face of suitably divided dials. The registering apparatus is in front of the wheel, and consists of six small circles, marked respectively X, C, M, XM, CM, and M. The divisions on these denote units of the denominations of the respective circles; that is, the X index, in one revolution, passes over its ten divisions, and registers $10 \times 10 = 100$ feet; the C index in the same way registers $100 \times 10 = 1000$ feet; and the other indices register, after the same manner, the number of feet up to a million. Hence the observer has only to record the position of the several indices, at the first observation, by writing in their proper order the lower of the two figures in the respective circles between which the index points, and to deduct the amount from that given by their positions at the second observation, in order to ascertain the velocity of the air which has passed during the interval. This, multiplied by the sectional area of the air-way in which the instrument is placed, will give, in cubic feet, the quantity of air that has passed during that time. The mechanism of this instrument is so delicately adjusted, that the vane-wheel will, in some cases, revolve in a current of air having a velocity as low as 30 feet a minute. A velocity of 50 feet a minute will cause the wheel to revolve in the least sensitive instrument. A front view of Biram's anemometer is given in Fig. 609.

Safety-Lamps.—The lighting of the underground workings of a mine is so intimately connected with the ventilation, that a description of the safety-lamps employed seems to be in place in the present chapter. The principle of the safety-lamp is founded upon the fact, first observed by Sir Humphry Davy, to whom the invention is due, that flame will not readily pass through fine wire gauze. The explanation of this fact is this:—In order to pass through the gauze, the gases in combustion must be divided into a great number of little jets, each distinct from the rest. These lose their heat by being brought into contact with the metal, and are consequently extinguished. In accordance with this fact, Davy constructed a lamp in which the wick was surrounded by a cylinder of wire gauze. This gauze was composed of twenty-eight wires to the linear inch, giving 784 apertures or meshes to the square inch. The same principle has been acted upon in all other safety-lamps of more recent introduction. Indeed, all the safety-lamps now in use are but modifications of the Davy.

The ordinary Davy lamp as at present used is almost identical in form with that constructed by the inventor. It consists, Fig. 610, of an iron wire-gauze cylinder fixed to a brass ring and screwed on to the oil vessel. The upper portion of the gauze is double for greater protection. Externally it is guarded by three iron rods placed equidistant from one another, and attached at the top to a metal roof, above which is the loop for suspending the lamp. For the purpose of trimming the wick and extinguishing the light, a wire passes up a close-fitting tube from the bottom of the oil vessel. The average weight of one of these lamps is $1\frac{1}{2}$ lb., and the average cost 7*s*.

A grave defect of the Davy lamp is its small lighting power. A moment's reflection will show that a very large proportion of the rays of light emitted by the flame are intercepted by the wire gauze. The proportion of opening to solid in the gauze adopted is about 1 to 4; that is, of the total surface of the gauze, about $\frac{4}{5}$ is solid metal. We cannot infer from this that only $\frac{1}{5}$ of the light is utilized, because some of the rays falling upon the wires are reflected; but the proportion utilized certainly does not exceed $\frac{3}{10}$. Hence the light emitted in the horizontal direction is very small. But it is evident that the proportion of light emitted through the gauze in other directions must be still less, by reason of the obliquity of the rays and the gauze, and that the proportion utilized diminishes as the point to be illuminated is situate nearer the roof of the workings. The light thrown in the upward direction is still further diminished by the double gauze and solid metal roof, so that the roof of the workings is only very feebly illuminated. This constitutes a very serious defect, inasmuch as it prevents a dangerous state of the roof from being observed, and furnishes a plausible excuse to the miner for opening his lamp.

Numerous modifications of the Davy lamp have been made for the purpose of remedying these defects. The attempts in all cases have been more or less successful, but also in all, success has been obtained by incurring defects of another kind. It is for this reason that the Davy in its original form still holds its ground. The chief means adopted in these modifications for utilizing a larger proportion of the light consists in employing glass in the place of a portion of the gauze. The defect of this means lies in the fragility of the material, which necessitates the adoption of a great thickness. It can hardly be disputed, however, that by employing a short cylinder of thick glass of a suitable quality, properly protected on the outside by vertical iron rods, a light greatly superior to that of the Davy is obtained without incurring serious danger from the fragility of the material. It should be remarked here, that when gas fires in a lamp so constructed, there is some danger of the glass cracking if rapidly cooled.

Some modifications of the Davy lamp have been made to lessen the danger due to strong currents of air and to the heating of the gauze. It will be observed that the employment of a cylinder of glass partially accomplishes the former object; but the end in view is more or less completely attained by providing certain points of influx and efflux for the air, by means of which distinct currents are formed that are not readily effected by the agitation of the external air. To effect the second object, the air is introduced as near to the flame, and passes as directly to it, as possible, in order that an explosive mixture may burn as it reaches the flame, while the chief portion of the space inside the lamp is filled with gases that have been already burned.

Dr. Clanny's invention, Fig. 611, consists in the substitution of a short cylinder of thick glass for the lower portion of Davy's wire gauze. The feed air enters, and the products of combustion escape, through the gauze above the cylinder. This arrangement is unfavourable to combustion, and hence the gain due to the substitution of the glass for the gauze is partially lost. Indeed, the light given by a Clanny lamp is but little superior to that furnished by a Davy, while it possesses the disadvantage of being much heavier and of being constructed of a fragile material. The glass cylinder, however, in the Clanny is thick, and well protected by vertical iron bars. This lamp, which was the first modification of the Davy, is still in use in some collieries of the north of England.

George Stephenson slightly increased the diameter of the Davy, and added a glass cylinder throughout the whole length of the lamp. This cylinder, Fig. 612, is placed inside the gauze, and is covered by a cap of perforated copper. The glass serves as a protection to the gauze against the heated gases inside, while the gauze serves as a protection to the glass against blows, and also keeps the lamp safe should the glass be accidentally broken. Air is admitted to the lamp through small holes in the rim below the cylinder. The method of admitting the feed air is a very good one, inasmuch as it tends greatly to prevent overheating, and also, in a considerable degree, to preserve the lamp from injurious influence of currents of air. When the air inside becomes highly heated, the flame is extinguished. The feed air-holes must be kept free from oil and dust, and the lamp be held vertically to enable it to burn well. It will be observed that the improvements in this lamp are not directed towards the removal of the defect of insufficient light. The Stephenson lamp, familiarly known as the "Geordie," is in common use in England.

Mueseler's lamp, Fig. 613, is the most satisfactory modification of the Davy yet introduced. Like the Clanny, it has a short cylinder of thick glass around the flame, and draws its feed air in through the gauze above the glass; but it is provided with a central conical metal chimney, placed immediately above the flame, and covered on the top with wire gauze. The products of combustion pass directly up this chimney, and cause a strong upward draught. By this means, the air is drawn briskly down on the inside of the glass cylinder, thus keeping the latter cool and promoting combustion on the wick. The glass cylinder is protected in the usual manner by vertical iron rods. These lamps give an excellent light, and for that reason are preferred by the miners to those already described. They have long been in general use in Belgium, where their adoption in fiery mines has been rendered obligatory. The fact of their being but little affected by a strong draught constitutes an important advantage over the Davy.

CHAPTER VI.

MACHINERY FOR THE TREATMENT OF MINERAL PRODUCTS.

Section I.—Crushing Machinery.

In order to separate ores from their associated gangues, it is necessary to break them into small fragments, and, in some cases, into a fine powder. The machines used for this purpose consist of three classes, known respectively as Rolls, Breakers, and Stamps. The two former of these are used to break down minerals to small fragments or to a coarse powder, suitable for subsequent treatment by stamps, and jigging or other dressing machines. The latter is employed to reduce the fragments or broken ore to a fine powder. The machines called "rolls" are also known as "crushers."

Crushers.—The crusher consists of a pair of cast-iron cylinders placed horizontally and nearly in contact, and connected together by spur-wheels of equal diameter, so that their surfaces revolve towards each other with equal velocities. Motion is given to one of these rollers either by steam or by water power, and the stuff to be broken is dropped from a hopper between the rollers. It was formerly the custom not to gear the two rollers together, but to allow one to be carried round by the friction of the stuff against it. Experience has, however, shown that the product is greater when the rollers are geared. The diameter varies between 14 inches and 34 inches, a common diameter being 27 inches. The length, or breadth of face, varies from 12 to 24 inches.

When the whole of the crushing is done by rolls, it is a common practice to have three or more of them. An upper pair, with fluted surfaces, is set so as to take in large masses; the fragments falling from this upper pair are divided between two pairs set below and pressed close together.

A Cornish crusher is shown in Figs. 614 and 615. The rollers of this machine are of unequal length, the driver being 24 inches, and the follower only 18 inches; both are 27 inches in diameter. These rollers are formed of thick cast-iron shells, keyed on to cylindrical bosses on a pair of plain shafts, which have couplings outside their bearings connecting them with a pair of lighter shafts, carrying the gearing wheels. The bearings of the shorter roller slide between parallel guides, and are kept in position by round bars passing through holes in the frame, which are pressed against by the shorter arm of an unequal armed bent lever, whose longer arm carries a loaded box; the relation of the two arms to each other is as 1 to 9. The object of this arrangement is to save the rollers from fracture in case any unyielding substance should get between them; for when the resistance of any fragment is greater than the horizontal thrust exerted by the loaded arms on the bearings, the shorter roller slides apart from its fellow and opens a passage for the unbroken substance to pass through. The broken material passes into a tubular or drum sieve, 42 inches in length and 24 inches in diameter, whose axis is set at an angle of 25° to that of the driving roller, with which it is connected by a pair of bevel wheels, the smaller wheel on the sieve shaft has eleven teeth, and receives motion from a larger one of forty teeth. The gauze has six apertures to the square inch; the particles passing through are received in a box, closed by a door, through which they are loaded into a truck on the railway below; the coarse fragments are thrown out into the buckets of the raff-wheel or lifting wheel, which resembles a reversed water-wheel, being closed on its outer circumference, but provided with a ring of buckets opening inwards; it is 15 feet in diameter, and, being coupled to the driving roller, makes the same number of revolutions; it discharges its contents on to a floor immediately adjacent to the feed hopper, to which they are returned to pass a second time through the rollers.

A crusher of this size makes from thirty to fifty revolutions per minute, requiring an effective driving power of from 12 to 20 horse-power; it will break down a quantity of ores, varying from 40 to 60 tons per day, according to the hardness of the associated gangues.

The surface of rollers soon becomes much worn, and when made of chilled iron, the irregularity of the chilling is soon made manifest by the unequal wearing away, the softer parts being hollowed out, while the harder are left in ridges and irregular bulges. It is preferred, therefore, to use ordinary hard pig-iron, or a mixture of hard white iron, similar to that used for the dies and shoes of stamps. The rollers are also made with an outer casing or shell, as in the foregoing example, that can be slipped upon the axis or core of the roller, and removed from it when too much worn. This hollow cylinder is usually cast so as to make a firm lock-joint upon the core, or it is keyed by means of two or three keys driven into recesses extending throughout the length of the cylinders, one half of the key being in the central core, and the other half in the shell or casing.

The means commonly used to keep the rollers in contact is a weighted lever; but lately india-rubber springs have been employed for that purpose. These springs, one of which is shown in Fig. 616, are placed one on each side of the frame. They consist of alternate discs of rubber and iron, the former being one inch, the latter one-quarter inch thick. The number of rubber discs is generally six. The requisite initial pressure is obtained by means of strong screws passing through the axes of the springs; by tightening up or loosening the nuts on these screws, the pressure may be increased or diminished as occasion requires. A great advantage of this mode of applying pressure to the rollers is that it allows the latter to be driven at a high speed. The system has been very generally adopted in Germany.

Crushers are usually driven by strong gearing. But at the Exposition of 1867 at Paris, a set of rolls exhibited by Messrs. Huet and Geyler were driven by a belt. This method is adopted in practice in Saxony, a crusher at Freiberg being driven by a strong belt. M. Huet mentions rolls having as great a diameter as 46 inches; but the rollers in machines of their construction, which are driven by a belt upon a shaft carrying at the other end a small pinion working into a larger spur-wheel upon the end of the shaft of one of the rollers, were of much smaller dimensions than these.

The hoppers of crushers for dealing with large quantities of stuff are usually made large enough to hold about one ton.

The following table gives some important details concerning a number of crushers now in use :—

DIMENSIONS AND PRODUCT OF CORNISH ROLLS AT VARIOUS MINES.

Name of Mine.	Rollers.				Total Pressure on Rolls.	Sifter.				Diameter of Raff-Wheel.	Horse-power.	Quautity Crushed in Ten Hours.	Cost of Crushing per Ton.
	Dia-meter.	Length.	Revo-lutions per Minute.	Crushing Area per Minute.		Dia-meter.	Length.	No. of Holes.	Revolu-tions per Minute.				
	ins.	ins.		sq. in.	cwts.	ins.	ins.	sq. in.		feet.		tons.	pence.
Grassington Mines ..	27	12	5½	5,593	91	21	48	6¼	37	14	..	80	..
Minera	14	14	8	4,920	73⅓	24	42	9	48	10 6–10	6	20	2½
Cwmystwith, No. 1 ..	27	14	4	4,748	78	20	33	9	24	16	..	32	2½
Cwmystwith, No. 2 ..	27	14	4½	5,341	85	24	36	9	24	16	..	35	2½
Goginan	30	14	5½	7,254	39	20	39	9	36	16	..	30	2¾
Cwm Erfin	27	14	7½	8,902	293	26	32	9	30	16	..	20	3
Lisburne, No. 1 .	27	15	6	7,632	180	22	36	12¼	30	16	..	42	2½
Lisburne, No. 2 ..	27	15	6	7,632	224	22	36	12¼	30	16	..	42	2½
Derwent	27	14	7	8,309	227	22	60	16	..	15	..	60	2¾
Goldscope	14	18	14	11,060	6	..	..	..	..	..	..	25	2½
East Darren .. .	30	18	6	9,996	207	24	36	16	45	16	..	25	2¾
Cefn Cwm Brwyno ..	20	13	5	4,080	84	20	48	16	27½	14	..	20	2½
Lisburne, No. 3 ..	18	16	8	6,432	169	22	36	25	30	16	..	42	2½
Llandudno	18	15	15	12,705	61	..	..	..	..	..	..	30	..
Wheal Friendship ..	23	12	10	8,670	123	24	36	36	30	13	13	20	11½
Pontgibaud	25	12	12½	12,075	36	22	44	36	60	15	15	17	2½
Devon Great Consols	34	22	7	16,443	458	24	84	64	21	..	..	65	3¾

BREAKERS.—The machine for breaking up rock now most in use is the invention of Mr. Eli Whitney Blake, of New Haven, Connecticut, and is generally known as Blake's Rock-Breaker. It was designed at first to break up trap-rock into fragments for macadamising roads. Its value for breaking ores into sizes suitable for feeding stamps or jigs was quickly seen, and in 1861 it was first applied to that purpose.

These machines consist, essentially, of a strong iron frame, supporting upright convergent iron jaws, actuated by a revolving shaft. The stones or masses of ore to be broken are dropped between these jaws, and a short reciprocating or vibratory motion being given to one or both of them, the stones are crushed, and drop lower and lower in the converging or wedge-shaped space, until they are sufficiently broken to drop out at the bottom. The size of the broken fragments may be regulated by increasing or diminishing the size of this opening between the jaws. The construction and action of the machine will be clearly understood from Fig. 617 and the following description of its several parts.

The drawing referred to is a sectional side view or elevation of the machine, representing the parts as they would be presented to view by removing one side of the frame. The parts of this figure which are shaded by diagonal lines are sections of those parts of the frame which connect its two sides, and which are supposed to be cut asunder in order to remove one side and present the other parts to view. The dotted circle D is a section of the fly-wheel shaft; and the circle E is a section of the crank. F is a connecting rod, which connects the crank with the lever G. This lever has its fulcrum on the frame at H. A vertical piece I stands upon the lever, against the top of which piece the toggles J J have their bearings, forming an elbow or toggle-joint. K is the fixed jaw against which the stones are crushed. This is bedded in zinc against the end of the frame, and held back to its place by cheeks, L, that fit in recesses in the interior of the frame on each side. M is the movable jaw. This is supported by the round bar of iron N, which passes freely through it and forms the pivot upon which it vibrates. O is a spring of indiarubber, which is compressed by the forward movement of the jaw and aids its return.

Every revolution of the crank causes the lower end of the movable jaw to advance toward the fixed jaw about one-fourth of an inch and return. Hence, if a stone be dropped in between the convergent faces of the jaws it will be broken by the next succeeding bite; the resulting fragments will then fall lower down and be broken again, and so on until they are made small enough to pass out at the bottom.

It will be seen that the distance between the jaws at the bottom limits the size of the fragments. This distance, and consequently the size of the fragments, may be regulated at pleasure. A variation to the extent of five-eighths of an inch may be made by turning the screw nut P, which raises or lowers the wedge Q, and moves the toggle-block R forward or back. Further variations may be made by substituting for the toggles J J, or either of them, others that are longer or shorter; extra toggles of different lengths being furnished for this purpose.

Machines are made of various sizes. Each size will break any stone, one end of which can be entered into the opening between the jaws at the top. The size of the machine is designated by the size of this opening; thus, if the width of the jaws be 15 inches, and the distance between them at the top 9 inches, the size is called 15 by 9.

The product of these machines per hour, in cubic yards of fragments, will vary considerably with the character of the stone broken. Stone that is brittle, like quartz, granite, and most kinds of sandstone, will pass through more rapidly than that which is more tough. The kind of stone being the same, the product per hour will be in proportion to the width of the jaws, the distance between them at the *bottom*, and the speed. The proper speed is about 180 revolutions per minute; and to make good road metal from hard, compact stone, or to prepare ores for stamps, the jaws should be set from $1\frac{1}{4}$ to $1\frac{1}{2}$ inch apart at the bottom. For softer and for granular stones they may be set wider.

The following table shows the several sizes of machines commonly made, the product per hour of broken stuff from the hardest materials, when run with a speed of 180, and the power required to perform this duty:—

Size.	Product per Hour.	Power Required.	Size.	Product per Hour.	Power Required.
10 by 5	4 cubic yards.	6 horse-power.	15 by 7	6 cubic yards.	9 horse-power.
10 " 7	4 " "	6 " "	15 " 9	6 " "	9 " "
15 " 5	6 " "	9 " "			

The whole length of the machines to the back side of the fly-wheels is from 8 to $8\frac{1}{2}$ feet; height to top of fly-wheels, 5 feet; width, from 4 to 5 feet.

The machine may be driven by any power less than that given in the table, yielding a produce per hour smaller in the same proportion.

Either of these sizes mentioned will break quartz enough in a few hours to feed a forty-stamp mill for one day. A machine of less capacity would, of course, have a smaller mouth and would not take large stones. It is usual therefore to use the largest-mouthed machine, and to run it a few hours each day. The rough quartz in blocks as it comes from the mine being ready on the platform near the mouth of the breaker, two men can feed it into the machine and break it up at the rate of from five to ten tons per hour, according to the size of the machine.

Breakers have been made larger than any of the above for breaking very large blocks of ore. They are in use at Lake Superior, where they take in masses of ore 18 inches in diameter by 24 in length, and crush them without difficulty. The fragments from these large breakers are received by two or three of the machines of the ordinary sizes and are broken again, so that the pieces will all pass through a 2-inch ring. The metallic copper is readily picked out by hand from this broken ore. These large machines would be useful at many mines, and would permit sledging to be dispensed with. The machine is made without the lever, and works very slowly, but without loss of power; since, when it is not crushing, the only power consumed is that required to overcome the friction, whereas with the heavy stamps, the greatest expenditure of power is when the least work is performed.

There are some modifications of the construction of this machine as here described. In England and in France they are commonly made without the lever, the eccentric shaft being mounted on the top of the frame directly over the toggles. A rod connects the eccentric shaft with these toggles, and thus produces the oscillating motion of the jaw. The construction is shown by a sectional view, Fig. 618, one half of the frame being supposed to be removed. One only of the fly-wheels is represented. This is the form of the machine exhibited at the Paris Exhibition by the manufacturers under the patent in France. The mouth of this machine is expanded, hopper-like, so as to be more convenient for the reception of the masses to be broken. This may be a desirable addition in some cases, where comparatively small stuff is to be broken and is to be shovelled in from a floor lower than the mouth of the machine; but when the mouth is placed, as it should be, on a level with the floor of the dump pile, the hopper is not required.

The rock breaker may be successfully used instead of stamps to obtain either coarse or fine fragments suited to concentration. It has been attempted to increase the fineness of the product of the machine by placing an "obturator" or obstruction, such as a triangular bar of iron, under the outlet between the jaws, arranging it so that it can be raised or lowered by means of screws, in order to diminish or increase the size of the outlet for the delivery of the crushed stuff. The effect of this obstruction is to retain the stuff between the jaws until it is so much broken and comminuted that it will sift through the narrow slits left on each side of the bar. This method of operating may be successful with some materials, but involves a considerable expenditure of power. It is also attended with some danger to the machine, since with materials that are easily impacted to a hard mass, the entire space between the jaws may become so tightly filled that some part of the machine must give way. The massive frame of a machine in California was broken asunder in this manner, simply by permitting the outlet between the jaws to become closed by the accumulation of a heap of broken stuff below it. Obturators have been tried; but the discharge from the machines is rendered so slow by them that they have been discarded as not practically valuable. A better way to accomplish the object is to first break the ores in an ordinary machine and then to pass the fragments through a machine with a mouth 10 by 2 inches, the jaws of which move only about one-eighth of an inch and make 600 bites in a minute. Machines of this kind have been successfully used in preparing ores for jigs.

At the Churprinz mine, Freiberg, Saxony, two rock breakers are used to prepare the lead ores for the various concentrating machines. One breaker takes the rough ore as it comes from the mine and breaks it up into coarse fragments; these pass to a second breaker with the jaws set nearer together, so as to make fragments small enough for jigging. The finer portions of the first product are separated from the coarse by means of revolving screens.

The fragments of ores produced by rock breakers are better adapted in size and shape to the operation of concentration by jigging than the fragments made by rollers and stamps. When set coarse, for breaking quartz to be fed to stamps, the product consists of masses which do not exceed a certain size, and this permits a uniformity in the action of the stamps which cannot be obtained upon quartz broken up by hand, since in the latter case there is great irregularity in the size of the masses, and, as a general rule, the hardest and toughest are the largest. With self-feeding batteries, it is very important that the ore should be uniformly broken, and machine-broken rock is especially well adapted to automatic feeding. When the masses fed into batteries do not exceed a certain size, the wear and tear of grates is less than when the size is irregular. It is easy also with breakers to reduce the whole quantity of the ore to be stamped to fragments very much smaller than can be obtained by hand-breaking, unless an expenditure of time be made far beyond what the economy of the breaking will permit. Quartz thus reduced greatly increases the product of a stamp-battery; the stamps have a greater and more effective blow, and it is said that from 20 to 25 per cent. more quartz can be worked with a breaker than without it, the battery being the same.

The jaws of the breaker are the only parts subject to rapid wear, and in California and Nevada it is usual to provide the movable jaw with movable faces of hard white iron. These are made about 4 inches thick, and in such a form that they can be turned over or end for end, until they are too much worn to be longer used. They are secured to the jaw by means of conical bolts, and bedded in zinc or refuse type-metal, in order to have an equal and solid bearing. The forward or fixed jaw can also be reversed in its bed, and is held back to its place by wedge-shaped cheeks on each side. It is usual to make both jaws with vertical coarse corrugations or furrows, so that the ridges of one jaw are opposed to the depressions on the other, thus giving a zig-zag form to the aperture at the bottom. This tends to prevent long and thin pieces from slipping through without being broken; but it is not otherwise essential to the satisfactory operation of the machine, and plain jaws are frequently used.

STAMPS.—Stamps consist of a series of heavy pestles of iron which are lifted to a height varying from 7 to 15 inches, and allowed to fall upon the ore that is to be crushed. They work in a mortar or trough, also of iron, into which a constant supply of ore is introduced, and from which the crushed material escapes through openings furnished with closely fitting screens, as soon as it is reduced to the desired degree of fineness. The mortar is usually rectangular in form, and contains from three to six, commonly five, stamps, forming what is usually called a "battery." The mortars rest on a solid foundation and are established in a substantial framework of timber. The stamps are lifted by means of revolving cams or arms of iron, keyed to a cam-shaft, which is placed directly in front of the batteries, and which receives its motion from the driving power of the mill. The stamps move vertically between guides that form a part of the battery frame.

Fig. 619 shows a front elevation, and Fig. 620, a transverse section, on the line A B of Fig. 619, of two five-stamp batteries, the several parts of which are indicated by the table of reference accompanying the drawing.

The foundation for batteries of this character generally preferred consists usually of heavy timbers, standing vertically, placed close together, and firmly connected by means of cross timbers and bolts of iron. The timbers are from 6 to 12 feet long, according to the character of the ground and the desired height of discharge for the mortar. Sometimes they stand on horizontal timber, so laid as to serve as the base of two or more batteries to be placed on a firm bottom. When the foundation timbers are in place, the space about them is packed and stamped as firmly as possible with clay or earth. Where the ground on which the batteries are to be built is a hard compact gravel, or a firm clayey material, the surface is sometimes levelled off so as to admit of laying the transverse sill-timbers T of the battery frame, and a narrow pit is then excavated, only long and wide enough to receive the ends of the mortar-blocks and several feet deep, into which the posts or blocks are introduced, in a vertical position, their bottom ends resting directly on the ground without any intervening horizontal timber. The remaining space in the pit may then be compactly filled with clay that is pounded or stamped firmly into its place. The sill-timbers T and the battery posts C are securely bolted to the foundation timbers. The posts C are braced by the timbers D and the rods R, and are connected by the tie-timbers G, G, which also support the guides g, g'.

Mortars.—The mortars are now usually placed directly upon the vertical mortar-blocks, without any horizontal piece intervening, and are secured in their place by bolts shown in Fig. 621. They may be constructed of wood and iron, having a solid iron bed-plate, with sides and ends of wood, forming the stamping trough; or they may be made entirely of iron. In the former case, there is often great difficulty in keeping the mortar tight enough to prevent leakage and consequent waste of ore.

The mortar in general use for wet crushing is an iron box or trough, about 4 or 5 feet in length and depth, and 12 inches inside in width, and so cast that bottom, ends, and sides are in one piece. A front and end view of one of the most approved forms is shown in place, in the drawing of a battery of stamps. The feed opening l is an aperture about 3 or 4 inches wide and nearly as long as the mortar, by means of which the rock is supplied to the stamps. On the opposite side is the discharge opening, furnished with a screen i, through which the crushed material must pass. This opening is as long as the mortar, or nearly so, and 12 to 18 inches deep, the lower edge being 2 or 3 inches above the top of the die. In some mortars, especially for dry crushing, the discharge is on both sides, in which case the feed opening is above the screen.

The mortar in common use upon the Pacific coast is known as the high mortar, and is represented in cross section and in front view in Figs. 622 and 623. It is 4 feet long, 4 feet high, and weighs about 3000 lbs. They can be made for three, four, five, or six stamps, but five stamps to each mortar are found to work best. The ore to be stamped is fed through the longitudinal opening B at the back of the mortar, and falls upon the dies ranged side by side in the bottom.

All the rock is supposed to have been made small enough by the breaker to pass through the narrow opening at the top. The large opening in the front of the mortar is intended for the screen, made of Russian sheet-iron, punched with fine holes. This is screwed or tacked securely to a wooden frame, which is slid into grooves C in the section, cast in each end of the frame, and is firmly secured there by long wedges of iron. Two lugs or ears of cast iron, placed at equal distances at the bottom of the opening in the front of the mortar, serve to sustain the screw-frame in front. The whole mortar is securely bolted down to the foundation through the heavy flanges cast upon the bottom.

Mortars which have to be transported into places difficult of access are made in sections, so that they can be taken apart and packed upon the backs of mules. These are called section mortars, and their construction is shown in Figs. 624 and 625. This mortar, like the preceding, is for five stamps, and is 4 feet long. The upper portions A A are made of boiler-plate iron. The feed opening is shown at B. There are double screens D D, one on each side. The method of securing these screens to the openings by means of movable lugs or clamps, is also shown. The bottom is cast in sections *c c c*, and these are accurately fitted together with tongued and grooved joints, planed, and held by heavy iron bolts running through them from end to end, and secured by strong nuts upon the outside.

A form of mortar known as Donnell's, used in gold mining, is shown in Figs. 626 and 627. The ore, as in other mortars, is thrown in at the feed opening B, in the section, and the delivery is through one of the two openings in front and in the back. The screen C is narrow, and is placed high above the dies, and occupies only a part of the opening in front. The lower portion of this opening, and the opening in the back, is closed by a door of wood A A, covered on the inside by a sheet of amalgamated copper, which catches and retains the particles of gold. By removing the screen C, and making the floor A higher, it may be used as a float mortar.

Wet stamping or crushing is generally resorted to. Mortars for dry crushing are, however, not unfrequently used; silver mills, crushing ore which has to be subsequently roasted, require this form. Screens for the latter are placed higher and made wider, and wire-cloth is substituted for perforated iron plates.

Screens.—The screen is attached to a screen-frame *j*, which is secured in grooves cast in each end of the mortar, and by two lugs *o*, cast in front of the discharge-opening, being held firmly in place by a wedge driven behind it in the grooves just referred to.

Screens are placed vertically, sometimes inclined, as shown in the figure. The discharge is generally thought better in the latter case. Screens are made of fine brass wire-cloth, having from forty to sixty meshes to the lineal inch, or, more generally for wet crushing, of Russia sheet-iron, perforated by finely punched holes, varying from $\frac{1}{40}$ to $\frac{1}{24}$ of an inch in diameter. The wire-cloth or sheet-iron plate is attached to the screen-frame by nails or screws. The punch plate is preferred for wet crushing. The wire-cloth, though affording more discharging surface, wears out faster, and not only is more liable to break, and so permit large particles to pass through, but frequently stretches, giving meshes of irregular size. A piece of canvas is usually hung before the screen for the crushed ore to splash against as it issues from the mortar; falling thence into the trough below.

The screens vary in length from 3 to $3\frac{1}{2}$ feet, according to the length of the mortar, and are from 10 to 15 inches wide. When wooden frames are used, the punched screens are tacked on at the edges with common carpet tacks, a strip of baize or blanket being under the edge to make a tighter joint, and to facilitate the removal of the screen when worn out. The screens are also secured in iron frames, and made with crossbars so as to sustain them. Sometimes the holes in the sheet iron are made in the form of narrow slits, about one-third of an inch long, with a view of increasing the rapidity of the discharge of the stamp. For the same purpose, the screens are not placed vertically in the mortars, but are inclined forward at the top as indicated in the figures of mortars by the recess for the reception of the screen-frames.

Dies.—The mortar is furnished with dies, which are fixed in the bottom to receive the blow of the stamp and sustain the wear which would in its absence fall upon the mortar itself. The die is a cylindrical piece of cast iron, corresponding in form to the shoe of the stamp that falls upon it. It is from 4 to 6 inches high. In the bottom of some mortars there are circular recesses made for the reception of the dies which are caused to fit into them. In others, to prevent the rock from working in under the die and displacing it, the circular recess in the bed-plate is cast with a flange, and the die with a small projection or lug. A groove is also made in the bottom of the mortar, so that the die may be introduced with its lugs dropping into the groove. The die being then turned about 90 degrees, the lugs come under the flanges of the recess, and the die is consequently held in place. A simpler and most common form is to cast the cylindrical part of the die on a flat, square base, as shown in Fig. 628. The bottom of the mortar is also made flat, and the dies dropped in, resting on their bases, which just fill up the space in the bottom of the mortar. The corners of the bases of the dies are bevelled off so as to allow the insertion of the point of a pick, by which means they can be taken out when necessary.

In addition to the dies, plates of iron, half an inch thick, are sometimes applied to the sides and ends of the mortar exposed to constant wear, which plates, like the dies, can be taken out, and renewed when necessary. The top of the mortar is covered by two pieces of plank, cut so as to fit closely, and resting on flanges cast on each end. Semicircular recesses, cut opposite each other on the adjacent edges of the two pieces of plank, afford a passage for the movement of the stamp-stems.

Stamps.—The stamp consists of a stem or lifter; a head or socket, attached to the lower end of the stem, and furnished with a shoe, a movable part which sustains the force of the blows and the wear of the operation; and the collar, or tappet, by means of which the revolving cam lifts the stamp for its fall. The stem is a round bar of wrought iron, about 3 inches in diameter, usually turned in a lathe. Its length is 10 or 12 feet. Its lower end is slightly tapered, and corresponds in form to a socket or conical hole in the upper part of the stamp-head. The rest of the stem is usually made round throughout its entire length, the method, now in general use, of attaching the tappets to the stems not requiring any modification in the form of the latter, as was formerly the case.

The stamp-head, illustrated in Figs. 629 and 630, is a cylindrical piece of tough cast-iron about 8 inches in diameter and 15 inches high. In its upper end is a socket, shown by dotted lines, corresponding with the axis of the cylinder and conical in form, designed to receive the slightly tapering end of the stem, to the dimensions of which it must be adapted. This conical hole, or socket, is about 7 inches deep. At its bottom is a hole, or key-way *a*, passing through the head, at right angles to the cylindrical axis, by which passage a key may be driven in to force the head from the stem when necessary.

To attach the stamp-head to the stem, the latter is placed in its position between its guides, and the head standing immediately under it. The stem being dropped enters the socket, and a few blows of the hammer drive it in with sufficient force to cause the head to be raised when the stem is lifted. The stem and the head, being suffered to drop together a few times, become firmly connected. In the lower end of the head is a similar hole or socket *b*, but larger than the upper one, likewise tapering or conical in form, made to receive the stem or shank of the shoe, which is thus connected with the head in a similar manner, a rectangular hole, or passage, *c*, through the head at the end of this lower socket permits the removal of the shoe in the same way as the stamp-stem is forced out from the upper socket. A stout wrought-iron hoop encircles each end of the stamp-head, being fitted and driven on when hot, and allowed to shrink in place.

The shoe in common use is a cylindrical piece of cast iron about 8 inches in diameter and 6 inches high, above which is a shank or stem, the base of which is 4 or 5 inches in diameter, tapering in form and about 5 inches high. It is made of the hardest white iron. It is attached to the head in manner somewhat similar to that just described for connecting the head and the stem, but is wedged on by means of strips of pine-wood. These strips, which are cut about as long as the stem of the shoe, a quarter of an inch thick and about half an inch wide, are placed round the stem of the shoe and tied with a piece of twine, as shown in Fig. 631. They must be thick enough to wedge the stem of the shoe firmly in its socket, without allowing the head to come in contact with the body of the shoe. When the shoe is ready to be fixed to the head it is placed in proper position with the stem of the shoe directly under the socket of the head, and the stamp and head are then allowed to drop upon it. If necessary a few blows of a hammer are struck upon the top of the stamp-stem. The whole may then be raised, the shoe keeping its place, and suffered to fall repeatedly until the shoe is firmly established in its socket. During this operation, a piece of plank is interposed between the die on the bottom of the mortar and the shoe, for the latter to strike upon· Whenever a shoe has been worn out, it may be removed from the socket by driving the key into the key-way *c*, and forcing it off. Care must be had that the shoe does not become so thin as to permit the head to sustain undue wear, and so become weakened. Shoes should be removed when worn down to one inch of thickness.

The collar, or tappet, is a projecting piece, firmly secured to the upper part of the stem, by means of which the revolving cam may lift the stamp and let it fall upon the substance to be crushed. Tappets vary in form and method of attachment to the stem, but that which seems to combine the greatest number of advantages and to have been most generally adopted on the Pacific coast, is that which is known as Wheeler's "gib-tappet." Figs. 632 and 633 show an elevation and vertical section of this contrivance. It is a piece of cast iron, cylindrical in form, about 8 inches in height and diameter, and hollow at the centre, so as to receive the stamp-stem. To secure the tappet to the stem, there is a gib *g*, about 2 inches wide, and nearly as long as the tappet, having its inside face curved so as to correspond in form to the circular hole through which the stem passes. The gib being fixed in its place in the tappet, and the latter being upon the stem, it is pressed against the stem by means of two keys *k k*, driven into the key-ways, with force sufficient to hold the tappet and stem firmly together and prevent slipping between them. This is found to be a very effective method of securing the tappet, while permitting it to be fixed at any desired point on the stem, according to the wear of the shoe. The stem is uniform in size, and the work of cutting facings, screw-threads and key-seats on the stem required by other methods in use elsewhere, is thus avoided. The rotary motion of the stamp, imparted by the friction of the cam against the tappet, is in very general use in Nevada. This is one of the advantages offered by the use of round shoes, stems, and tappets. The revolving cam, meeting the tappet, and raising the stamp, causes it, while being lifted, to make a partial revolution about its vertical axis, which rotary motion being continued during the free fall of the stamp produces a grinding effect between the shoe and die upon the substance to be crushed. Not only is the effective duty of the stamp at each blow increased in this way, but the shoe wears down much more evenly than when it falls without such rotary motion.

The stamp is held vertically in its movement by guides, between which the stem passes. These were formerly made of iron, but such have been almost entirely replaced by wooden ones in Nevada and California. One set of guides is placed below the tappet, about a foot above the top of the mortar; the other set is placed near the top of the stem, so that 6 inches or a foot of the latter may project above the guides. They are supported by the cross-timbers, or ties, G, G′, which form a part of the battery frame, connecting the two uprights or posts. They are usually made of pine, though hard wood is preferred, and are from 10 to 16 inches wide. One part of the guide is made in a single piece for the whole battery, and bolted to the cross-timber; the other may be in one piece like the first, or cut into as many pieces as there are stamps in the battery, as in Figs. 634 and 635, which are then secured to the corresponding part by bolts. In each part are cut semicircular recesses, which, when the two parts are put together so that the recesses correspond, the holes, or stem-ways for the reception of the stamp-stems, are formed. When the guides are so much worn by friction as to permit too much motion of the stems, they may be dressed down on their adjacent faces, by which means the recesses are reduced to nearly the proper dimensions.

The cam is a curved arm fixed to a shaft, which is so placed in front of the battery that, by the revolution of the shaft, the cam is brought into contact with the tappet of the stamp-stem, causing the tappet to rise to a height determined by the length of the cam, and to fall at the moment of its release from such contact.

In Nevada, the cams are made of tough cast iron, and are usually "double armed," that is, have two arms attached to one central hub. Figs. 636 and 637 show the form of cams generally in use; in Fig. 537 *a*, is the hub, *b*, *b* are the arms, *c* is the face, and *d* a strengthening rib.

The proper curve of the face of the cam, in order that it may perform the required duty with the least friction, is the involute of a circle, the radius of which is equal to the distance between the centre of the cam-shaft and the centre of the stamp-stem. This produces a line for the face of the cam which meets, better than any other, the various requirements. The bottom of the tappet is constantly perpendicular to the radius of the curve of the cam; the tappet, and with it the stamp, is lifted vertically and uniformly, so that the lift of the stamp is always regularly proportioned to the revolution of the cam-shaft.

The cam-curve may be constructed on paper by means of tangents, as shown in Fig. 636. If *c* represents the centre of the cam-shaft, and *c r* the distance from the centre of the cam-shaft to the centre of the stamp-stem, the circle described about *c*, with *c r* as a radius, is the developing circle of the involute. The distance, representing the height to which the stamp is to be lifted, is laid off upon the circumference of this circle, as from the point 1, which distance is subdivided into a convenient number of equal parts, determining, as in Fig. 636, the points 2, 3, 4, * * * 13. From each one of these points in the circle, a tangent is drawn, on which is laid off a distance equal to the length of arc between the point 1 and the point from which the tangent is drawn. All the points thus determined in the tangent lines are points in the cam-curve, and may be connected, as shown in the figure, thus producing the line for the face of the cam.

In practice, the line of curvature is produced by cutting from a thin board a circular piece, the radius of which is equal to the horizontal distance from the centre of the cam-shaft to the centre of the stamp-stem. At a given point on the periphery of the circular piece is fixed one end of a thread, which must have the length of the greatest desired lift of the stamp, and to the other end of which is attached a pencil point.

The circular piece, with the attached thread wound on the periphery of the circle, is laid on a smooth board, on which the line is to be traced, and the thread being constantly stretched to its farthest reach, is unwound until it forms a tangent to the circle at the point where the other end is attached. The line described by the pencil point is the desired curve.

Some builders slightly modify this curve, giving to the cam-arm a greater curvature near each of its ends, in order that the cam in its revolution may come in contact with the tappet at the least practicable distance from the cam-shaft, where the concussion is less than at a greater distance, and to diminish the friction between the extreme end of the cam and the face of the tappet. The face of the cam is 2 or $2\frac{1}{2}$ inches wide. Its extreme end is fashioned so as to correspond to the outer edge of the tappet, which is circular. The cam is placed as near the stamp-stem as practicable, without coming in contact with it. The cams are caused to revolve by means of the cam-shaft, to which they are secured by one or sometimes two keys or wedges.

The cam-shaft is a round shaft of iron, which is smoothly turned and finished, having one or two key-seats or grooves cut in it lengthwise, for the purpose of securing the cams in their places. The shaft rests in boxes, which are usually supported by shoulders cut on the upright posts of the battery frame. Cam-shafts vary in diameter from 4 to 6 or 7 inches, according to the number of cams to be fixed upon them and the weight of the stamps to be raised. In some mills a single cam-shaft is made long enough to carry all the cams for as many batteries as there may be. In Nevada and California, however, short cam-shafts are in general use, a separate shaft being employed for each battery, or, in many cases, one shaft for two batteries. Separate cam-shafts are preferred on account of the independence of each battery, so that if one be stopped by any accident to the cams or stamps, or for repairs of any kind, the operation of the others is uninterrupted. Each shaft in such case is driven by its proper pulley, which receives its motion by means of belting from a counter-shaft. In the drawing of the stamp battery, the pulleys and belting are shown. The cam-shaft is set in motion by applying the tightening pulley to the belt.

The number of stamps in each battery is commonly four or five. The latter number seems to be preferred. The order in which they are allowed to drop is not always arranged in the same manner in different mills, but the desired conditions are that the weight of the stamps to be raised may be uniformly distributed on the cam-shaft, so that the weight of metal lifted may be as nearly as possible the same at any moment of the revolution, and that each stamp may fall effectively upon the material to be crushed, and by the force of its blow aid in the proper distribution of the stuff among its neighbouring stamps. If the stamps are allowed to rise and fall in regular succession from one end of the battery to the other, the material is usually found to accumulate at one end, and the effective duty of all the stamps is greatly diminished. The order must therefore be varied. In a five-stamp battery, a common arrangement is to let fall first the middle stamp, then the end stamp on the right, then the second stamp on the left, then the second stamp on the right, and finally the end stamp on the left. The order in which the stamps are to fall being determined, it is carried into effect by fixing the cams on the shaft in such position that each cam, by the revolution of the shaft, will lift its respective stamp at the desired moment. For this purpose, the key-seats cut in the hub of the cam must be determined with care; one common key-seat being cut on the cam-shaft, when the desired position of any given cam has been ascertained, the key-seat in the hub is cut to correspond with that of the shaft.

When it becomes necessary to hang up a stamp so that the cam may revolve without reaching the tappet, it is supported by a prop or stud *n*, which is shown in the drawing. The lower end of the studs, of which there is one for each stamp, is pivoted on a small shaft fixed across the battery from end to end, resting in boxes, which are secured to the uprights. Each stud is just long enough to support the stamp, when placed under the tappet, at a height which is about an inch above the highest lift given by the cam. To bring the end of the stud into this position when desired, the workman lays a smooth stick on the face of the cam as it is rising to the tappet, and holds it there while the stamp is lifted. The stick is as wide as the face of the cam, and long enough to be held conveniently, and an inch and a half thick at the end which comes between the cam and tappet. By this means the stamp is raised high enough for the stud to be put in place, which being done the stamp is supported above the reach of the cam. To set it again in motion the operation is repeated, the stud being withdrawn at the moment when the stick on the face of the cam has lifted the stamp clear of its support.

In Nevada, the weight of stamps in most general use is between 600 and 700 lbs. They are usually run at about 70 or 80, sometimes 90 or even 100, blows per minute; they drop from 7 to 10 inches, according to their speed, the greater number of blows per minute requiring shorter lifts. In reducing the quartz of the Comstock lode by wet-crushing, discharging through a No. 5 or No. 6 screen, the average duty is about 2 tons in twenty-four hours. In some mills it is said to reach 3 tons per day. Much of the effectiveness of the stamps depends on the degree of care devoted to keeping the working parts in good condition and on the regularity with which they are supplied with ore. This is commonly done by hand labour, the rock being shoved in at such a rate as it is crushed and discharged. In some mills, however, automatic feeders are employed, which give satisfaction. These consist of a hopper filled with ore, from which a trough or chute leads to the feed-opening of the battery, so inclined that the ore will slide down from the hopper to the battery, if the chute, which is hung on a pivot, be agitated. A rod is attached to the chute, and so placed that the tappet of the stamp, when the latter gets so low as to require an additional supply of rock, will strike its upper end, thus giving a shock which causes the ore to move down and fall into the battery.

The following details of the stamp batteries at the Mettacom Mill, at Austin, Nevada, with valuable remarks thereon, are given by Mr. Raymond, a well-known authority on these matters :—

"The weight of the stamps is nearly 900 lbs. each. There is not so much difference of opinion now as formerly among good mill-men as to the proper weight for stamps. As the amount of horse-power (and hence of fuel) required to run a battery depends directly upon this weight, it has been necessary to find out by experience whether heavy blows do as much work in proportion as lighter ones, and where the proper medium lies. The question has quite as much to do with the discharge as with the crushing. The blow of the stamp not only pulverizes the rock, but drives it outward through the screens. In dry-stamping, this is the only force which effects the discharge. Hence the weight of the stamp should not be so great as to necessitate slow running. Probably 750 to 800 lbs. is the best weight for general use; though if all mills were run as skilfully as the Mettacom, even 900 lbs. would not be too heavy.

"The stems are $3\frac{1}{8}$ inches in diameter. The usual size is $2\frac{7}{8}$, and these stems are, therefore, nearly 20 per cent. stronger and heavier than ordinary; the proportion being as the squares of the diameters. The advantage of putting a larger proportion of the total weight into the stem is the diminished vibration from the blow on the tappet. The stems should always be fitted as closely as possible to the guides; but light stems spring or bend, and wear the guide in rising. There is no wear of this kind in falling, so long as the stem is true. The stems are set $8\frac{1}{2}$ inches apart, the bosses and shoes work within about 2 inches of each other, and the distance between the tappets is about three-fourths of an inch. The whole length of each battery mortar is therefore about 5 feet 6 inches.

"The cam-shaft is rigged with single cams. The old fashion of triple cams is now about obsolete; but the usual form is the double cam, which many mill-men still prefer, claiming, that as it gives two drops of the stamp for each revolution, it saves friction in gearing, and enables the battery to be run at high speeds without running the engine as fast. These and other arguments for the double cam only prove that it suits the machinery which has been calculated for it. As a matter of fact, however, I have never seen double-cam batteries equal the single cams in speed; and I think Mr. Howell is right in claiming the advantage for single cams, that the shoulder can be brought directly under the tappet, so as to prevent catching. With the ordinary double cam, the shaft must be set farther back from the stems, and the cams are easily caught and broken.

"This subject is directly related to the speed of the battery. The Mettacom mill has vindicated triumphantly the wisdom of its peculiar features by the most extraordinary running on record. For months together the batteries have been kept at from 98 to 100 drops per minute, rising to 102, or even 105, and never falling below 94; yet there has never been a cam broken in the mill. The Manhattan, an excellent mill, with double cams and stamps weighing only 750 lbs., cannot safely run on the same ore at higher speed than 85 to the minute, and Mr. Curtis, the able superintendent, with the performances of the Mettacom before his eyes, naturally declares himself in favour of the single cam, which would enable him to run his batteries up to 110 per minute. The Mettacom stamps fall 10 inches. The original drop was $9\frac{1}{2}$ inches; but it was increased to ease the cams and give less jar. The rebound of the stamps amounts sometimes to $1\frac{1}{2}$ inch. Strange to say, the high speed maintained has not caused excessive necessity for repairs. On the contrary, the battery has stood the strain better than any other within my knowledge. Even the shoes and dies, which were not supposed to be unusually good, being bought for ordinary hard iron, lasted for five months of continuous running without being replaced. This fact cannot be adequately explained. Probably that particular set was a lucky cast. Ordinarily, it would have worn out in about six weeks; but I do not doubt that the heavy charges put through the batteries at high speed protected the shoes and dies from pounding on one another, which they are quite likely to do in ordinary mills, especially when the feeder is careless. A mill running at 100 to the minute keeps the feeder busy; and he does not wait for a stamp to thunder out, by pounding on its anvil, that it has finished its last mouthful and wants another.

"A fact not to be overlooked in this connection is the great solidity of the battery frame and foundations. Nine-tenths of the stamp-mills ordinarily erected would rack themselves to pieces if run as the Mettacom has been, without breaking so much as a bolt.

"The gain in quantity of ore crushed is more than proportionate to the increase of speed. As I remarked, this quantity depends, in dry-crushing especially, on the discharge. I shall speak of that presently, as it regards the arrangement of screens; but I now refer to the frequency of the drops which supply the direct impulse and the air shock, by which the dry "pulp" is driven through the screens. Mr. Howell found by experiment that with 60 drops per minute he could put through in twenty-four hours only about $4\frac{1}{2}$ tons; 90 drops gave a little over 10 tons; and 102 drops *more than* $15\frac{1}{2}$ *tons.* If we assume that the increase in consumption of fuel would be the same as that in the power generated by the falling stamps per minute, we shall have—

No. of Drops per Minute.	Horse-power per Stamp.	Increase of Power.	Yield.	Increase of Yield.
60	1·36	..	$4\frac{1}{2}$	..
90	2·04	50 per cent.	10	122 per cent.
102	2·22	10 per cent.	$15\frac{1}{2}$	55 per cent.

"The increase of speed from 60 to 102, or 70 per cent., increased the yield from $4\frac{1}{2}$ to $15\frac{1}{2}$, or 244 per cent. To this should be added the gain in wages, interest on capital, &c., secured by rapid running. This comparison does not fairly apply to wet-crushing, though I am satisfied that in that process also high speeds are the best. But the difference is not so startling. Most wet-crushing mills come pretty near the average of $1\frac{1}{4}$ ton crushed in twenty-four hours per horse-power developed by each stamp. But the above table shows a variation from 0·33 tons at 60 to 0·70 at 102. The performance of the Manhattan mill is about 0·45 ton crushed in twenty-four hours per horse-power developed by each stamp; and this is a fair, perhaps high, average for such mills.

"When the throat of the battery is open, the pulp will be thrown both ways, and some of it comes back on to the feeding-floor. This indicates a fact too often ignored in the construction of mortars, namely, that since the impulse given by the stamp is radial in all directions, the greater the surface of discharge the higher will be the duty performed. The Mettacom batteries are not perfect in this respect. They have only a single front discharge, but this is 18 inches high instead of 12, as is usual. It is noticed that the fine pulp comes mostly through the upper 6 inches, and hence, in most batteries, would be thrown back into the mortar until it found exit below. Various forms of mortar with increased discharge have been recommended. The maximum discharge per stamp is attained by Clayton's circular mortar, containing only one stamp. There are also mortars with universal discharge, in which the screens go all the way round, being curved at the ends. The most common are the double dischargers, having screens in front and behind, and the feed over the rear screen. The objection hitherto made to all arrangements involving curved screens is the difficulty of properly stretching and keying them, while in dry-crushing, even a rear screen is found to be inconvenient on account of breakage from coarse ore. Mr. Curtis, of the Manhattan, however, prefers a double discharge, while Mr. Howell cares more for end-dischargers. The Mettacom end-stamps are hung with three-eighths of an inch more fall than the others, and still do less work. The order in which the stamps fall varies in different mills, and for wet and dry crushing. The two extremes to be avoided are a simultaneous drop of all the stamps which would rack the frame, strain the engine, destroy the continuity of discharge, and probably break the screens; and a drop in regular succession (1, 2, 3, 4, 5), which would shove the ore to one end of the mortar, and give the stamps at one end too much, and at the other end too little, to do. Some mill-men prefer to arrange the succession so that no stamp shall immediately follow its next neighbour. The orders 1, 4, 2, 5, 3; 1, 3, 5, 2, 4; 4, 2, 5, 1, 3, would satisfy this condition. Others prefer dropping the two-end stamps first, as, 1, 5, 2, 4, 3, or 1, 5, 4, 2, 3. The wave of discharge, or splash of the water through the screens in wet-crushing, is to be taken into consideration. In dry-crushing, the objects to be secured are an equal distribution of ore under the stamps, giving an equal work per stamp, and a maximum discharge of pulp through the screens. The latter seems to be best secured by letting the middle stamp drop last. The outer stamps should then have slightly longer cams, to increase their fall. It will be found that the central stamps take and distribute nearly all the feed. Much depends on the skill and fidelity of the feeder, in both kinds of crushing. Hence the automatic self-feeding batteries used in Cornwall have found little favour in this country. They do not "humour" the stamps; and the difference in regularity of running and in duty performed is more than equivalent to the wages of a good feeder.

"The screens of this mill are No. 40 brass wire (1600 meshes to the square inch), which is preferred for dry-crushing to the 'Russia-punched.' The latter are frequently preferred by mill-men in wet-crushing, on account of alleged greater durability, or in the belief that slits are better adapted to discharge liquid pulp than meshes. I take leave to doubt, however, whether these advantages in any case counterbalance the greater proportional discharge area offered by wire screens. The

Mettacom screens are not vertical, but lean outward about 10 degrees. The pulp generally goes through obliquely, and is as fine as the siftings of a horizontal No. 60 sieve. The angle given has been established as the best for dry-crushing. The gain in amount of discharge, wet or dry, from inclined screens, is universally recognized; but mill-men do not so generally bear in mind that the screen so set should be a little coarser than the fineness required for the pulp, if the best results are to be obtained. Mr. Howell's observation is that stamps ordinarily crush faster than the batteries discharge. He has often put the pulp back through his battery, and found that it took about as long to go through as fresh rock. Running slow gives the fine dust a chance to fall back under the stamps; running fast keeps it constantly in motion, and much of it gets out. I venture to suggest some consideration based upon the foregoing facts, and calculated, I think, to put mill-men upon the right track in increasing the efficiency of dry batteries. It seems to me that dropping 900-lb. stamps is a costly way of making currents of air to promote discharge. The object of the mill-man should be to get the highest practicable speed from his stamps, and then to give them such facilities for discharge as that every drop shall do its full work in crushing. The increase of the discharge area is the first and most obvious means, and a useful auxiliary will, I think, be found in producing a current of air with a fan, which shall suck or drive the fine dust through the sieve. I have seen exhausting fans applied in this way in several mills. There was one in the Sheba, at Star City, Humboldt County, and there were several in the early Austin mills, which were finally condemned. Mill-men are too ready to reject such appliances as soon as they cause a little trouble, whether through faulty construction or careless management. But this point will be found too important to be dismissed so easily. I do not remember ever in my life seeing a stamp-mill in which the difficulty of discharge did not really delay the work of crushing. The extreme of excessive discharge, which would do no harm, is carefully avoided, and no one can tell to this day how much the stamp now in use could be made to do by simply improving batteries in this respect. The tide of invention is, it appears to me, running the wrong way. We have innumerable devices to increase the force and efficiency of the blow of the stamp, which is already in advance of the rest of the machinery, while the inventions for improving the mortars and discharges are few, generally imperfect, and regarded with too little favour by those practical mill-men who are alone competent to take hold of them and perfect them.

"The screens at this mill last nearly four weeks. When the threads wear thin they begin to shift, and the screens must be removed. They are turned to prolong the wear. The middle of the screen lasts longest. The dies, when new, come up to within about one inch of the lowest portion of the discharge. It is very important to make this interval, called the 'height of issue,' as small as the screens will bear. The dies used for five months wore away about $1\frac{1}{2}$ inch, and the introduction of new ones raised the capacity of the battery nearly 2 tons per day. Much trouble was experienced in keeping the dies in their places in the bottom of the mortar. Finally, 150 lbs. of melted lead was poured in, filling the mortar-bed about one inch. This is found to work well. I think that for dry-crushing a single die, filling the whole bed, would be better yet. When it wears on one side it can be turned, and so used till it is worn out. This is a German plan, and used successfully in some dry-crushing mills managed by Germans in this country.

"The foundation of a battery is the most important part of its construction, and it is the feature most neglected in this country. Few mill-owners like to put so much money 'out of sight'; the work of preparing foundations is parsimoniously, ignorantly, or carelessly managed;

and the result is that the batteries cannot be run at high speed, and even at low speed they are continually settling or getting out of line. The great efficiency and stability of the Mettacom mill is due to its carefully prepared foundation. The mortar-blocks are set on end, upon solid bed-rock. They are 9 feet deep. Before placing them, the rock was thoroughly smoothed and levelled, and the bottom of each block was planed true. The upper ends of the blocks being (as is the case with all large timbers) sun-cracked, melted sulphur was poured into the cracks. The mortars are set on the blocks and screwed down tight. If screwed (as is frequently the case) directly to the blocks, they will in a few months get loose, and rock and sand will work between, putting the machinery out of plumb and endangering the mortar. To prevent this, two thicknesses of blanket soaked in tar were put between the mortars and the blocks. An arrangement was made by which the settling of the mortars could be measured. It is found that after more than a year of steady running they have sunk uniformly less than one-fourth of an inch—doubtless due to the compression of the blankets. The freedom from jar in the mill, while the batteries were running at tremendous speed, impressed me as decisive proof of the utility of the arrangements described. There is, however, some vibration in the cam-shaft, which should have been 5 inches instead of 4 in diameter. Mr. Howell recommends also heavier bearings. The latter are now 8 inches, and should be 10. No Babbitt metal is used in the upper box; it cannot be kept in, and smooth iron is therefore preferred. The battery, running at 98 to 100 per minute, requires about 22 horse-power, which is perhaps a little more than half the power employed in the mill, and crushes easily 7 tons in twelve hours.

CHAPTER VI.—*Continued.*

MACHINERY FOR THE TREATMENT OF MINERAL PRODUCTS.

Section II.—Machinery for the Preparation of Gold and Silver Ores.

THE machines employed and the processes adopted for the preparation of gold and silver ores on the Pacific coast are acknowledged to be superior to any in general use in other parts of the world. We shall, therefore, confine our illustrations and descriptions of this class of machines to those there employed. The superiority of the American machinery designed for this purpose lies chiefly in the details of its construction. The general features are everywhere the same, so that it is undesirable to describe machines which are the same in principle as the American, but differ from them only in being more clumsily constructed, formed of less suitable materials, or driven in a less efficient manner. Moreover, the Pacific coast machines are taken as a type for imitation in other mining districts, so that in a few years they may be expected to have superseded generally the less efficient designs now in use.

The stamps in Colorado, Figs. 638 to 642, are, as a general rule, heavier, run more slowly, and with greater fall than is usual in the mills of California and Nevada. Some of them weigh 900 lbs. each, and although the mills of most recent construction have generally adopted a 500-lb. or 600-lb. stamp, the average is probably somewhat higher than that at present. Some run with as low a speed as 15 drops per minute; others as high as 40; while the average will probably not exceed 28. The fall is from 12 to 18 inches. The revolving stamp is in general use. The high mortars, having the bottom and sides cast in one piece, so generally used in Nevada and California, are not found in Colorado. The mortar in common use in this territory is a simple iron trough, 4 or 5 feet long, 12 or 14 inches wide, and 9 inches deep, cast with a solid bottom which should be 9 or 10 inches thick, but is often less. It is laid on wooden foundations, made sometimes, like those already described, of sound timbers set vertically, their ends resting on firm ground; or, more commonly, on a long horizontal mortar-block, that rests on other cross-timbers, placed horizontally. The bottom of the mortar on the inside contains recesses into which the dies sink and are secured. The latter have usually flat octagonal bases with a wearing surface rising above them of cylindrical form, corresponding to that of the shoe, usually 8 inches in diameter. The battery-work above the mortar is all of wood. The housings are of plank, the front and back being so made as to be readily taken down, giving access to the inside of the battery. The screens are of Russia sheet-iron, 9 or 10 inches wide, and as long as the battery, fixed in a frame that can be secured in front of the battery by keys fitting in the grooves, or other simple contrivances, one of which is shown in the drawing, Fig. 642. The discharge is usually only in front. The screens are punched with very fine slits about one-third of an inch long, and the same distance apart. The battery usually contains four or five stamps. These in general features resemble those already described, consisting of a stem, head, shoe, and tappet or collar, by means of which the cam raises the stamp. The tappet in Colorado is usually adjusted to its place on the stem by turning it on a screw-thread, cut for the purpose, and is fixed by means of a key or wedge that is driven into a key-seat cut in the tappet and stem. In some mills, the stamp-stems are made with a slight taper in the part to which the tappet is to be attached, and the latter, having a corresponding form, being driven on to the stem, holds its place by friction. Such is the form of the tappet shown in the drawing already referred to. The California tappet described in the foregoing section, and deemed by mill-men who have used it as superior to any other, has not yet come into general use in Colorado.

The stamp-mills are generally driven by steam, though some that are favourably situate on the water-courses obtain power from that source. Many mills, however, are located on the mine supplying the ore, the stamping machinery being under the same roof with the hoisting or pumping works and operated by the same power, which, where practicable, affords a great saving in cost and care of machinery and in the labour of handling the rock. The power is generally transmitted from the engine by belt to a counter-shaft, from which the stamps are usually run by gearing. The convenient method in use in Nevada and California, of running each battery or two batteries by a belt, so that by applying or withdrawing a tightener, any battery may be set in motion or stopped independently of the other batteries, is not here in use. A cam-shaft in Colorado is generally made long enough for all the stamps in the mill, or if the mill be a large one, for twenty or more stamps, the stoppage of one battery involving the delay of all the others run by the same shaft. The cam-shaft is generally driven by a geared wheel, though the shaft carrying the driving pinion is commonly driven by belting.

Wet-crushing is used altogether in the milling of gold ores in Colorado.

Water is introduced into each battery by a number of small pipes that draw their supply from a trough *w*, shown in the drawing. The quantity must be sufficient to carry out the material as soon as it is reduced to the necessary degree of fineness, this being determined by the mesh of the screen in front of the battery through which it is discharged. Amalgamation is performed in the battery, in which a supply of quicksilver is maintained for the purpose of taking up the gold as soon as liberated by the crushing process. The quicksilver is usually introduced into the batteries in small quantities from time to time, as may be necessary, according to the richness of the ore and the rapidity with which the amalgam is formed. The appearance of the latter, as it issues from the battery, is one indication, to the attendant, of the quantity of quicksilver present. Hard, dry, and dense particles of amalgam show the lack of a sufficient quantity, while from the degree of fluidity of the particles the presence of a sufficient quantity, or of a surplus, of quicksilver, may be inferred. The ends of the batteries are lined with amalgamated copper-plates, while another plate of the same kind, about 10 or 12 inches wide and as long as the inside of the battery, is so fixed in a frame that it may be introduced and secured in an inclined position behind the stamps. A similar plate, though narrower, is generally used on the front or discharge side of the battery. A portion of the amalgam, as it is formed in the battery and splashed against these plates, adheres to the amalgamated surfaces and is retained upon them. The batteries and plates are cleaned up at stated intervals, differing in length in various mills, in some once each day, in others only once in three or four days, and the amalgam that has collected in the battery about the stamps and on the plates is removed. From one-half to three-fourths of the total product is obtained from this source, while the remainder comes from the other appliances used outside the battery for the purpose of catching the amalgam. These consist mainly of aprons or tables, covered with amalgamated copper-plates and constructed in various ways. Usually the stream of water flowing from the batteries and carrying with it the finely crushed ore, some of the amalgam and quicksilver, with much still unamalgamated gold, passes over an inclined plane or table, 5 or 6 feet wide, and from 6 to 12 feet long, and covered with copper plate. These tables are placed in front of the batteries, so that the stream passes directly over them. Generally one table of the dimensions above given is provided for each battery of stamps, though in some mills there is but one table for two batteries. The table should be fixed at such an inclination that the stream of water may run down steadily over its surface, carrying with it the charge of crushed rock, but with not so great a velocity as to wash away the amalgam or prevent its adherence to the plate. This inclination is usually about 1 inch of fall to 6 inches or 1 foot of length, but is variously determined by different mill-men, depending chiefly on the quantity of water used, and other conditions as experience may direct. In some mills, the material first passes over a short copper-plated apron, only 20 or 30 inches long, and thence to shaking-tables, that, instead of being fixed, are suspended at about the same inclination as the stationary table, and to which a slight forward and backward movement is given, accompanied by a sudden shock or percussion. The surface of the table, instead of being smooth, has a number of rifles or grooves at right angles to the long side of the table or the line of motion, which serve to contain quicksilver, and afford increased opportunities for contact with the ore and amalgamation of the gold. Leaving these machines, the stream continues to flow on, in some cases immediately out of the mill into tanks or basins where the residue of the material, or "tailings" is deposited; in other cases, over a variety of machines provided for the further saving of the gold or the concentration of the heavier and better portions of the ore and the escaping amalgam. Usually there is a long wooden sluice or canal, the bottom of which is covered with copper in the same manner as the tables just described, or with coarse blankets which catch the pyrites and some amalgam, which, being washed off from the blankets and collected, may be treated in grinding pans or sold to parties for treatment by other methods. The amalgam formed in the batteries and on the tables is cleaned up at intervals varying in length according to the richness of the ore. In some mills the outside plates or those on the inclined tables are cleaned daily, while the batteries are allowed to run three or four days without cleaning. The outside plates are cleaned by carefully scraping off the adhering amalgam, first gently with a knife, and finally with a thick piece of hard gum or rubber, which scrapes the surface closely without cutting or scratching it. The plate is then washed with water and prepared for use again by sprinkling quicksilver over it, spreading the same evenly by means of a cloth, thus forming a freshly amalgamated or quicksilver-coated surface.

The plates that are fitted into each battery, or mortar, are cleaned in like manner, and the mortars themselves, the stamps being hung up and the housings sufficiently removed, undergo a similar operation, the shoes, dies, and interior iron-work being carefully scraped with a knife, in order to remove the adhering amalgam. The amalgam, thus collected, contains some impurities, in the form of pyrites, iron, and dirt, which has to be removed before retorting. It is usually put into a Wedgwood mortar, or other suitable vessel, and stirred or agitated with water, by which means the dirt or lighter portions rise to the surface, and may be floated or washed off into a cistern or other vessel, and collected there for future treatment. The amalgam may then be rendered fluid by the addition of more quicksilver, the impurities brought to the surface by agitation, and skimmed or cleaned by a piece of coarse blanket, to which the particles of dirt and other foreign substances adhere. By repeated operations, the amalgam may be obtained in a very clean condition, the skimmings being subsequently cleaned in similar manner. When thus prepared, the amalgam is strained through a piece of cloth and forcibly pressed, so as to squeeze out as much as possible of the surplus quicksilver. The remainder is then retorted. After the ore, crushed by the stamps, has run over the amalgamated copper-plates of the tables, it is variously treated in different mills. In some, it is allowed to pass away in the tail-race without further attention; in others it is collected outside in dams and worked over by some simple methods of concentration. In many mills, the tailing stream passes first over blanket sluices; the product of the blanket washings is then either ground and amalgamated in Bartola pans or sold at the smelting works; while the great mass of the tailings, having passed over the blankets, is subjected to still further processes of concentration. In one or two mills, Rittinger tables are used.

The blanket sluices consist of a simple sluice or flat-bottomed trough, one or two feet wide, and of indefinite length, the sides of which are formed by two strips of wood two or three inches high.

The sluices are slightly inclined, so that the stream may flow readily. On the bottom of the sluices are laid coarse blankets. The stream of tailings is allowed to run over these sluices, and the heavier particles of ore lodge in the blanket, while the lighter particles are swept away. The blankets are washed out at regular intervals. The material obtained is usually a rich concentration.

The greater part of the tailings is subsequently treated in common square buddles. The buddle is a long wooden box about 4 or 5 feet wide, 10 feet long, and 15 inches deep, fixed at a gentle inclination, so that the stream may run down through it readily, and so arranged that water may be supplied at the head or upper end, and distributed evenly over the whole width of the table. The tailings are fed at the top, being thrown upon an apron above the head, and washed down into the box by the stream. The workman standing at the side, by means of a broom or light scraper, assists the even distribution of the material, and by sweeping it very gently upward toward the head of the box, aids the separation of the heavier from the lighter particles, the former remaining near the head, the lighter being swept away by the current. When the buddle is full, the contents are divided into three equal parts, that which is nearest the lower end being allowed to run away, the middle portion returned to the apron to be treated again in the buddle as just described, while the headings, or the 3 feet nearest the upper part of the buddle, being richest, is treated in a "keeve"; that is, agitated or stirred in a barrel or tub, and then allowed to settle, the heavier part collecting on the bottom being the concentrated mineral; the upper portion of the stuff in the tub is returned to the buddle for a repetition of the process. Two men, or a man and a boy are required to work one buddle. It is usually estimated that 6 tons of common or raw tailings produce 1 ton of dressed tailings. One great desideratum in order to improve the efficiency of the process adopted, and, at the same time, to reduce the cost of working, in some respects appears to be the adoption of some suitable method of concentration, which, being combined with the present process of crushing and amalgamation, should render available the contents of the tailings in a more perfect and less expensive manner than is now done by the means generally employed. Very satisfactory results have been generally obtained by the Rittinger table in Europe. The following description of this percussion table is given in Von Rittinger's 'Lehrbuch der Aufbereitungskunde.' The details of its construction are shown in the drawings Figs. 643 to 648. Fig. 643 is a front elevation of a double table; Fig. 644 a plan; Fig. 645 a side view.

This apparatus consists of a wooden table or platform, about 4 feet wide and 8 feet long, which is suspended by iron rods at the four corners, as shown at *b b*, presenting an inclined plane over which the water and material supplied at the upper end may flow evenly toward the lower end. The table is so hung as to move freely in a lateral direction when acted on by a cam *c*, and may be thrown back by the action of a spring *d*, so as to strike forcibly against a timber *e*, firmly imbedded in the ground, by which means a shock is imparted to the table and the material upon it. The characteristic features of this table, as compared with the ordinary percussion table, already many years in use, are that the shock is applied at one of the long sides, instead of at the end, and that it is self-discharging and continuous in its operations.

On the old-fashioned percussion table, the material being supplied at the upper end and evenly distributed across the width of the table by a stream of water, and the shock being likewise imparted at the same end, the tendency of the heavier particles is to move backwards at each throw, or shock, of the table, while the lighter particles following the impulse of the stream, move downwards toward the front edge, and are there discharged. In the case of the Rittinger table, all the particles which are fed at the upper end and near one side move downward with the stream, but as the percussion is applied at the opposite side, they obtain at each throw of the table a lateral motion, which varies in amount according to the density of the particles, so that the heaviest, the grains of ore, move entirely across the table to the side opposite to that at which they entered; the lighter particles, or grains of ore and gangue combined, move a part of the way across, while the lightest, or grains of earthy character, move downward in a nearly straight line, describing curves such as are shown in Fig. 2, at a, a^1, a^2, a^3, a^4. By this means a separation of the particles is effected according to their density, and as they are discharged at different parts of the front edge of the table, they may be received there in separate vessels or troughs, provided for the several classes; the first, consisting of nearly pure ore, being ready for smelting or other metallurgical treatment; the second, consisting of mingled ore and gangue, may be returned for repeated dressing; and the third, nearly pure gangue, is allowed to run to waste.

Fig. 646 shows the construction of the frame of a double table, consisting of two cross-pieces *f*, and five longitudinal pieces *g*. This frame is covered by hard-wood plank or boards, which are smoothly dressed and carefully fitted together, forming the surface of the table over which the material for concentration is allowed to pass.

As the top of the table, hitherto constructed of maple boards, soon begins to rot or wear upon the surface, and thus to lose its desired smoothness, it is better to cover it with a stout waterproof gum cloth, which must possess the requisite degree of smoothness or polish, that the fine particles of slime may not adhere to it, and be white, or of light colour, that the dark streaks of ore may be clearly distinguished. The cloth should be applied to the table when warm, that it may be well stretched under ordinary temperature. When stretched and nailed upon the table, the edges of the cloth are covered with narrow strips of leather, to prevent tearing, and at the upper end it is covered with a strip of zinc, 10 or 12 inches wide, upon which the water and solid material fall from the distributing boards, passing thence quietly on to the cloth. Such a cloth-covering is said to last over a year, and to be especially well adapted to the treatment of the finest material; only the number of shocks must be increased for such to 120 or 150 per minute. The sides and upper end of this surface are furnished with bordering strips of wood *h*, and a similar strip divides the surface longitudinally in the middle, thus forming a double table. The lower end of the table is also furnished with short strips *i*, which may be moved on a pivot toward one side or the other, and which have the upper ends pointed, to assist somewhat in the division of the several classes of the material at the place of discharge.

These pointed strips may also be fixed in any desired position or place by driving wooden wedges between them and a transverse piece of wood that crosses the table near the lower end, and is supported above it by resting on the upper edges of the side and partition strips *h*, to which it is nailed.

The lower end of the table is also pierced with slits or apertures, *j* and *k*, Fig. 644, through which the material may be discharged from the table before reaching the lower edge, falling thus into troughs, or launders which conduct the different assortments to their appropriate places. The outer one of these launders, *l*, receives the clean ore from the lower edge of the table, the second, *l′*, receives the "middlings" through the aperture *k*; and the inner, *l″*, receives the waste stuff through the aperture *j*.

Another arrangement for the disposition of the assorted material without the use of apertures is shown in Fig. 647, in which the poor stuff, or gangue, is discharged over the edge of the table into the launder *l″*; the other two classes fall into the box *m*, which is divided into two parts opening in opposite directions, that part which is under the discharging point of the clean ore opening to the right and delivering the stuff into the launder *l*—the other part receiving the middlings and delivering into the launder *l′*. The table is suspended in an upright framework, as shown in the drawing, by iron rods, the length of which may be somewhat increased or diminished, as may be desired, by means of the screw near the point of support. The percussion timber *p* forms a part of the frame of the table. One end of it rests against the timber *e e′*, being strongly pressed in that direction by the spring *d*, which is attached to the other end. Motion is communicated to the percussion timber *p*, and thus to the table by rods *n*, which connect it with a perpendicular rod *o*, against which the cams *c* strike. The rods *n* are attached to *p* by means of a nut *q*, shown in Fig. 648, which moves on a screw, and may be adjusted, for the purpose of shortening or lengthening the stroke by turning the head *n*. When the cam *c* presses against the block at *o*, it moves the table in a lateral direction, compressing the spring *d*, which latter, as soon as the pressure of the cam is relieved, throws the table back against the timber *e*, producing the shock, the force of which is regulated by a screw *s*, applied to the middle of the spring and entering the framework above the table. The force of the stroke is increased by screwing the spring up closer to the frame, or diminished by withdrawing the screw.

In the improved arrangement, motion is imparted to the table in a somewhat different manner the cam acting directly upon the frame instead of by the means shown in Fig. 643, and drawing the table to one side and then releasing it for the movement in the opposite direction, by which it receives the shock, instead of pushing it as indicated above. To effect this, the end of the percussion timber *p* nearest the cam, is furnished with two stout iron plates, one attached to each side of the timber and extending towards the cam; the two plates are connected at their other ends by a cast-iron piece which fills the space between them, and has its inner surface curved so as to correspond to the curve of the cam. The latter revolves between the two plates, in the reverse direction from that indicated in Fig. 643, and, striking against the cast-iron piece, draws the table to one side. When the table is released by the cam it is drawn to the opposite side by the action of a spring, which, as in the case already described, is of wood, but is placed horizontally, the two ends being fixed and the middle attached to the end of the percussion timber. When thus drawn forward the end of the percussion timber strikes against a buffer, which is firmly secured in an iron bed-plate that is screwed down to an underlying timber; and as the sharpness of the shock—an important condition for effective work—depends upon the firm position of this timber, the latter is made long enough to extend entirely under the table to the opposite side, and is fixed by holding-down bolts to a solid foundation of masonry. The timber is connected with and braced by other timbers that are so laid in the masonry as to distribute the shock as evenly as possible to the entire mass of the latter. The opposite end of the timber may serve as the foundation for the supports of the cam-shaft, one end of which is furnished with a driving pulley and the other end with a 400-lb. to 600-lb. fly-wheel, 3 feet in diameter.

The movement of the table is guided by two uprights, one on each side of the percussion timber.

The buffer is adjustable, and by advancing or retiring it, the length of the stroke may be regulated.

The distributing board *t* is divided into four parts, or aprons, for each single table, each of which aprons is provided with a group of distributing points. The material for concentration is supplied from a trough *u*, and enters the table by the apron *t*. Clear water, of which a supply is kept in the box *w*, the surplus flowing off through *w'*, is furnished thence, through separate cocks, to the aprons t^2, t^3, and t^4, and thus distributed evenly over the table. In the manipulation of this table the following conditions are important. The surface of the table must be made as smooth as possible. The width of the apron from which the material for concentration is supplied to the table should not exceed 8 or 12 inches, clear water being distributed over the remainder.

If a very clean product is desired the width of the washing surface may be increased to 4 feet, making a total width of 5 feet, or, maintaining a total width of 4 feet, the distributing surface of the sluices may be reduced to a width of 8 or 9 inches. The inclination of the table must be adapted to the character of the material to be treated; it should be about six degrees for sands, and three degrees for fine slimes. The supply of stuff to be treated should not exceed $\frac{2}{10}$ of one cubic foot, containing 15 lbs. of sands per foot; or $\frac{1}{10}$ of one cubic foot, containing 6 lbs. of slimes per foot. According to this, a double table will treat in twenty-four hours 4·640 tons of sands, or 0·864 ton of slimes. The amount of clear water required is about the same quantity per foot of distributing breadth as that which brings the ore upon the table, so that if the breadth of the ore-distributing surface is 1 foot, and that of the water-distributing surface is 3 feet, the quantity required for one table will be, for sands, $\frac{6}{10}$ of one cubic foot per minute; and, for slimes, $\frac{36}{100}$ of one cubic foot per minute. The quantity of clear water must, further, be increased as the inclination of the table is decreased. The outer edge of the table, that is, the side opposite that on which the ore enters, should have a little more water than the rest of the surface, in order to carry off the heavier material that reaches that side. The number of strokes per minute is, for sands, seventy to eighty; for slimes, ninety to a hundred. The length of each stroke depends upon the tension of the spring *d*, by which the table is pressed against the block *e*. The spring has a length of 11 feet, a breadth of 3 inches, and a thickness of from 2 to $2\frac{1}{2}$ inches. If the spring has a tension of 180 or 200 lbs., the length of stroke should be, for sands, $2\frac{1}{2}$ inches, and, for slimes, $\frac{1}{2}$ to $\frac{3}{4}$ of an inch.

Under too strong tension of the spring, the table makes its return movement too speedily for the desired action of the particles; the result is that they move in the reverse direction. The operation of the table demands great uniformity in treatment, especially as regards the number of blows and the quantity of water and of material. When the stream carrying the material upon the table contains less sand or slime per cubic foot than the maximum above given, the tension of the spring should be relieved, and the inclination of the table diminished. Under ordinary conditions, the average performance of a double table is from 2 to 4 tons in twenty-four hours, with a consumption of water of 1000, or 1500 cubic feet. One table requires $\frac{1}{4}$ horse-power.

The ore to be treated by the ordinary Washoe process, as that of pan amalgamation is called, is delivered from the mine to the mill in pieces varying in size from fine particles to those as large as a man can lift. It needs first to be crushed to a fine condition. This operation is performed by stamps. The larger pieces of ore are first broken to a suitable size for feeding the stamps, either by a sledge hammer or a mechanical rock-breaker, Blake's machine being in general use for this purpose.

Wet-crushing is always employed for these ores; that is, a stream of water is admitted to the mortar with the ore, and, flowing off, carries with it the pulverized ore as soon as the latter is sufficiently reduced in size to pass through the screens placed in front of the discharging apertures of the mortar.

The screens, through which the crushed material is discharged from the mortar, are either of brass wire-cloth, having 35 or 40 meshes to the lineal inch, or more frequently of Russia sheet-iron, perforated with fine holes.

Screens of the latter sort, in general use, are known as Nos. 5 or 6. In the last named, the hole has a diameter of $\frac{1}{40}$ of an inch.

In former years, the amalgamation of the precious metals of the ore with quicksilver was carried on in the mortar, a supply of quicksilver for that purpose being introduced with the rock into the mortar. This feature of the process has, however, now been given up in the mills of the Washoe district. The stuff being discharged from the battery is conveyed into troughs, by means of the flowing water, to settling tanks, of which there is a series placed in front of the batteries. These tanks are usually built of plank, are 3 or 4 feet deep by 5 or 6 or more feet square, and are so arranged as to have communication with each other near the top, so that the stream of water carrying the crushed ore in suspension, having filled one tank, may pass into the next, and so on through several, depositing the material and not finally leaving the tanks until it has become tolerably clear. The number of tanks must be sufficient to allow of a certain portion being emptied, while others are receiving their supply, and the conveying troughs are provided with gates so arranged that the stream can be admitted to one portion of the tanks and shut off from the others at pleasure. The stream having deposited in these tanks the bulk of the material, is still charged with slimes, or rock reduced to an impalpable fine condition, which rock is only settled by a slow process. For this purpose, the stream is sometimes permitted to pass through other large settling tanks, or to slowly deposit its charge in a pond or dam outside the mill, where such an arrangement is possible.

The slimes form a variable and in some mills a large percentage of the whole amount crushed; in some instances, it is stated more than 10 per cent.; and although they have a high assay value, they have not until recently been worked successfully and with profit. When one or more of the settling tanks in the mill have been filled, the stream is diverted from such to others that have been emptied, and the full ones are in their turn cleaned out, the sand or crushed ore being then subjected to the grinding and amalgamating process of the pan.

For the purpose of comparison, the following particulars are added of the machinery employed in the chief gold-mining districts of Australia :—

At the Port Phillip Company's Mines at Clunes, the large masses of quartz are passed through rock breakers, of which there are two. The number of stamps at work is eighty; of these fifty-six weigh about 600 lbs. each, including the lifter. They give about seventy-five blows per minute, require about 1 horse-power per stamp, and crush an average of about 2 tons 4 cwt. per head per twenty-four hours. The remaining twenty-four stamps weigh about 800 lbs. each, including the lifter, give seventy-five blows per minute, require in the aggregate about 30 horse-power, and crush about 4 tons per head per diem. These stamps have the larger portion of the small quartz delivered to them. The quantity of water required to work the stamps efficiently is about eight gallons per head per minute, being 921,600 gallons per diem.

The construction of the batteries and the method of saving the gold in troughs is shown in Fig. 649, which is a section through the battery.

In this, *b* is the lower end of the self-feeding hopper, with a spring *c* below it. Just below this is the water-trough *d*. The stamp-lifter or stem is made largest at the lower end, so as to be wedged into the head *f* by a key at the side, in this respect being very different from the method of attachment in California. The head is cast also in one piece, without a shoe, and is renewed when too much worn. The die *g* is placed loosely in the bottom box or bed *h*. The delivery is through grates upon both sides of the battery, at *e e*. A perforated plate *j* serves to retain any coarse particles thrown out, and the stamped material, passing through this plate, falls into the mercury-boxes *k*, *k*, *k*, and thence upon a long line of blanket strakes, the extreme upper end of which only is shown in the figure. These strakes are each several inches broad, and there are nine in succession, one below another, with a mercury-box at the lower end, through which the material passes before entering the waste-trough. This mercury-box serves to catch any fine particles of gold that may have passed the blankets and any stray globules of quicksilver from the upper boxes.

In the Ballarat mining district, the stamp-heads and shanks or lifters vary in weight from 4 cwt. to 8 cwt. 2 qrs. The height the stamp-head falls ranges from 7 to 10 inches. The number of strokes made by stamp-heads per minute is from fifty to eighty-five. The quantity of quartz crushed per head per diem of twenty-four hours varies from 1 ton to 4 tons. The number of holes per square inch in the gratings used is from forty to two hundred.—(The latter number is made use of by the Victoria Company at Clunes; the grating is fixed at the back of the stamper-box.) The horse-power required to work each stamp is from 1 to 2. The quantity of water used per stamp-head in crushing varies from 950 gallons to 8640 gallons per diem of twenty-four hours. The quantity of mercury used in the ripples per stamper is from 5 to 75 lbs. The quantity of mercury lost per stamp-head per week varies from 1 ounce to 8 ounces.

In the Beechworth mining district the stamp-heads and shanks or lifters vary in weight from 4 cwt. 1 qr. 17 lbs. to 7 cwt. 3 qrs. The height the stamp-heads fall varies from 5 inches to 14 inches. The number of strokes made by the stamp-heads per minute is from forty to ninety. The quantity crushed per head per diem of fourteen hours ranges from 16 cwt. to 4 tons. The number of holes per square inch in the gratings used is from sixty to one hundred and forty.

The horse-power required to work each stamp-head is from 0·75 to 1·50. The quantity of water used per stamp-head in crushing varies from 720 gallons to 11,520 gallons per diem of twenty-four hours. The quantity of mercury used in the ripples per stamper is from 5 to 70 lbs. The quantity of mercury lost per stamp-head per week varies from ½ ounce to 8 ounces.

In the Sandhurst mining district, the stamp-heads and shanks or lifters vary in weight from 5 cwt. to 8 cwt. The height the stamp-heads fall varies from 6 to 18 inches. The number of strokes made by the stamp-heads per minute is from twenty-five to seventy-five. The quantity of quartz crushed per head per diem of twenty-four hours ranges from 18 cwt. to 3 tons 3 quarters. The number of holes per square inch in the gratings used is from sixty-four to one hundred and forty. The horse-power required to work each stamp-head is from 0·66 to 2. The quantity of water used per stamp-head in crushing varies from 4000 gallons to 8640 gallons per diem of twenty-four hours. The quantity of mercury used in the ripples per stamper is from 10 to 40 lbs. The quantity of mercury lost per stamp-head per week varies from ½ ounce to 5½ ounces.

In the Maryborough mining district, the stamp-heads and shanks or lifters vary in weight from 4 cwt. 2 qrs. to 8 cwt. The height the stamp-heads fall varies from 6 to 22 inches. The number of strokes made by stamp-heads per minute is from fifty to seventy-five. The quantity of quartz crushed per head per diem of twenty-four hours ranges from 1 ton to 3 tons. The number of holes per square inch in the gratings used is from seventy to one hundred and forty-four. The horse-power required to work each stamp-head is from 0·50 to 2·50. The quantity of water used per stamp-head in crushing varies from 900 gallons to 8640 gallons per diem of twenty-four hours. The quantity of mercury used in the ripples per stamper is from 3 to 30 lbs. The quantity of mercury lost per stamp-head per week varies from 1¾ ounces to 8 ounces.

In the Castlemaine mining district, the stamp-heads and shanks or lifters vary in weight from 4 cwt. 2 qrs. to 8 cwt. The height the stamp-heads fall varies from 6 to 15 inches. The number of strokes made by the stamp-heads per minute is from thirty-five to seventy-five. The quantity of quartz crushed per head per diem of twenty-four hours ranges from 1 ton to 3 tons 5 cwt. The number of holes per square inch in the gratings used is from forty to one hundred and forty-four. The horse-power required to work each stamp-head is from 0·50 to 2. The quantity of water used per stamp-head in crushing varies from 4800 gallons to 12,960 gallons per diem of twenty-four hours. The quantity of mercury used in the ripples per stamp is from 6 to 40 lbs. The quantity of mercury lost per stamp-head per week varies from ¼ ounce to 24 ounces.

In the Ararat mining district, the stamp-heads and shanks or lifters vary in weight from 5 cwt. to 6 cwt. 3 qrs. The height the stamp-heads fall varies from 7½ to 10 inches. The number of strokes made by the stamp-heads per minute is from sixty to seventy-two. The quantity of quartz crushed per head per diem of twenty-four hours ranges from 1 ton 5 cwt. to 1 ton 10 cwt. The number of holes per square inch in the gratings used is from ninety to one hundred and twenty. The horse-power required to work each stamp-head is 0·75. The quantity of water used per stamp-head in crushing varies from 4320 gallons to 12,960 gallons per diem of twenty-four hours. The quantity of mercury used in the ripples per stamp is from 6 to 47 lbs. The quantity of mercury lost per stamp-head per week varies from ½ ounce to 7 ounces.

In the Gipp's Land mining district, the stamp-heads and shanks or lifters vary in weight from 6 cwt. to 7 cwt. 2 qrs. The height the stamp-heads fall varies from 7 to 10 inches. The number of strokes made by the stamp-heads per minute is from sixty to eighty. The quantity of quartz crushed per head per diem of twenty-four hours ranges from 1 ton 10 cwt. to 2 tons 1 cwt. The number of holes per square inch in the gratings used is from seventy to two hundred and fifty. The horse-power required to work each stamp-head is from 0·75 to 1·50. The quantity of water used per stamp-head in crushing varies from 1600 gallons to 25,000 gallons per diem of twenty-four hours. The quantity of mercury used in the ripples per stamp is from 10 to 37 lbs. The quantity of mercury lost per stamp-head per week varies from $\frac{1}{6}$ ounce to 32 ounces.

Grinding and Amalgamating Pans.—The pans employed for this purpose present a great variety in the details of their construction. The common features are a round tub, see Figs. 650 to 658, usually of cast iron, but sometimes with wooden sides, 4 to 6 feet in diameter and about 2 feet deep, having a hollow pillar cast in the centre, within which is an upright shaft projecting above the top of the pillar that may be set in revolution by gearing below the pan. To the top of this shaft is attached, by means of a key or feather, a yoke or driver by which the muller or upper grinding surface is set in motion. To the bottom of the pan, on the inside, is fixed a false bottom of iron, cast either in sections, commonly called dies, or in one piece, having a diameter a little less than that of the pan, and with a hole in the centre adapted to the central pillar. This serves as the lower grinding surface. The muller, forming the upper grinding surface, is usually a circular plate of iron corresponding in size and form to the false bottom just described, having a diameter nearly equal to that of the pan, and a flat, conical, or conoidal form according to the shape of the pan-bottom. Its under side is furnished with shoes or facings of iron, about an inch thick, that may be removed when worn down and replaced by new. The muller is attached to the driver, which is put on and over the central pillar of the pan, and being connected with the interior upright shaft as above described, is thus caused to revolve. There are various appliances for raising or lowering the muller, so that it may rest with its whole weight upon the pan-bottom in order to produce the greatest grinding effect, or be maintained at any desired distance above it when less friction or more agitation is required. Various devices are also in use for giving proper motion to the pulp, so that, when the muller is in revolution, the material may be kept constantly in circulation, passing between the grinding surfaces and coming into contact with the quicksilver. Some pans are cast with a hollow chamber, an inch or two deep in the bottom, for the admission of steam in order to heat the pulp, while others employ only "live steam," which is delivered directly into the pulp by a pipe for that purpose.

The operation of the pan consists in the further reduction or grinding of the stamped rock to a fine pulp, and in the extraction of the precious metals by amalgamation with quicksilver. The quantity of ore with which a pan is charged for a single operation, varies from 600 or 800 to 4000 or 5000 lbs., according to the size of the pan. The ordinary charge of pans, most generally in use at present, is 1200 to 1500 lbs.

In charging the pan, the muller is raised a little from the bottom, so as to revolve freely at first, water is supplied by a nose pipe, and at the same time the sand is thrown into the pan with a shovel. Steam is admitted either to the steam-chamber in the bottom of the pan or directly into the pulp. In the former case, the temperature can hardly be raised as high as in the latter; but, on the other hand, when steam is introduced directly, care is necessary to avoid reducing too much the consistency of the pulp by the water of condensation. The pulp should be sufficiently liquid to be kept in free circulation, but thick enough to carry in suspension, throughout its entire mass, the finely divided globules of quicksilver. In some mills, both the methods of heating are employed in the same pans, the temperature being first raised with each charge by live steam, and afterwards sustained by admitting steam to the chamber only. Some pans are covered with wooden covers to assist in retaining the heat. When properly managed, the temperature may be kept at or near 200° Fahrenheit. When, in the use of live steam, the pulp becomes too thin, the supply of steam is cut off, the covers removed, and the pulp allowed to thicken by the evaporation of the water. The steam in the chamber may keep the temperature up to the desired point in the meantime. Another advantage of the steam-chamber is that the exhaust steam from the engine may be used in it, while for use in the pulp it is better and customary to take steam directly from the boilers, because that which comes from the cylinder of the engine is charged with oil and is injurious to amalgamation. The muller is gradually lowered after the commencement of the grinding operation, and is allowed to make about sixty or seventy revolutions per minute. In the course of an hour or two, the sand should be reduced to a fine pulpy condition. When this has been accomplished, and by some mill-men at a still earlier stage, even at the beginning of the operation, a supply of quicksilver is introduced into the pan, the muller slightly raised from the bottom to avoid too great friction, which would act to the disadvantage of the quicksilver, and the action continued for two hours longer, during which the amalgamation is in progress. The quicksilver is supplied by pressing it through canvas, so as to scatter it upon the pulp in a finely-divided condition. The quantity varies greatly in different mills, the ordinary supply being about 60 or 70 lbs. to a charge of ore consisting of 1200 or 1500 lbs. In some mills a quantity, varying from 75 to 200 or even 300 lbs., is put into a pan when starting after a clean-up, and subsequently a regular addition of 50 or 60 lbs. made with each charge.

Two hours having been devoted to the grinding, and two or three more to amalgamation, the pan is discharged and its contents received by a settler or separator. The discharge of the pan is usually aided by a supply of water, which dilutes the pulp and permits it to run freely from the pan into the settler. The pan being emptied and partly washed out by the stream of water, is again charged with a fresh quantity of sand, and the grinding operation is resumed without delay.

The main objects sought for by inventors of pans, have been to produce grinding surfaces of most effective form securing the greatest uniformity of wear with economy of power; to obtain the most favourable conditions for amalgamation, depending mainly on the free circulation of the pulp, the uniform and thorough distribution of the quicksilver, and the proper degree of heat; and to combine, with these requirements, simplicity and cheapness in construction, facility in management and repair, large capacity, and economy of time, labour, and materials in the performance of duty.

The attempts that have been made to obtain these results have met with varied success, the different devices of any one pan sometimes obtaining a high degree of excellence in certain details at the cost of it in others.

Among the differences in characteristic features of pans the most noticeable is that of the bottom and the grinding surfaces, some being flat, and others variously curved; other details, of more or less importance, such as the construction of the muller and the method of attaching it to the driver, the form of the shoes and dies, the means of fixing them in place, of providing for the heating of the pulp and for its circulation during the grinding and amalgamating process, vary considerably in the several patterns.

The opinions of practical mill-men are somewhat divided regarding the comparative advantages of the different forms of pan-bottoms. The prevailing opinion, however, seems to be, all things considered, in favour of the flat bottom. While other forms of grinding surfaces may possess superior advantages, theoretically, their greater efficiency, in practice, is often lost by the unequal wear of the surface of the muller, usually resulting from the difficulty of keeping the other parts of the machine, on which the grinding surfaces depend, in perfect order. The various parts of the flat muller are simpler in form, more easily handled, and more conveniently replaced when worn out.

While the flat-bottomed muller involves the expenditure of more power in carrying its load of thick pulp, this disadvantage is counterbalanced, in the opinion of some, by the more complete distribution of the quicksilver, and the consequently more perfect amalgamation.

In Figs. 650 to 652, views are given of three well-known pans. They show the three different forms of pan-bottoms, the flat, conical, and conoidal. The flat-bottomed pan, Fig. 650, known as Wheeler's Amalgamator, is, perhaps, in more general use than either of the others, although Hepburn and Peterson's pan is in great favour among many mill-men.

Wheeler's Pan.—The Wheeler pan of ordinary size is about 4 feet in diameter, at the bottom, and 2 feet, or a little more, in depth. The general arrangement of the several parts of the machine may be readily seen by a glance at the drawing, Fig. 650. A is the rim of the pan, in the centre of which is the hollow cone B rising from the bottom, with which it is cast in one piece. Through this cone the vertical shaft C passes, which, being driven by the gearing below the pan, gives motion to the muller D by means of the driver E, which is keyed to the shaft C. The muller is provided, on its under side, with shoes *g* that form the upper grinding surface. The form of the shoes is shown in the drawing. They are attached to the muller by means of two lugs or projections *f f*, which are received in corresponding apertures in the muller-plate and securely wedged with pieces of wood. The lower grinding surface is formed by the dies *i*, which are usually four or eight in number, covering the greater portion of the pan-bottom and secured to it in a manner similar to that by which the shoes are fixed to the muller. There is a radial slot or space between the dies which is commonly filled with hard wood. Below the bottom is a steam-chamber for heating the pulp. The vertical shaft or spindle C rests in a step-box *h*, to which oil is conveyed by the pipe *p*. A vertical pin passes downward through the centre of the step-box, in contact with the shaft and resting its lower end on the lever *j*. This lever may be raised or lowered slightly by the hand-wheel, on the rod *k*, thus raising the muller from the dies, if desired. The shaft C is also furnished with a screw, by means of which the muller may be raised up entirely above the rim of the pan for the purpose of cleaning up or of changing the shoes and dies. The hoisting apparatus required in the absence of this screw is thus avoided. In order to impart an upward current or movement to the pulp, there are inclined ledges *l* on the rim of the pan, and smaller ledges *m* on the periphery of the muller, but inclined in the opposite direction. The pan is also provided with wings, or guide-plates *n*, four in number, which serve to direct the moving pulp toward the centre. They are fitted into and may be removed, at pleasure, from a T projection on the pan-rim. The muller is usually caused to make about sixty revolutions per minute; it requires from two and a half to three horse-power. Its ordinary charge is from 800 to 1000 lbs. In some mills, a still larger charge is worked. The capacity of the pan is sometimes increased by adding a rim of sheet iron so as to increase the height of the side. The treatment of the charge usually requires four hours. The shoes and dies wear out in from three to six weeks, though they are made to last longer in some mills, their duration depending greatly upon the order in which the pan and all its principal working parts are kept. On this condition, the economy in the wear of iron and the efficient operation of this and other pans chiefly depend. Neglect in oiling the working parts of the running gear is apt to cause unequal wear, the vertical shaft gets loose and out of line, the grinding surfaces cease to work together evenly, and the efficiency of the pan is greatly impaired, while the costs of working are very much increased. Mill-men generally prefer a shoe and die of moderate rather than excessive hardness. The former wear out faster, but are thought to grind more efficiently. Such are usually cast of an equal mixture of white and soft iron.

Hepburn and Peterson's Pan.—Fig. 651 presents a view of Hepburn and Peterson's pan. The bottom of this pan has the form of an inverted cone, inclining toward the centre, as may be readily seen in the figure. The bottom is covered by four dies of corresponding form, which are secured in a manner similar to that employed in the pan already described. There is no steam-chamber in the bottom, steam being introduced directly. In the centre of the pan, a hollow pillar rises, through which the driving shaft passes. The form of the muller corresponds with that of the bottom, and at the centre has an upright hollow cone, by means of which it is connected with the hub or driver. The under side of the muller is furnished with shoes, between which, when attached to the muller, there is a channel or radial passage left for the circulation of the pulp. The muller also contains radial grooves between the shoes, so that, when the latter wear down, the channel may still be large enough to permit an easy movement of the material. The muller is raised or lowered by means of a screw and movable nut at the top of the hub, the screw resting on the top of the driving shaft to which the hub is keyed. The circulation of the pulp in this pan is effected without the use of wings or guides, such as are commonly employed in other pans for this purpose. When the muller is in motion, the pulp, passing between the grinding surfaces from the centre to the circumference of the pan, descends again by its own weight towards the centre, on the upper side of the muller; a movement promoted by the conical shape of the muller-plate. In the use of guide-plates or wings to aid the circulation, there is sometimes a difficulty experienced in the tendency of coarse sand to settle and pack firmly, if the pan is stopped for a little while, and giving much trouble in starting again. By thus dispensing with the use of wings some inconvenience is avoided. The charge of the pan is about 1500 lbs., usually working four hours on a charge. It runs at sixty or seventy revolutions per minute.

Wheeler and Randall's Pan.—Fig. 652 presents a view of a pan known as the Excelsior, devised by Wheeler and Randall. This pan differs from those before described chiefly in the form of the bottom, which is conoidal. The object of this device is to produce surfaces of such form as to insure perfect uniformity of wear and the highest degree of grinding effect. Its efficiency, in this respect, is attested by the experience of practical mill-men. It is not, however, so generally used as the ordinary Wheeler or other pans already mentioned.

The dies, muller, and shoes, have of course a form corresponding to that of the pan-bottom. They are secured in place in much the same way as in the Wheeler pan. There are guide-plates to assist in directing the movement of the pulp, and there are openings in the muller between the shoes for its free passage between the grinding surfaces. The gearing of the pan, step-box, and driving shaft, and means of raising the muller, do not differ materially from the common Wheeler pan. This pan is made of various sizes; the largest is $4\frac{1}{2}$ feet in diameter, and treats 3000 lbs. of ore at a single charge. It weighs 5000 lbs.

Within the past few years pans of much larger dimensions, and consequently of greater capacity than those formerly used, have been introduced, and have generally found great favour among mill-men. Until lately they have been chiefly used in working tailings, to the treatment of which, as well as of low-grade ores, they are especially adapted. It is claimed in their favour that they treat a charge of ore three or four times that of the ordinary pans in the same or but comparatively little more time, economizing thereby not only time, but labour and power. One large pan requires much less machinery and fewer auxiliary parts in its operation, than three or four smaller ones of equal capacity in the aggregate. The attention of the workmen is more concentrated, and there is a much smaller loss, proportionately, by waste of ore, quicksilver, and other materials. While the time allowed for amalgamation is much less in the larger charge than in the smaller one, in proportion to the quantity of ore treated, the results so far seem to be nearly, or equally as good. These considerations are of special importance in the working of low-grade ores, which can only be done profitably on a large scale, and at a small expense per ton, and in whch the loss of a small percentage of the value is comparatively trifling in amount.

McCone's Pan.—The McCone pan, constructed by Mr. McCone, is one of this kind. Some of the details of its construction, and the method of setting it up, are shown in Figs. 653 to 656. Figs. 653 and 654 show the pan, as it is mounted on a timber framework, and the gearing by which it is set in operation. In Fig. 654 a portion of the pan-rim is removed to show the interior. Fig. 655 shows a vertical section, and Fig. 656 a plan of the pan. In the latter, a portion of the muller plate is shown, and another portion is removed, exposing the shoes and dies below. This pan is 5 feet in diameter, and 28 inches deep. It is flat bottomed and made either with or without a steam-chamber. When the latter is desired, the false bottom is cast separately, with a rim an inch deep, and is then bolted to the main pan-bottom, thus forming the chamber. There are no standards or legs for the pan to stand upon, the bottom being a square-cornered plate of iron, projecting beyond the pan-rim, and it may be bolted directly to the timbers on which it is to rest. The bottom, with its central hollow cone, may be cast in one piece with the pan-rim, or, instead of the latter, a simple flange may be cast, corresponding in size with the rim, to which flange the rim, which may then be either a cast piece or be made of sheets of iron riveted together, is bolted.

An improvement has lately been made to save the wear of the rim or side of the pan, and prolong its usefulness, by placing in the bottom of the pan a false rim or circular facing for the pan-side, about 9 inches deep. This is cast in segments and made to correspond in form to the rim of the pan. When fixed in place, it saves the pan-rim from wear in that part which would otherwise suffer the greatest degree of friction, just as the shoes and dies protect the pan-bottom and muller-plate. When worn thin by the friction of the pulp, the plates may be removed and new ones substituted for them. The driving shaft or spindle *c* passes up from below through the central hollow cone *b*; but its point of support is usually independent of the pan, resting, in such case, in a step-box *h*, which is fixed on a timber below. Some, however, prefer to have hangers bolted to the bottom of the pan and furnishing the support for the driving shaft, so that, if the foundations of the pan settle, the relative position of the several parts is more readily maintained.

The step-box is cast in one piece, with a bearing for the end of the shaft on which the vertical mitre-wheel and pulley of the common driving gear are fixed.

The driver or hub E, which is secured to the vertical shaft, is in two parts, an upper and a lower. The upper is fixed to the shaft by two strong feathers or sliding keys *k*. The base of the upper driver is cast with lugs, or projections, which fit into corresponding recesses in the top of the lower driver, by which means the latter is supported and set in motion. Above the upper driver is a cap-piece *j*, carrying the usual screw and nut arrangement for raising and lowering the muller, the bottom of the screw resting on the upper end of the vertical shaft. The lower part of the driver has three or four stout lugs, or projections, at its base, which fit into carriers on the circular part of the muller at *d*, Fig. 656. These carriers are also made to serve as the means of aiding the circulation of the pulp, as they assist in directing the current toward the centre when the muller is revolving. For this purpose they are sometimes cast 5 or 6 inches high, presenting a curved surface, not shown in the case illustrated, to the pulp and forcing it toward the centre of the pan. By this means, the guide-plates or wings, usually fixed to the side of the pan, but which to some extent obstruct the motion of the pulp, are dispensed with. Grooves for attaching guide-plates, are, however, cast in the pan-rim, so that those who prefer may use them. The dies and shoes used in this pan resemble, in many respects, those of other pans. There is an inch and a half space between the outer edge of the die and the edge of the pan, and a similar space between the adjacent edges of the dies. The shoes, between which are similar spaces and which also have radial channels or grooves on their under side, to facilitate circulation, have the same radial width as the dies. The radial width of the muller-plate is a little less than that of the shoe and die, in order to allow a freer inlet and outlet to the pulp. The muller makes from sixty to eighty revolutions per minute. The pan takes 4500 lbs. of pulp at an ordinary charge, and sometimes more. It is set up very simply, being bolted to timber supports below, and is put in motion or arrested by the application or withdrawal of a tightener to the driving belt, as shown in Fig. 653.

Experience has led to the adoption of more simple forms of pans, in which the grinding is effected between horizontal flat surfaces, instead of the curved and the conical bottoms. In the pans now most in use, these flat grinding surfaces form an annular floor around the central cone, through which the vertical shaft passes. This central cone is not now used for grinding, and it is made much smaller than formerly. Wood is also commonly used for the side of the pan.

In Patton's pan, shown in Fig. 657, it will be seen that the wooden sides are vertical, and that the staves are held by a strong iron hoop upon an iron flange or shoulder of the bed-plate, which rises inside the pan as high as the top of the muller. The bottom is cast in one piece, and is provided with a chamber beneath for the admission of steam to heat the pulp, and thereby to promote amalgamation. The pan is 5 feet in diameter and 2 feet deep. The motion of the muller is communicated to it from below. The distance between the grinding surfaces is regulated by a screw on the top of the vertical shaft.

Wheeler's pan, as now made, is shown in Fig. 658. It is of the same diameter as Patton's pan, but it is not quite so deep. The mode of fixing the stoves to the bottom is different, and there is a wider annular space between the dies and the muller and the sides. The distance between the muller and the dies is regulated by means of the screw with a hand-wheel upon the outside of the pan, which screw raises, through the medium of the bent lever, the vertical shaft, whereby the muller is lifted. This arrangement, it will be observed, is the same as in the older forms. Sometimes this pan is made with sheet-iron sides; the annular space between the dies and the sides is then not so great, but the bottom plate rises higher, and so guards more effectually against leakage. The iron sides possess the advantage of lightness: but a greater advantage lies in the fact of their not being liable to shrink and crack, when left dry for a long time.

Horn's pan is shown in Fig. 659. It is cast in one piece and is slightly flaning. Around the dies there is a depressed annular space 3 inches wide traversed, as the muller rotates, by an arm which reaches to the bottom. The muller is raised by a screw at the top, as in the case of Patton's pan. Like the two preceding, this pan is made with a double bottom, to give an annular steam-chest for heating the charge.

Settlers or Separators.—These, like the pans, differ somewhat in details of construction, but they usually are round tubs of iron or of wood with cast-iron bottoms, resembling the pans in general features, but larger in diameter. A hollow pillar or cone C, Figs. 660 and 661, is cast in the centre of the bottom, within which is an upright shaft S. This shaft is caused to revolve by gearing below the pan. To its upper end is attached a yoke or driver D, that gives revolving motion to arms A, extending from the centre to the circumference of the vessel. The arms carry a number of flows, or stirrers, of various devices, usually terminating in blocks of hard wood P, that rest lightly on the bottom. No grinding is required in the operation, but a gentle stirring or agitation of the pulp is desired in order to facilitate the settling of the amalgam and the quicksilver. The stirring apparatus, or muller, makes about fifteen revolutions per minute.

The settler is usually placed directly in front of the pan, and on a lower level, so that the pan is readily discharged into it. In some mills, two pans are discharged into one settler, the operation of settling occupying four hours, or the time required by the pan to grind and amalgamate another charge. In other mills, the settling is allowed only two hours, and the two pans connected with any one settler are discharged alternately.

The consistency of the pulp in the settler is considerably diluted by the water used in discharging the pan and by a further supply, which in many mills is kept up during the settling operation. In other mills, however, the pulp is brought from the pan into the settler with the addition of as little water as possible, and allowed to settle for a time by the gentle agitation of the slowly revolving muller, after which cold water is added in a constant stream. The quantity of water used, affecting the consistency of the pulp, and the speed of the stirring apparatus, are important matters in the operation of settling or separating. Since the object of the process is to allow the quicksilver and amalgam to separate themselves from the pulp and settle to the bottom of the vessel, it is desirable that the consistency should be such that the lighter particles may be kept in suspension by a gentle movement, while the heavier particles fall to the bottom. If the pulp be too thick, the metal will remain suspended; if it be too thin, the sand will settle with it. Too rapid or too slow motion may produce results similar to the above named, because, by too violent motion, the quicksilver will not be allowed to come to rest on the bottom, while, if the motion be too slow, the coarser sand will not be kept in circulation.

A discharge hole, near the top of the settler, permits the water carrying the lighter portion of the pulp to run off, and at successive intervals the point of discharge is lowered by withdrawing the plugs from a series of similar holes, *h, h,* in the side of the settler, one below the other, so that finally the entire mass is drawn off, leaving nothing in the settler but the quicksilver and amalgam. There are various devices for discharging these. Usually, there is a groove or canal in the bottom of the vessel, as shown in the drawings, leading to a bowl B, from which the fluid amalgam may be dipped or allowed to run out by withdrawing the plug *p* from the outlet pipe.

The quicksilver charged with amalgam is carefully cleaned by washing with water and removing from the surface the associated impurities, such as heavy particles of dirt, pyrites, &c. In some cases, the cleaning is performed in a small iron pan, resembling the settler in manner of construction, but much smaller, in which it is stirred slowly with plenty of clean water, which serves to wash out the impurities and remove them from the pan. When properly cleaned, the amalgam is strained through a canvas filter or conical bag, 10 or 12 inches in diameter at the top, and 2 or 3 feet long. The quicksilver is drained off and returned to the pans for further use, while the amalgam is thus obtained for the retort.

From time to time, as at the end of the month or other given period, or when any special lot of ore has has been finished, of which it is desired to know the exact yield, the pans and settlers must be stopped and cleaned up thoroughly. For this purpose, the mullers must be raised, the shoes and dies removed from their places, and all the iron work of the pans and settlers carefully scraped with a knife to remove and collect the hard amalgam which attaches itself to such surfaces. In many cases, one-fourth, or even a greater proportion of the total product of amalgam, is obtained in this way.

Agitators.—The agitators through which the pulp passes after leaving the separators are, in general, wooden tubs, that vary in size from 6 to 12 feet in diameter and 2 to 6 feet in depth. The main object in letting the stream of pulp pass through them is to retain and collect as much as possible of the quicksilver and amalgam and heavy particles of undecomposed ore that are carried out with the pulp discharged from the separator. A simple stirring apparatus, somewhat resembling that of the separator, keeps the material in a state of gentle agitation, the revolving shaft carrying four arms, to which a number of staves are attached. In some mills, there are several agitators, in most cases only one, and by some they are not used at all. The stuff that accumulates on the bottom is shovelled out from time to time, usually at intervals of three or four days, and worked over in pans. Beyond these, are a number of contrivances for concentrating the most valuable portions of the tailings. Among them are blanket sluices and other variously devised machines, some of which have been already described.

General Arrangement of Mills.—The general arrangement of the machinery in a mill, working silver ores by the method described in the foregoing pages, is shown in Fig. 662, which presents a sectional view of the building and the more important machines employed in it.

The batteries of stamps, as many as there may be, are arranged in one straight line. Behind them, that is, on the feed side, is the breaking floor where the rock is prepared by a stone-breaking machine, or, in its absence, by hand. When the slope of the ground permits it, large bins are sometimes constructed above and behind the breaker, into which receivers the waggons or cars bringing the ore from the mine may discharge their contents. As the outlet of the bins is on a higher level than the mouth of the breaker, the rock is delivered to that machine without much handling. Such bins, where practicable, are of great advantage in providing a reserve of ore for the mill whenever communication with the mine is interrupted for a time. The batteries discharge the crushed ore upon an apron, or, as in the case illustrated, into a trough, or launder, which conveys it to the settling tanks. These stand directly in front of the batteries, though in some mills, for lack of space, they extend along the adjacent side of the building. A platform is usually provided upon which the pulp may be deposited when shovelled out of the tanks. Some mills are so arranged as to use a waggon in which the pulp is moved from the tanks to the pans. This is especially necessary when the tanks are more remote from the pans, or when the latter are arranged in a line at a right angle to the line of the batteries.

Generally the pans are arranged in a straight line, parallel to the line of batteries, as in the case illustrated. The separators stand in front of the pans, arranged in a parallel line, and on a sufficiently lower level to permit the charge of the pan to run into them. Below the separators are the agitators or other similar contrivances for the purpose of preventing the escape of quicksilver or amalgam. The power is usually communicated from the steam engine or other motor, by gearing or belting to a line-shaft, which is placed in front of, and parallel with, the line of batteries. On this shaft are pulleys opposite to those of the several cam-shafts, to which they transmit, by belting, the power necessary for the stamps. The same shaft imparts motion, by means of countershafting and belting, to the rock-breaker and to the pans. For the latter, a line shafting is usually arranged under the row of pans, from which shaft each pan, separator, agitator, or other similar machine may be driven by a separate pulley. The power required for each stamp of ordinary or average weight, with due allowance for friction, is about one and a half horse-power. The power needed for the pans is from three to six horse-power, according to their size and capacity. The expenditure of power per ton of ore, crushed, ground, and amalgamated, judging by the relation existing between the power of the engines provided and the work performed by the mills, is between one and a half and three horse-power, averaging probably about two, but varying according to the capacity of the mill and the economy with which the power is applied.

In the preparation of the rich silver ores of Colorado for smelting, the machinery used consists of rock-breakers, crushers, screens, or appliances for sizing the material, and some kind of jigging machine. In Colorado, where the ore is argentiferous galena, mixed with blende, pyrites, sulphurets of silver, and gangue, in varying proportions, Collom's machine is commonly used. This apparatus has been proved by long experience to be a very efficient ore dresser. Figs. 663 to 666 show some of the details of the construction of this machine, or, more correctly, of two machines, which, for convenience, are put together as one, though they are, in their action, quite independent of each other. The drawings referred to show a longitudinal section, a transverse section, a horizontal section on line A B, and a perspective view.

A double machine, like that shown in the drawings, consists of a box or tank about 7 feet long and between 3 and 4 feet wide, divided by a middle partition into two parts. Each of these parts is fitted on the inside with inclined partitions sloping from the four sides toward the centre of the box, and thus forming two cisterns C, above each of which is placed a sieve *b*. The sieve frame may be furnished with a wire-cloth sieve of any desired degree of fineness, according to the character of the ore to be dressed. Between the two sieves are the piston or plunger compartments *e*, separated from each other, and each connecting by an aperture *f* with one of the cisterns C. Each aperture *f* affords communication to the cistern nearest to it, but without any connection with the other cistern. The plungers *d* move up and down in the compartment *e*, being forced rapidly downwards by the rockers *i* and lifted again by the action of springs *p*. The rockers are set in motion by pulleys K, with which they are connected by eccentric rods *l*. The cisterns and plunger compartments are supplied with water by pipes *g*, and when the outlets *o* are closed, the machines are filled with water, the overflow being at *q*, in front of the sieves. The movements, therefore, of the plungers, which follow each other in rapid succession, produce an agitation in the water, which rises through the sieves with a constantly throbbing motion. The crushed ores, consisting of heavy mineral and gangue, are brought upon the sieves *b* by a stream of water that enters through the distributing boards *c*, and, being subjected to the agitation caused by the plungers *d*, are held in a state of partial suspension, during which the heavier metallic particles sink, while the earthy matters rise to the top, and are carried off by the water at the overflow *q*. That portion of the metallic substance which is fine enough to pass the meshes of the sieve falls through into the hutch or cistern C, and may be withdrawn thence at stated intervals by the outlet pipe *o*; while the coarse part remains upon the sieve, and is cleaned up from time to time, leaving a stratum on the sieve for continued operations. The thimbles *r*, on the plunger-rods *p*, serve to adjust the length of the stroke. The action of these machines is excellent. They effect the separation of the galena in a very thorough manner, not only from the earthy gangue, but from the lighter metallic minerals, such as the zincblende and grey copper. The last two are obtained together, owing to the similarity of their specific gravities, and they are also mingled with heavy spar and some quartz.

The general arrangement of this crushing and concentrating machinery is as follows:—The ore is brought upon the receiving floor, where the larger pieces are broken sufficiently to admit the fragments to the crusher. The clean pieces of galena and zincblende are also selected by hand as far as possible before the material is sent to the dressing machinery. After passing through the crushers the ore falls upon a screen furnished with a No. 6 sieve, that is, having six meshes to the lineal inch. Whatever passes over this screen without falling through must be still further reduced in size before going to the washing machines, and passes, therefore, from the screen to a set of Cornish rollers placed below. The material that falls through the sieve enters an elevator, and is raised to the sizing sieve that stands above the washers. The elevator also brings the material delivered from the rollers, still further reduced by them in size, to the same point. The sizing sieve or screen consists of a frame about 6 feet long by 18 inches wide, slightly inclined from one end to the other. The upper end of the frame is fixed on a pivot, while to the lower end is attached a long arm and connecting rod, by means of which a revolving cam raises the lower end of the frame about 2 inches, and lets it drop again upon a fixed support below. The movement is rapid enough to impart a constant jigging motion to the screen, and thus to assist the material upon it to slide down over its surface. The upper part of the screen is furnished with a No. 9 sieve, while the lower half has a No. 6. The material that passes through the first goes to the finer washing machines; that which falls through the second, to a coarser machine; while all that passes entirely over is returned to the rollers for finer crushing and a repetition of the process. The material then goes to the ore-washers. Two of the double machines, containing four sieves, stand on a raised floor sufficiently elevated above the other two that the material delivered from the outlet pipes *o* of the first may flow to the sieves of the second. One of the upper machines, and one of the lower immediately in front of it, are furnished with No. 6 sieves for washing the coarser material, while the other two, upper and lower, are furnished with No. 10 sieves for the fine stuff. The ore that enters upon the upper sieves is therefore rewashed on the lower sieves, in order to ensure a more effective separation. The overflow of the two upper sieves of either degree of fineness, that is, the material discharge at *q*, is washed again upon one of the lower sieves of the same degree of fineness—the overflow from that sieve being worthless gangue—while that which passes through the sieve is second quality ore, or blende and copper mixed. The stuff that passes through the two upper sieves of either degree of fineness is delivered from the outlet pipes *o*, and comes upon the remaining sieve of corresponding degree of fineness, the material which passes through that sieve being of first quality, while the overflow at *q* is of second quality.

By this arrangement there are three products obtained; the pure galena, which is almost entirely free from other mineral; the zincblende and grey copper, mixed with heavy spar and quartz almost free from galena; and the gangue, which is very clean and free from valuable mineral.

Collom's jigger has been successfully adopted in Wales, and in some continental countries, for the dressing of lead ores and other minerals; and recently it has been introduced into Cornwall for use in tin dressing. Like all jiggers, it is only applicable for dressing tinstuff from which the slimes have been previously extracted by a proper separator. In this machine, a very complete separation of the different qualities of ore is effected by an entirely self-acting process, and with a very small proportion of loss in the waste. The machines in use at the Restronguet Stream Tin Works have given complete satisfaction, and it is proposed to adopt them at several of the mines in the county of Cornwall. This jigger is evidently equally suitable for dressing copper ores, and mining engineers would do well to apply it to this work. It is generally conceded that Collom's machine is the most efficient and the most complete of its kind yet introduced.

CHAPTER VI.—*Continued.*

MACHINERY FOR THE TREATMENT OF MINERAL PRODUCTS.

Section III.—Machinery for the Preparation of Tin, Copper, and Lead Ores.

In the preparation of the ores of tin, copper, and lead, much of the machinery already described is used, so that little remains for description in the present section. In dressing these ores, rock-breakers, crushers, stamps, and jigging machines are required. And besides these, a few special machines are employed, to which attention will here be directed. Rittinger's shaking table, and Collom's washing machine were described in the preceding sections; other machines of a like character to these are used in various mining districts.

The process of jigging or hutching is resorted to chiefly in the dressing of minerals in fragments of a comparatively large grain, such as we obtain from the crusher. The charge or ore is placed in a sieve, or in a frame having a bottom of wire gauze or perforated metal plate, where it is subjected to a series of small lifts or jerks in rapid succession from a column of water forced through the perforations; by these means, the specifically lighter earthy fragments are gradually brought to the top, the clean ore being found immediately above the plate. To produce the jigging motion, either the sieve is jerked up and down in a cistern of water, or the water is forced up through the sieve by means of a piston. The latter method has been already illustrated in the case of Collom's machine. The process is often an intermittent one, the jigging motion being suspended during the time of charging and emptying the sieves. But it may be made continuous by the addition of feeding and discharging apparatus.

The common hand-lever jigging machine used in Cornwall is shown in Figs. 667 and 668. The sieve is rectangular; to each of the short sides a vertical iron bar is attached. These bars are perforated at their upper ends with three long holes, through which a pair of bolts are passed, linking them to the two parallel arms of an oscillating frame. By altering the holes through which the suspension bolts pass the sieve is made to hang at a greater or less depth in the rectangular water cistern or hutch in which it is worked. The suspension frame is an unequal-armed lever, the sieve is attached to the shorter side, while the longer arm is terminated by a slotted part, in which works a T-headed fixed link or connecting rod attached to the shorter arm of a second lever placed below it. The motive power is supplied by a boy, who jerks the longer arm of the second lever, moving it through a height of 48 inches, while the sieve is only moved through 8 inches. Clean water is introduced through a square pipe on one side of the cistern to replace the muddy waste which is carried off through a similar pipe fitted with discharging apertures at different depths on the opposite side. The sieve is emptied by scraping out the contents with an iron scraper or limp; they are usually classified into three parts, the uppermost being thrown away; the middle, containing mixed ore with earthy matter, requires a further treatment, while the bottom is clean ore fit for sale. The hutch work or fine stuff passing through the sieve collects in the cistern, and is subsequently treated on the round buddle or some other slime-washing machine. The sieve shown is 57 inches long and 24 inches broad, and 10 inches deep, the hutch measuring 90 inches in length, 43 inches long, and 45 inches deep. The power arm of the jigging frame is four times as long as that to which the sieve is attached, while the relation of the same parts in the second lever is as $1\frac{1}{2}$ to 1.

One of the best jigs of the continuously working class is the invention of Rittinger, and was exhibited at the Great Exposition in Paris in 1867.

It is represented in Fig. 669, and is characterized by the inclination of the grates and the lowness of the front partition, over which the poor and lighter stuff falls continuously, and with very little water, while the heavier and richer portions fall through the opening or slit *o*, at the base of the partition. This partition is the segment of a cylinder, and is supported upon the lever or arm *d*, so as to be movable backward and forward in such a manner that the opening slit *o* may be increased or diminished at pleasure. The heavy stuff, passing through the opening, falls into the box K, from which it is removed as required. The inclination of the grate in this machine is from five to eight degrees. It is fed through the hopper B, which plunges below the surface of the stuff accumulated on the grate. The loss of water which occurs at each stroke of the piston is replaced from a reservoir W at the back of the apparatus. According to Rittinger, experience has shown that the duty of self-acting machines of this kind is generally three times as great as that from the ordinary intermittent working apparatus.

Messrs. Huet and Geyler have constructed an excellent form of jig, shown in Fig. 670. It is constructed of cast iron, and is very compact. Most self-acting jigs require a large quantity of water, and this in many localities is a great objection to their use; but this jig is designed to work with but little loss of water, and, at the same time, by the aid of an automatic scraper, to increase the product.

The tub is shaped like the letter U, and is divided into two compartments, one for the piston and the other for the working grate. Water is supplied through the valve A, at the side, and the fine stuff or slime which falls through the sieve settles upon the bottom, and is discharged through an opening B, controlled by a lever reaching out to the front of the apparatus. The piston is operated by means of a shaft and crank, which works in an inclined slide C, connected with a lever carrying the piston, so as to give a rapid descending stroke with a period of rest at the bottom, and then a slow upward movement; thus giving the most favourable conditions for the rapid and perfect separation of the stuff upon the grate.

The motion of the piston may be varied at will, in order to secure the best flow or motion of the water for different grades of ore. This adjustment is effected by shifting the position of the head of the piston along the lever or arm, and by this means increasing or diminishing the amplitude of its motion. The construction of this slide is shown in the figure. By turning the fixed screw *s s*, the head of the piston may be moved forward or backward.

The machine is provided with a scraper R, actuated by the long rod D, which is attached to an eccentric on the main shaft and moves the levers E and F, giving to the scraper a forward and backward motion over the top of the stuff upon the grate, and throwing out a portion of it at each movement. The path of the scraper is determined by the guides G, attached to each side of the tub. It can be varied by means of screws upon the lever or arm F. In passing backward, the roller or projection on the scraper, which follows the guides, rises upon the movable inclined plane G, and on its return passes below this plane, following the double-dotted line in the figure. The poor stuff from the top, which is constantly thrown forward and off by this scraper, falls over the front of the tub at R, along the chute M. The grate is inclined as in the machine of Rittinger, and the opening for the escape of the heavier and rich portion is similarly placed at the foot of the incline and just below the bridge over which the poor stuff is scraped. The opening is shown at H. It is closed by a valve which extends along the whole front edge of the sieve, and can be opened and closed at pleasure by a lever. The stuff passing through this valve falls into a receptacle K, from which it may be removed at pleasure through the opening L. The scraper is so made of perforated sheet-iron that it does not throw the water out together with the waste. These jigs are made with great care and accuracy, and work in a satisfactory manner.

A two-sieved continuous jigging machine, used at Clausthal, is shown in Figs. 671 to 673. It works with $1\frac{1}{2}$-inch stroke, 100 strokes a minute being made for the coarser, and 120 strokes a minute for the less coarse ore. The ore is led on to the first sieve through the opening *a* at the bottom of the hopper. The stuff, which during the jigging forms the lower layer next to the sieve, passes underneath the cap *b*, which by means of two thumbscrews can be raised or lowered to suit the requirements of the ore to be jigged, into the slit *c*, Figs. 672 and 673, from which it falls out through the small shoot *d*, Figs. 671 and 673, into the receiver *m*. The remaining portion of the ore passes from the first sieve over the cap on to the second sieve, and from here the raggings pass off beneath the cap (likewise adjustable), in doing which they pass over the sheet iron projections shown in Fig. 672, into the slit *f*, and from which they fall out through the small shoot *g* into the receiver *n*, whilst the remainder as attle or skimping, passes over the cap *e* into the dam box *h*, and from thence along the small shoot *i* into the receiver *o*. The very fine ore (hutch work) which may happen to be present, or which is formed during the jigging process, goes through the meshes of the sieves, and is let off through the conical openings *k k'*, and passes along the small channels *e e'* into the receivers *r r'*. The meshes of the sieves are 0·79 inch to 0·118 inch wide according to the size of ore they are intended to jig.

The water which passes over with the jigged ore and attle falls into the receivers *m*, *n*, and *o*, and escapes through the sieve *p*, Fig. 671 (see also the shaded portion, Fig. 673), into the channel *g*, from whence, in conjunction with the water passing off from the receivers *r r'*, it flows through the channel *t* into the chief collecting channel *u*. This channel conducts it to a settling tank, whence, after clearance, it is led away to the lower-lying works to be used as clear water. The hutch work, which falls through the sieve, and is consequently under 0·079 inch to 0·118 inch, is emptied from time to time out of the receivers *r r*, in which it is collected.

In the processes of tin dressing, the preliminary operations on the stuff are performed by rock-breakers, crushers, and stamps. The machines employed in the subsequent operations are described in the following remarks on dressing machinery used in Cornwall, contained in a paper read before the Institution of Mechanical Engineers, by H. T. Ferguson.

The material is raised from the mine in skips or kibbles containing from 10 to 20 cwt. each. On reaching the surface, it is tipped into a tram waggon, and run out along a tramway raised about 10 feet from the ground. The floors under the tramway are divided into spaces called "slides," into which the stuff is tipped from the waggons; each slide contains the stuff sent to surface by one set of men called a "pare," usually consisting of four men and two boys. The larger stones are broken up with sledge hammers by hand, which is called "ragging"; and are then further reduced by hand hammers to a size sufficient to allow of being passed through a 4-inch ring; this is called "spalling." In some mines, both these operations are now superseded by the use of Blake's stone-breaking machine. The contents of each of the slides are kept separate, and after spalling are divided into heaps or doles, those containing tin being placed on one side, and copper on the other, wherever the two minerals are found in the same lode.

Tin Dressing.—In dressing the ores, the object is to separate the ore itself from the large proportion of foreign matter with which it is associated in the lodes, the ore itself amounting to only from 1 to 2 per cent. of the whole stuff raised. The ore of tin is a peroxide, which, when pure, contains 78·6 per cent. of metallic tin and 21·4 per cent. of oxygen. The impurities with which it is associated are mostly quartz, iron pyrites (sulphide of iron), commonly called "mundic," yellow copper ore (sulphide of copper and iron), commonly called "copper pyrites," arsenic, sulphur, cobalt, and wolfram (tungstate of iron and manganese). The specific gravity of these minerals is shown in the following table, which is particularly interesting in consequence of the circumstance that the principle of dressing the ores consists mainly in separating the particles by taking advantage of their difference in specific gravity :—

	Specific Gravity.
Sulphur	2·03
Quartz	3·00
Copper pyrites	4·25
Iron pyrites, or mundic	4·90
Arsenic	5·00
Cobalt	5·00
Peroxide of tin	6·50 to 6·90
Wolfram	7·00 to 7·50

Stamping.—The stone that has been ragged and spalled is ready for the next process of stamping, in which it is crushed by stamps to a fine powder. The ordinary stamps, shown in Fig. 674, are arranged in sets of four heads each, contained within a coffer or wooden box; each stamp consists of a rectangular cast-iron head A, having a wrought-iron bar or lifter B, cast into it; the lifter works through vertical guides, and is raised by a set of cams on a revolving shaft C, usually five in number, which act upon an arm keyed upon the lifter. The height of lift is about 10 inches, and each stamp-head makes from fifty to seventy blows per minute, and weighs with its lifter from 6 to 7 cwt.; the quantity of stuff stamped by each head is from 15 to 20 cwt. per twenty-four hours. The tinstuff, as the broken stone is called, is brought to the stamps in tram waggons, and tipped upon an inclined plane known as the pass D and half-pass E; the inclination of the pass D is about 1 in $1\frac{1}{2}$, and that of the half-pass E about 1 in $2\frac{1}{4}$. The half-pass E, leading down to the coffer in which the stamps work, regulates the speed at which they are fed; and a gentle stream of water is discharged continuously upon the stuff in its passage down this inclined plane. The water remains mixed with the tinstuff in the bottom of the coffer, and the action of the stamps is to reduce the stuff gradually to a fine powder, the finest portion of which is carried off with the overflowing water, the flashing up of the water at each blow of the stamps causing it to carry off the finest material in suspension. The overflow takes place through gratings G in the front and sides of the coffer, consisting of thin copper plates, called grates, which are perforated with very small holes varying from the size of a pin's head to that of only a needle point. The size of the holes is of considerable importance, and is determined according to the quality and degree of fineness of the stuff that is being stamped, and the proportion of foreign matter that it contains; usually the grates contain about 144 holes per square inch. The stamps are arranged in long rows, each cam-shaft lifting sixteen heads or four sets; the number of heads depends upon the extent of the mine, and in some there are as many as twenty-five sets or one hundred heads. The disadvantage in the action of these stamps is that they produce a large proportion of "slime," or material so very finely pulverized that much of it remains permanently mixed with the water throughout the subsequent processes of separation, and thereby gets carried away as waste though containing tin ore. The production of slime by the stamps is in consequence of their slow action allowing much of the pulverized material to settle down in the coffer and become further crushed to an unnecessarily fine powder, instead of passing out at once through the grates; and a quicker speed than fifty to seventy blows per minute cannot be obtained with the height of fall of these stamps.

Figs. 675 and 676 show Husband's Pneumatic Stamps, in which this difficulty has been met by an ingenious arrangement for greatly increasing the rapidity of the blows by the use of an air spring. The stamp-head is not lifted direct, but is attached to a piston H, working in an air cylinder K; and this cylinder has a reciprocating motion given to it by a crank-shaft, through a forked connecting-rod that is coupled to trunnions upon the cylinder. When the cylinder is raised by the crank, the air below the piston is compressed, and the stamp is thrown up; and on the crank turning the centre, the air above the piston is compressed, and the stamp is driven down with a velocity considerably greater than that due to gravity. The stamp-head and piston rod, weighing together nearly 3 cwt., are by this means made to have a fall of about 16 inches, with a stroke of only 10 inches in the crank, and a speed of 150 blows per minute; in comparison with a fall of only 10 inches in the ordinary stamps, and a maximum speed of only seventy blows per minute. A ring of small holes is made all round the cylinder immediately above and below the centre position of the piston, to ensure both ends of the cylinder being filled at each stroke with air at atmospheric pressure. A continuous stream of water is made to flow through the hollow piston rod, for the purpose of preventing risk of heating by the compression of the air in the cylinder; this water is discharged through small holes at the bottom of the piston rod, just above the stamp-head, and serves as part of the supply of water for the stamping operation. The main portion of the water supply to the stamp-head is delivered in a circular jet, under a pressure of several feet head, upon the outside of the piston rod, where it passes through the cover of the coffer. In order to prevent the unequal wear of the stamp-head that would arise from the supply of fresh uncrushed stone being on one side only, an arrangement is made for turning the head round into different positions at regular intervals. This is done by a horn L, fixed on the piston rod by a set-screw, and working between two vertical guide-bars, and about once per day the position of this horn is shifted so as to turn the piston rod partly round, and cause the stamp-head to wear in a fresh place. These pneumatic stamps are erected in pairs, and stamp from 8 to 10 tons per head per day, in comparison with only $\frac{3}{4}$ to 1 ton per head per day, the work of the ordinary stamps; the comparative consumption of coal per ton of ore stamped is also in favour of the pneumatic stamps. They have an important advantage in portability; and in the case of starting new mines they can be readily transported from one point to another if found desirable, requiring but little foundation.

The pulverized stuff comes away from the stamps in a state of sand and slime, containing the tin ore mixed with a very large proportion of foreign matter, the ore not amounting to more than $1\frac{1}{2}$ to

2 per cent. of the whole; and the object of all the subsequent processes is to separate the ore from the rest of the material. This is effected by taking advantage of the greater specific gravity of the tin ore than of the other materials with which it is mixed: excepting as regards the wolfram, which is dealt with by chemical means. The stream of sand and slime flows away from the stamps over a floor F, placed at an inclination of about 1 in 12, and passes into the "strips," which are wooden troughs from 20 to 30 feet long, 18 inches wide, and 12 inches deep, placed at right angles to the line of the row of stamps. The pulverized stuff is here deposited according to its specific gravity; the first portion or "head," at the upper ends of the strips, is the best, the middle the second best, and the lower end or "tail" contains the lighter particles, while the slime passes off into pits, where it is collected for further treatment. There is a great difference of opinion as to the utility of depositing the stuff in the strips; and at some mines the next process, which is that of "buddling," is commenced directly the stuff is stamped.

Buddling.—The form of buddle generally used in the first stage of the buddling process is shown in Figs. 677 and 678, and is known as the Convex or Centre-head Buddle. It consists of a circular pit, about 22 feet diameter, and from 1 to $1\frac{1}{2}$ foot deep at the circumference, with a raised centre 10 feet diameter, and a floor falling towards the outer circle at a slope of about 1 in 30 for a length of 6 feet. The stuff is brought to the centre of the buddle in launders A, into which a constant stream of water flows; and it is distributed upon the raised centre from a revolving pan B, carrying a number of spouts, so as to spread the liquid stream very uniformly in a thin film, which flows gradually outwards over the whole of the sloping floor to the circumference. In its passage down the slope, the material held in suspension by the water is gradually deposited according to its specific gravity, and the tin ore being the heaviest is the first thrown down, and is consequently in greatest proportion towards the centre of the buddle. The outflow C for the waste and slime from the circumference of the buddle is regulated by a wood partition perforated with horizontal rows of holes, which are successively plugged up from the bottom as the height of the deposit in the buddle rises. To facilitate the uniform spreading of the stuff over the floor of the buddle, and prevent the formation of gutters or channels in the deposit, a set of revolving arms D are employed, from each of which is suspended a sweep carrying a number of brushes or small pieces of cloth, and these being drawn round on the surface of the deposit keep it to an even surface throughout; the distributing spouts and sweeps are driven at about five or six revolutions per minute.

As the deposit accumulates in the buddle, the sweeps are successively raised to a corresponding extent; and the process is thus continued until the whole buddle is filled up to the top of the centre cone, which usually takes about ten hours. The contents are then divided into three concentric portions, each about a third of the whole breadth, which are called the head, middle, and tail; the head, or portion nearest the centre, contains about 70 per cent. of all the tin in the stuff supplied to the buddle, the middle nearly 20 per cent., and the tail, or portion next the circumference, contains only a trace; the remaining particles of tin are carried off by the water in the state of slime.

The heads from several buddles are then shovelled out, and thrown into a trough or launder, into which a stream of clear water flows, of sufficient quantity to convey the stuff to another buddle of a different construction, the Concave Buddle, shown in Figs. 679 and 680. The stuff is supplied at the centre of the buddle as before, but is conveyed from thence direct to the circumference, by revolving spouts that deliver it in a continuous stream upon a circular ledge, from which it flows uniformly over the conical floor falling at a slope of about 1 in 12 towards the centre; it is kept uniformly distributed by means of revolving sweeps, as in the previous buddle. The greatest portion of the tin is in this case deposited round the circumference of the floor, and the slime and waste flow away through rows of holes in the sides of a centre wall; as the depth of deposit increases, the level of the overflow is gradually raised by plugging up these holes in succession.

In Figs. 681 and 682 is shown an improved construction of concave buddle, by Mr. Edward Borlase, now in extensive use at several mines, which has a mechanical arrangement for adjusting the level of the central outflow, by raising a ring R, that slides upon the centre vertical shaft, as shown in the detail view to a larger scale. By this means the height of the outflow is adjusted more gradually and uniformly than by the plugged holes in the ordinary buddles, and there is less liability to waste by guttering. The sliding ring R is raised by hand by the rod I and lever L, provided with the double adjusting nuts N; and the arms of the sweeps D being supported upon the rising ring are kept constantly at the proper height by the same adjustment. A mechanical agitator M at the head of the feeding launder stirs up the stuff before entering the buddle.

Another form of buddle has been recently introduced, called the Propeller Knife Buddle, which is shown in Figs. 683 to 685. It consists of a cylindrical frame, $9\frac{1}{2}$ feet long and 6 feet diameter over all, rotating on a horizontal axis, and carrying a series of scrapers or knife-blades arranged in spiral lines round its circumference, which revolve close to a cylindrical casing lined with sheet iron, but without touching it; the casing forms the bottom of the buddle, and extends rather less than one quarter round the circumference of the revolving frame, as shown in Fig. 685. The tinstuff is supplied at one end of the buddle from the hopper A, and is made to traverse gradually along the whole length to the other end by the propelling action of the revolving knives, which are fixed obliquely and follow one another in spiral lines round the cylindrical frame. A gentle stream of clear water flows down over the whole curved surface of the bottom of the buddle from a trough B along its upper edge, and washes away continuously into the two side hutches C and D, the lighter materials that are mixed with the tin ore, whilst the particles of tin ore remain behind on the bottom of the buddle, and are gradually propelled to the farther end, where they drop over the edge into the receptacle E. The machine is driven at about twenty revolutions per minute, giving the knife-blades a speed of about 370 feet per minute. The action of this machine is found to be very perfect, the whole of the stuff being continually turned over by the knife-blades and pushed upwards against the descending stream of water, which washes out the lighter particles; the result is an unusually complete separation of the tin ore, in a single operation, with only a small proportion of loss in the waste. The contents of the second waste hutch D are so poor as not to pay for any further dressing; and the waste in the first hutch C containing a small proportion of slime tin is passed through the buddle a second time.

Tossing and Packing.—The process of buddling is repeated three or four times in successive buddles, for further separating the foreign matter from the tinstuff; and the latter is then subjected to the process called "tossing." It is put into a tub or "kieve," about $3\frac{1}{2}$ feet diameter and $2\frac{1}{2}$ feet deep, and having been mixed with an equal bulk of water is then stirred up with a shovel continuously in one direction until the whole of the stuff is in a state of motion; the object is in this way to get rid of the finer particles of foreign matter, the buddling having separated all the heavy matrix. The stuff then undergoes the process called "packing," which consists in tapping the side of the kieve with a heavy iron bar continuously for a period varying from a quarter of an hour to an hour; the bar is held vertically with one end resting on the ground, and with the upper end repeated blows of about 100 per minute are struck by hand against the edge of the kieve. This keeps up a constant gentle vibration in the contents, and facilitates the separation of the tin ore, which gradually settles down to the bottom of the kieve. Instead of a bar worked by hand labour, a hammer worked by mechanical means is employed at some mines for performing the packing, with the advantage of maintaining complete regularity in striking the blows for any length of time required. When the packing is finished, the upper portion of the stuff in the kieve is skimmed off and buddled over again; and the remainder, now called "whits," is taken to the burning house to be calcined. The kieve is completely cleared out, before being refilled with a fresh charge.

Calcining.—The next process is roasting or calcining the partially dressed tinstuff or "whits," for the purpose of getting rid of the arsenic, sulphur, and other volatile impurities, and also to facilitate the subsequent removal of other foreign materials. Two kinds of calciners are now in use. The older one, known as Brunton's calciner, consists of a horizontal revolving table, about 12 feet diameter, enclosed in a shallow reverberatory furnace; the table is slightly conical in shape, its surface sloping downwards from the centre to the circumference. The tinstuff delivered on the centre of the table through a hopper in the roof of the furnace is exposed to the flame passing through the furnace, and is continuously stirred by a set of scrapers fixed in the roof whilst the table rotates very slowly below them, making only about six revolutions per hour. The scrapers being set obliquely shift the stuff gradually from the centre to the circumference of the table, where it falls off, and is collected in a chamber beneath.

In Figs. 686 to 688, is shown Oxland and Hocking's calciner, which is now adopted at several mines. It consists of a long wrought-iron cylinder A, lined with firebrick, 3 feet inside diameter and 32 feet long, placed at an inclination of 1 in 16 to 1 in 24 according to the nature of the stuff to be treated, and supported upon rollers, upon which it is made to revolve at a very slow speed of six or eight revolutions per hour. The tinstuff or "whits" is supplied into the higher end of the cylinder through a hopper fitted with a feeding screw B, and gradually traverses the length of the cylinder to the lower end, where it falls into a chamber C, from which it is removed for further treatment. The heating furnace D opens into the lower end of the cylinder, and the volatilized arsenic and sulphur, &c., are carried off by a flue E from the upper end; this flue is extended to a considerable distance and divided by baffle walls into a succession of chambers, in which the arsenic is deposited and periodically collected. The time taken for the stuff to pass through the calciner is from three to six hours. The firebrick lining of the calciner is constructed with four longitudinal ribs projecting internally, as shown in the transverse section, Fig. 687, and extending two-thirds of the length from the lower end, as shown in Fig. 686; in the revolution of the calciner these have the effect of continuously stirring the stuff and exposing the whole of it to the heat. In this calciner the stuff being supplied at the upper end, farthest from the heating furnace, is exposed first to the lowest heat; and afterwards to a gradually increasing heat, as it works its way along to the hotter end of the calciner; by this means the most advantageous effect is obtained from the fuel consumed in the furnace. The stuff comes from the calciner in the state of a fine dry powder, which is cooled with water and taken again to the buddle; and the whole of the previous processes of buddling, tossing, and packing are again gone through, and repeated a number of times, according to the quality of the ore, until this is finally in the condition ready for smelting; in this state it is sold as "black tin."

Results of Dressing.—The whole process of dressing the tin ore for smelting occupies usually from eight to ten days, including the stamping; and the result obtained is an increase in the proportion of pure oxide or black tin from $1\frac{1}{2}$ or 2 per cent. in the tinstone raised from the mine, up to 95 per cent. in the finally prepared ore that is sold for smelting. As tin dressing is only a process of separating by mechanical precipitation a very small proportion of saleable produce from the large mass of mineral through which it is disseminated in minute crystals, it is essential that the greatest precautions should be taken to prevent any waste of the valuable product. For instance, in buddling, the occurrence of any gutters or channels down the sloping surface of the stuff in the buddles would immediately cause the larger and more valuable grains of tin ore that are first deposited at the top of the slope to be carried away with the water and slime. The grains of tin which do pass off with the slime even from the best buddles are very fine and light; and notwithstanding all the care that is taken in dressing the slimes, large quantities of tin ore are washed away from the dressing floors of the mines into the numerous streams and rivers of the district. The slimes are consequently intercepted at successive works on a stream or river coming from a series of mines, and large quantities of tin are collected by treating them in hand frames and concave buddles at a very small expense, the stream itself working a small water-wheel which drives the buddles, while the frames are attended only by a few children.

Treatment of Slimes.—A very simple and effective form of self-acting slime frame or "Rack" is shown in Figs. 689 to 691, by means of which the attendance requisite is so far reduced that one boy is able to attend to twenty frames. The launder A bringing the slimes from the buddles passes between two rows of the slime frames, set back to back, and the delivery to each frame is distributed by a fluted spreader B, as shown in the plan, and then flows uniformly in a gentle stream over the surface of the frame, which is at a slope of 1 in 7, and is divided at the middle into two halves by a 5-inch step; the waste flows off at the bottom of the frame into the launder C. The stuff deposited on the frame is then flushed off at successive intervals of a few minutes each, by a self-acting contrivance consisting of two rocking troughs D D, which are gradually filled with clear water from a launder E; when full they overbalance, and discharge their whole contents suddenly upon the top of each half of the frame. The tipping movement of the troughs opens at the same time the covers of two launders F F, one at the foot of each half of the frame, into which the stuff deposited on the frame is washed by the discharge of water, the two halves being kept separate because the greater portion of the tin ore is retained on the upper half of the frame. The readjustment of the whole into the original position is effected by a cataract G of simple construction.

Pulverizing.—The difficulty in dealing with the slimes arises from the circumstance of the grains of tin ore being so minute, compared with the particles of foreign matter with which they are mixed, that they are carried away in suspension by the water, in consequence of their extreme absolute lightness, although their specific gravity is greater than that of the larger particles of foreign matter they are mixed with. For the purpose of reducing these larger particles of foreign matter to the same size as the tin grains, and thereby enabling the latter to be separated by the ordinary dressing processes with water, several different machines called "pulverizers" have been introduced, having either a reciprocating or a rotary action; these have been found very successful in reducing the particles to a uniform size, and thus affording the means of utilizing the waste, or "roughs" as it is called, which was previously thrown away because the cost of reducing it by re-stamping was greater than the value of the tin ore obtained by such a process.

Copper-Ore Dressing.—Copper ore is raised in the same manner as tin ore, but it presents a marked contrast to tin ore in being very much less finely disseminated throughout the lodestuff with which it is associated; the coarser spots or patches in which it is met with necessitate consequently a very different treatment from that adopted in dressing tin ore. The most abundant ore of copper is yellow copper ore, also called "copper pyrites," which has a bright yellow colour, much like good brass; it is a sulphide of copper and iron, containing when pure only 34·6 per cent. of copper, with 30·5 per cent. of iron, and 34·9 per cent. of sulphur. The other principal ores of copper are the red, black, grey, purple, and green ores. The red and black ores are oxides, containing when pure 89 and 80 per cent. of copper respectively; the red, which is the more common of the two, is quite brittle, and is easily broken up into a red powder. Grey copper ore is a sulphide, containing when pure 80 per cent. of copper; it has much the appearance of metallic lead, but may be broken up by a hammer. Purple copper ore, also called "horseflesh ore," is a sulphide, but not so rich as the grey, part of the copper being replaced by iron; when pure it contains nearly 70 per cent. of copper. Green copper ore, or "malachite," is a carbonate, and is much less common than any of the others; it contains when pure 57 per cent. of copper. None of these ores of copper are very hard, all being readily scratched with a knife.

The ore as raised from the mine is tipped into spaces called "slides," in quantities averaging from five to twenty tons in each slide. The larger stones having been separated, and "ragged" or broken up into smaller pieces by hand hammers, the whole is passed through two revolving riddles of different mesh, and then handpicked by children and sorted into three qualities. These are called "prills" or best, consisting of pieces of very nearly pure ore; "dradge" or second quality, in which the ore is more or less interspersed with matrix; and "halvans" or leavings. As much of the best as will pass through a riddle of $\frac{3}{4}$-inch mesh is taken at once to the pile ready for market, and the rest goes to the crushing rolls to be crushed down smaller. The second quality has to undergo both crushing and jigging.

The ore is tipped from a tram waggon into a hopper above the rolls, and after passing through them it falls into a shoot below, by which it is conveyed to an inclined revolving screen or riddle, having holes $\frac{5}{8}$ inch square, and making thirty-two revolutions per minute. The pieces that are too large to pass through the screen are delivered from its lower end into the rim of the revolving raff wheel, the cups of which raise the stuff to the upper floor, where it falls over an inclined plane into the hopper, and is again crushed by the rolls until all are reduced to a size small enough to pass through the screen. The best and second quality ores are crushed separately; the former does not require any further treatment, and is ready for the market. The second quality is taken to the jigging machines for further separation.

The Frue Vanning Machine.—An ore concentrating machine, known as the Frue Vanner, has lately been introduced and adopted on the Pacific coast, where it is said to work very satisfactorily. It has been applied to the dressing of all kinds of ores, with apparently equal success in all cases. At the Liberty Mine, in Maryland, ores of grey copper and purple copper, disseminated through a limestone gangue, have been treated with this machine with highly satisfactory results. In one run, the original ore contained 2 per cent. of copper, the concentrate showing 58 per cent., and the tailings 0·2 per cent. On a second trial, ore containing 2·3 per cent. of copper gave a concentrate of 60·4 per cent., the tailings showing only 0·09 per cent. Equally satisfactory results have been obtained in the treatment of other kinds of ore.

The dressing surface of this machine consists of a flanged rubber belt, which revolves slowly against a descending stream of sand and water, and receives a continuous lateral vibratory motion, that keeps the whole volume of water and sand in gentle movement. This side motion of the belt, the vanning, is the important feature of the machine; and, in connection with the perfect surface of the rubber belt itself, is the real element of the success of the vanner on fine slimes. The Brunton belt in England, and the Hoffman in Germany, are known as slime dressers; the first is merely a self-discharging inclined plane in principle; the last, receiving in addition a succession of blows, is an improvement on the former, being an intermediate stage between it and the present vanning machine. The difficulty of making the belts last in the Hoffman machine was, according to the statement of the well-known manufacturing firm at Kalk, near Cologne, the reason of the belt dropping out of use. In the vanner, no such difficulty occurs; the belt is of long duration, the only appreciable wear being caused by the attrition of particles of ore passing over its surface with the water; and this wear, which is slight, is remedied by the occasional application of a liquid rubber paint. That the lateral motion is in itself preferable to percussion few practical dressers will deny.

There are two forms of vanners in use; the single and the double. The first is a belt 27 feet 6 inches long and 4 feet wide, supported either in bearings or on toggles, within a stout wooden frame; both the side motion and revolving of the belt being run from a single pulley on the crank-shaft. In the second form, two belts are placed side by side, their supporting frames being bolted together and slung from above by iron rods; and both belts receiving motion from the same crank-shaft and driving drum. The belts are in this case generally 33 feet 6 inches long by 4 feet wide.

THE END.

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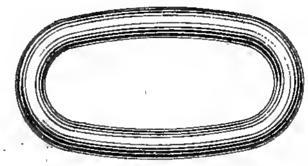

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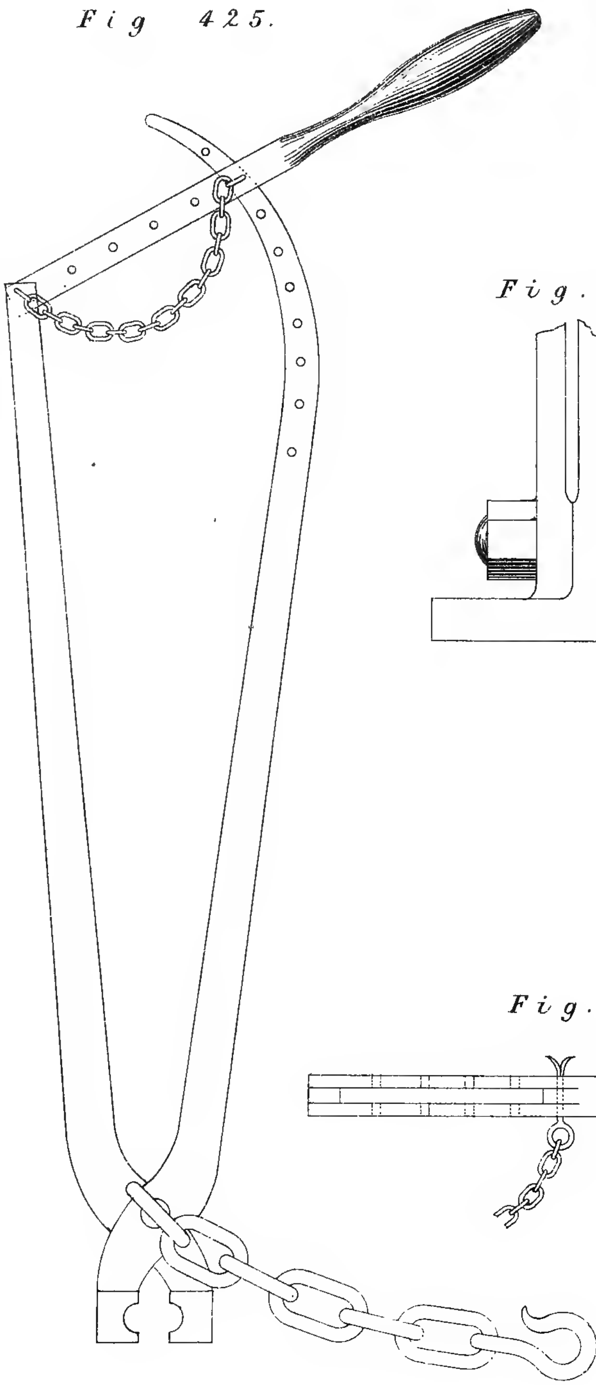

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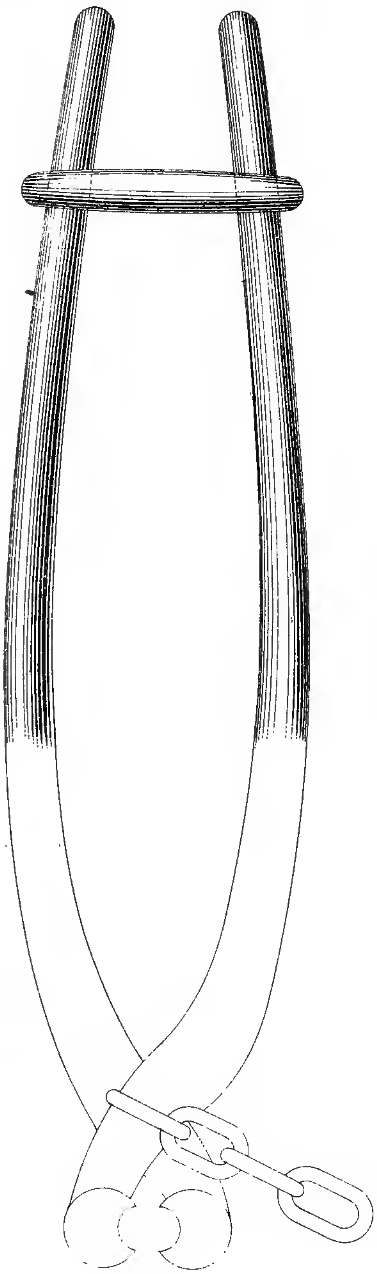

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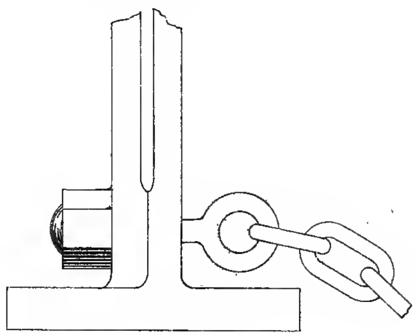

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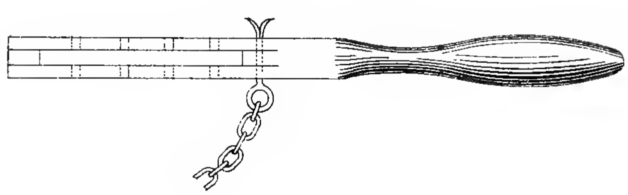

Fig. 426.

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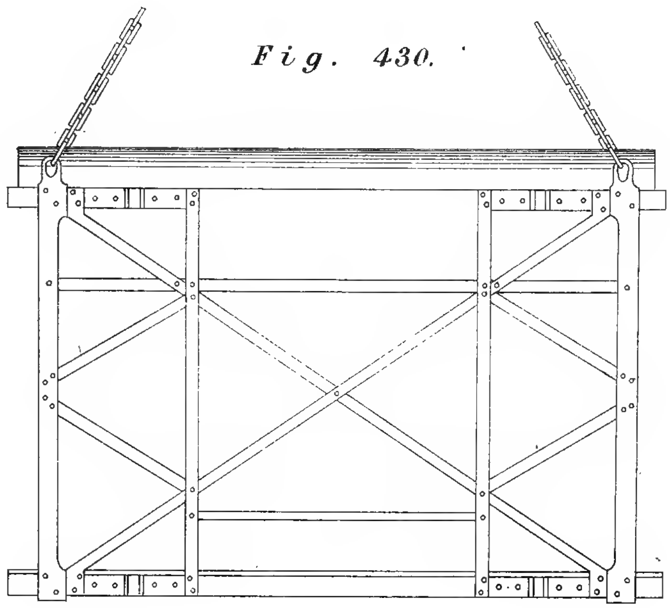

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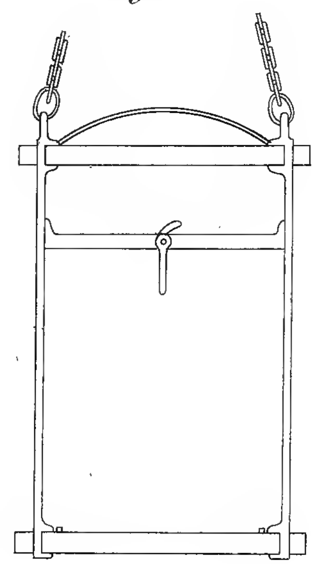

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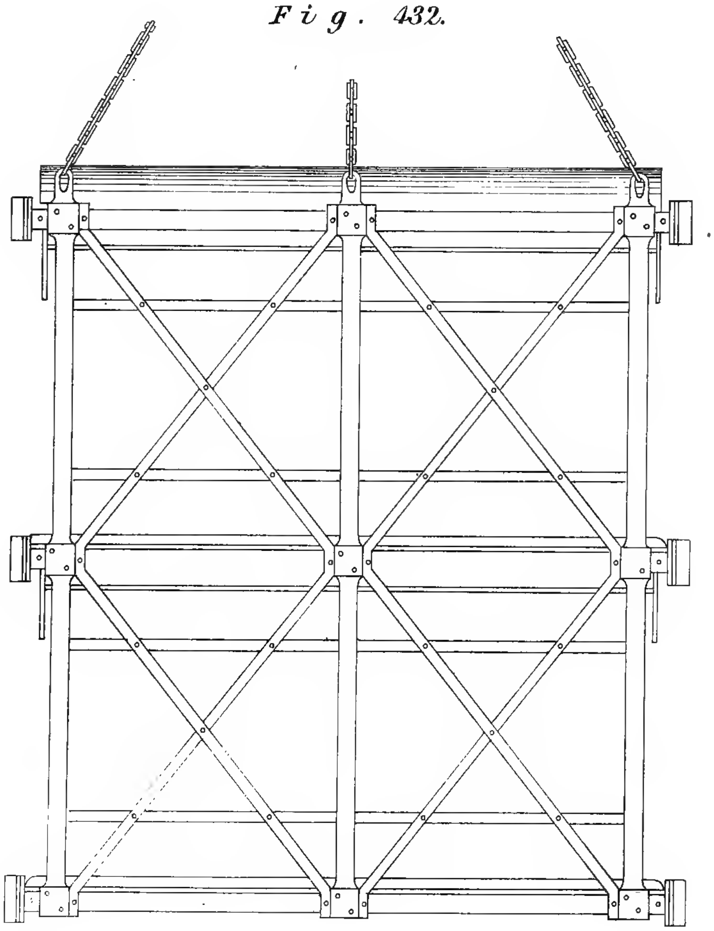

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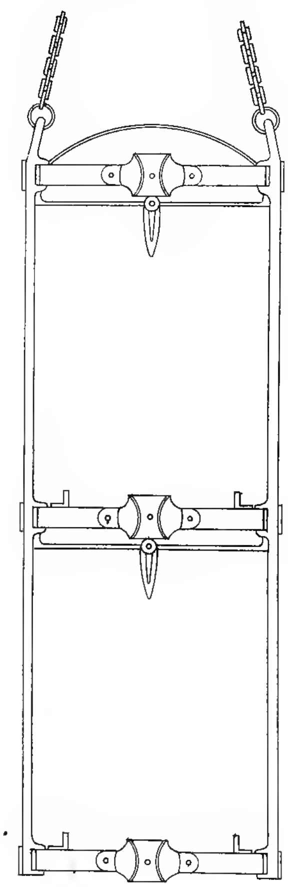

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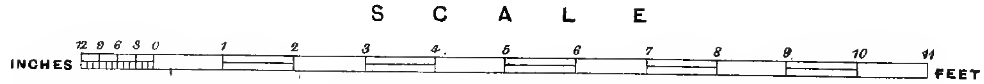

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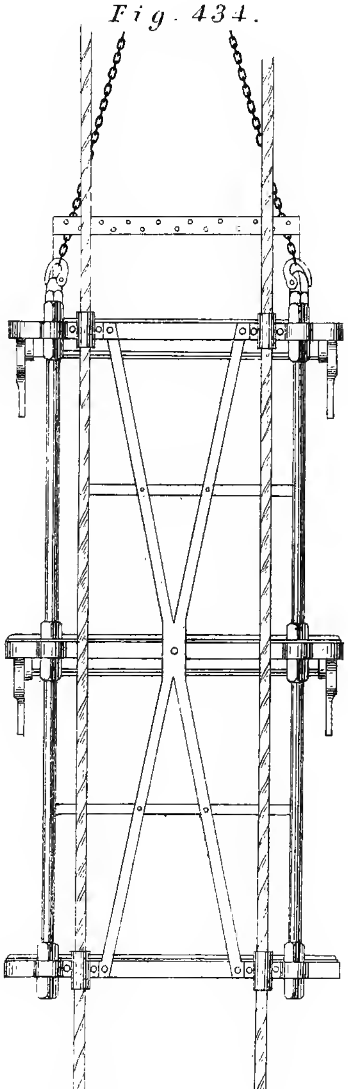

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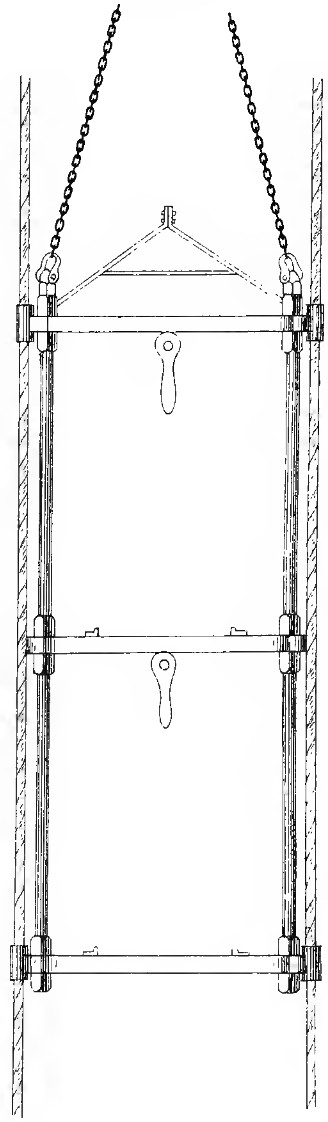

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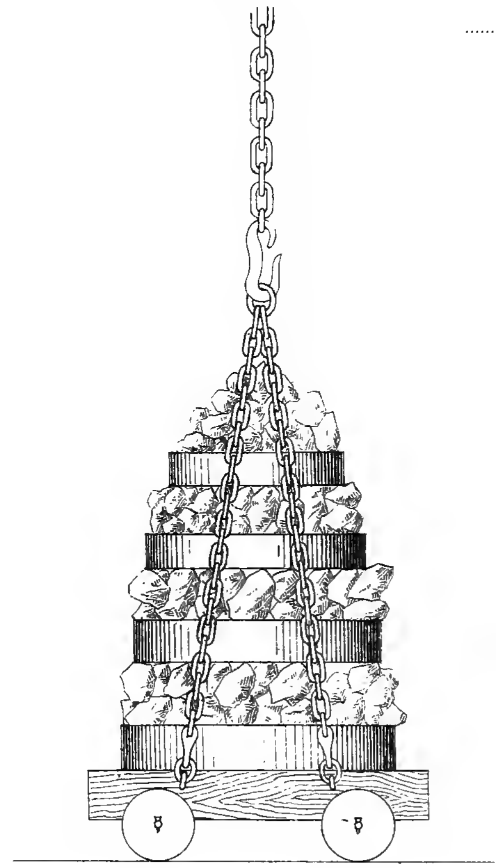

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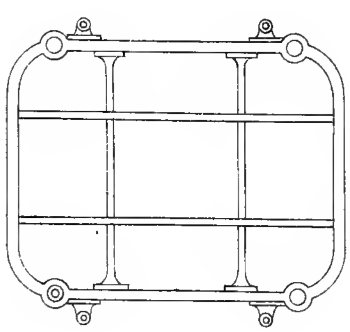

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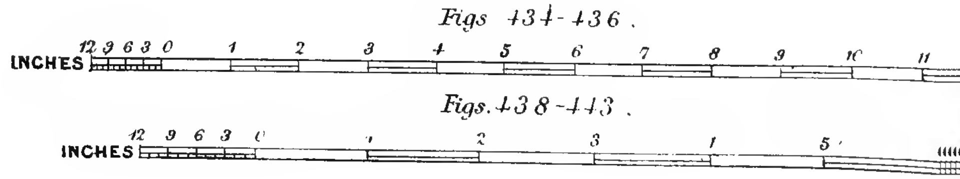

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AND KEEPS.

Fig. 438.

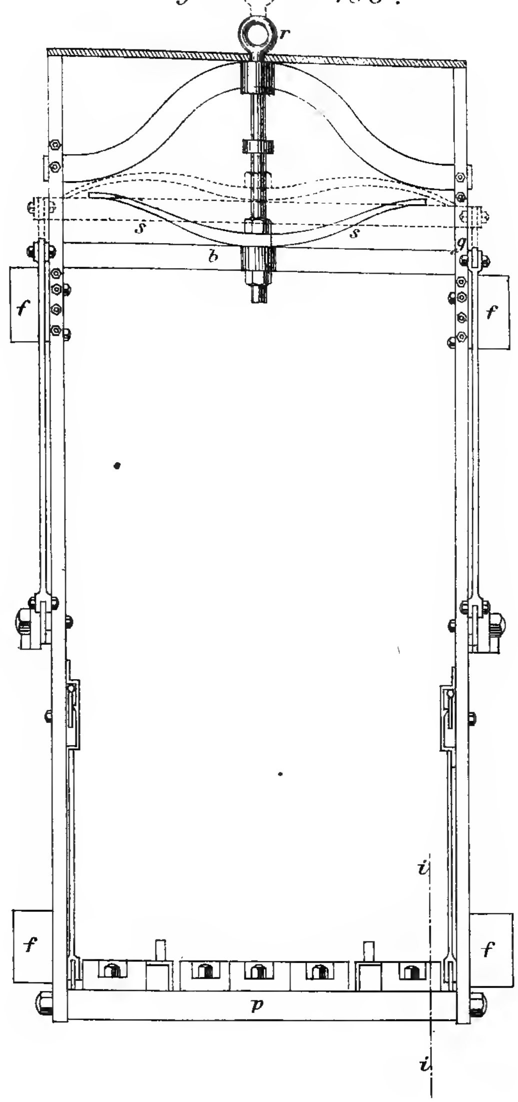


Fig. 439

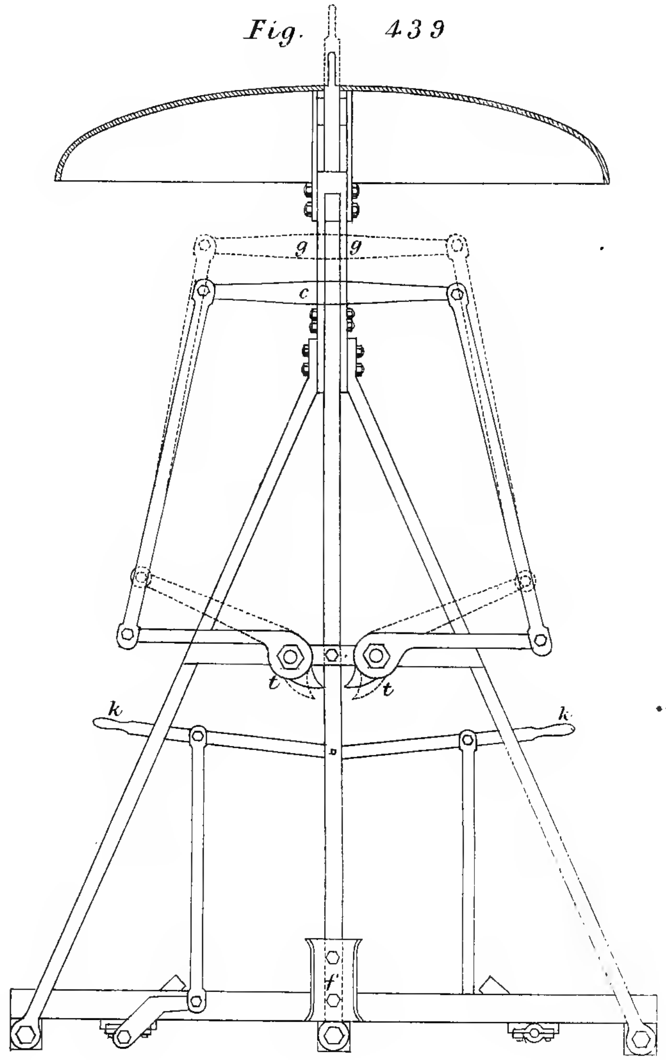
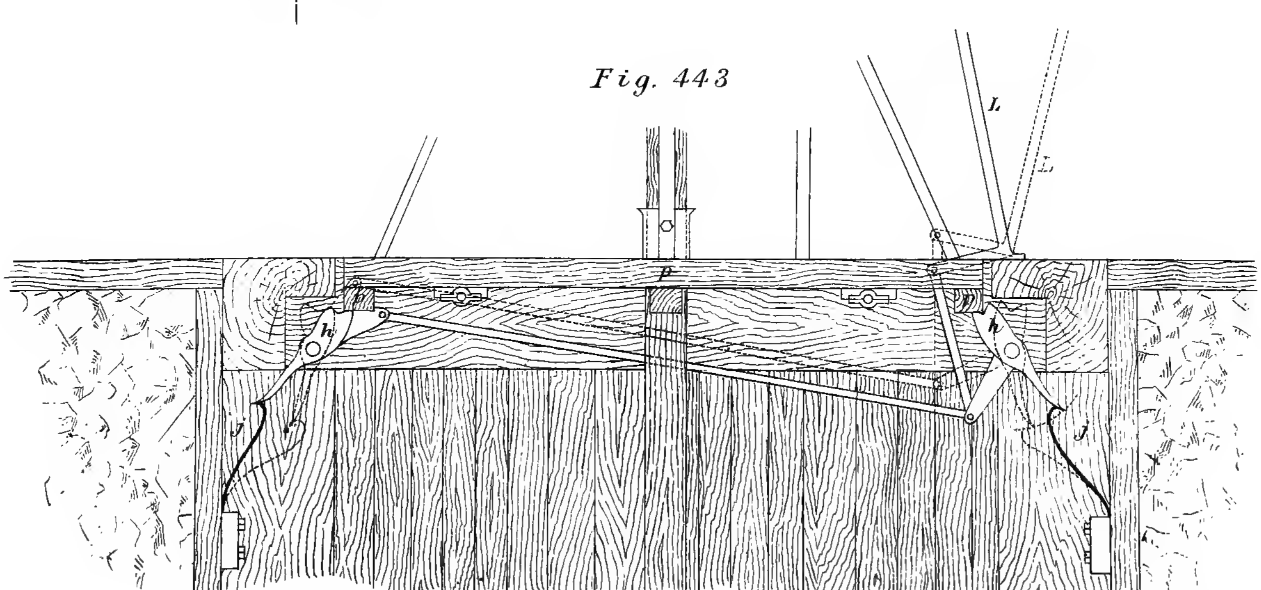


Fig. 443



12 FEET

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G. G. ANDRÉ.

& New York

CAGES.

Fig. 440.

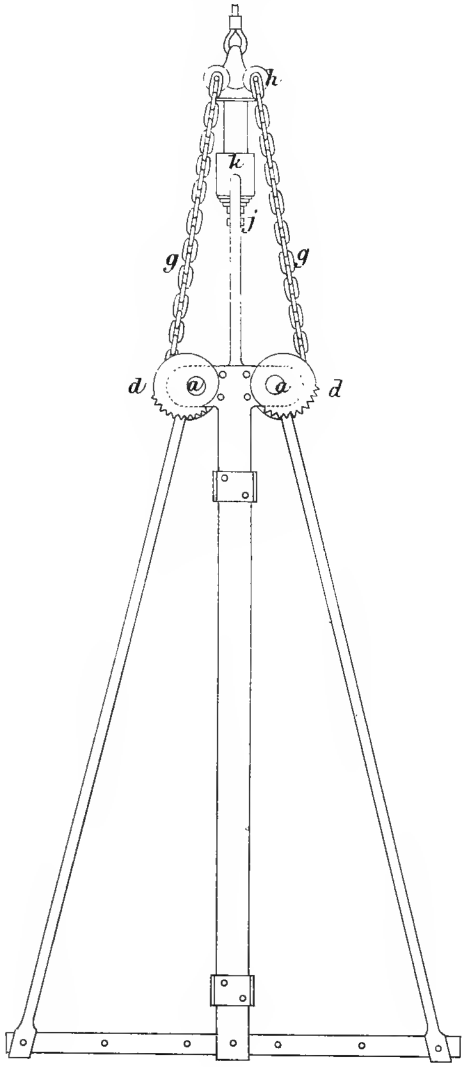


Fig. 441.

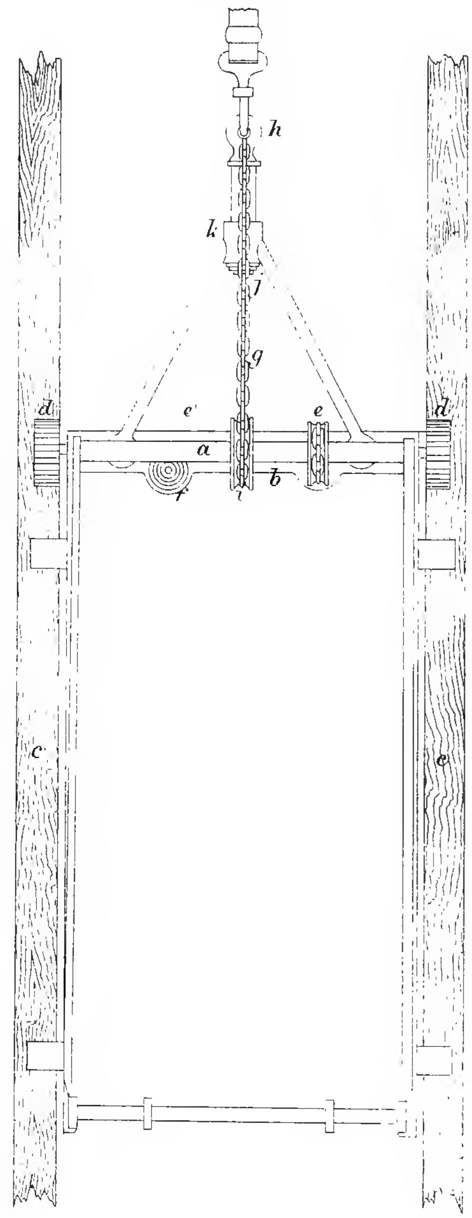
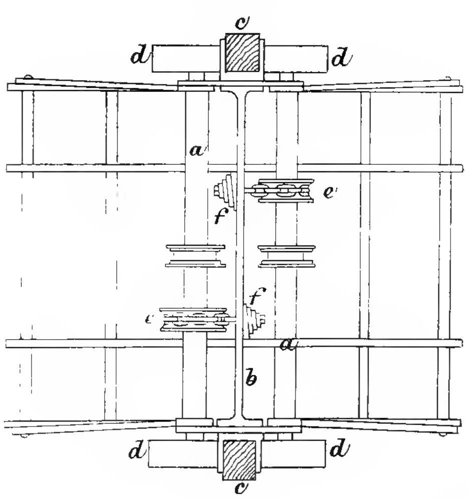
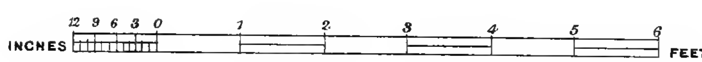


Fig. 442.



SCALE



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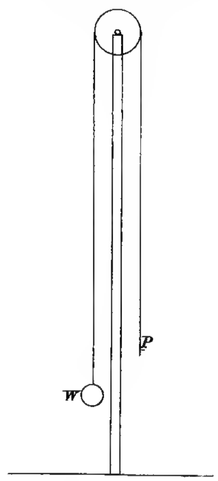
PIT-HEAD FRAMES.

Fig 444.



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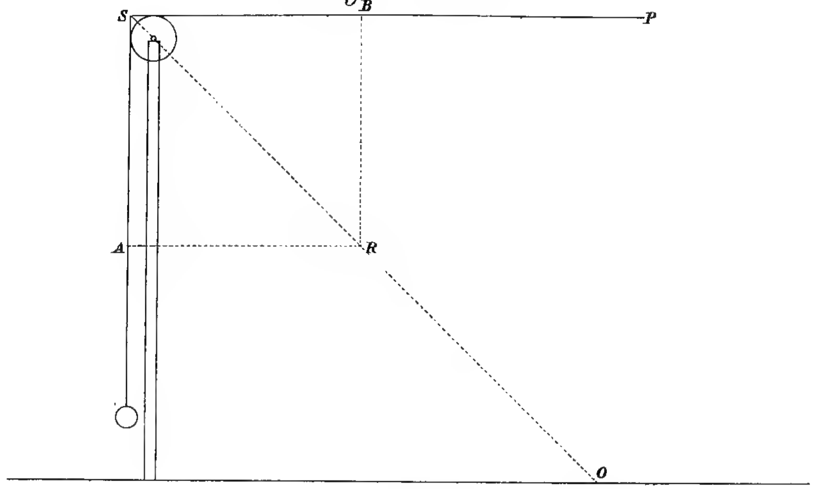


Fig. 448.

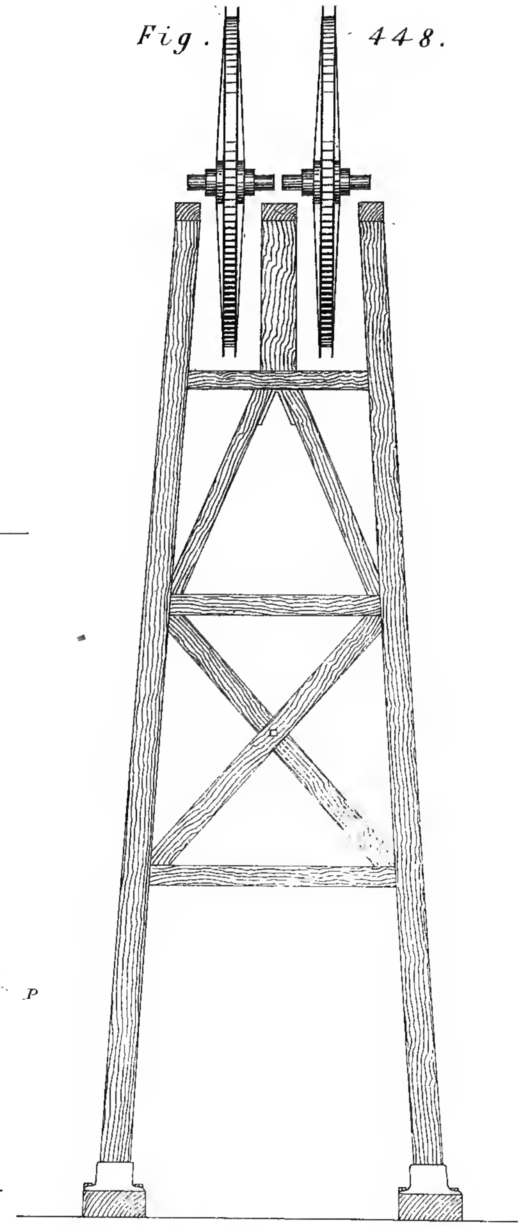


Fig 445.

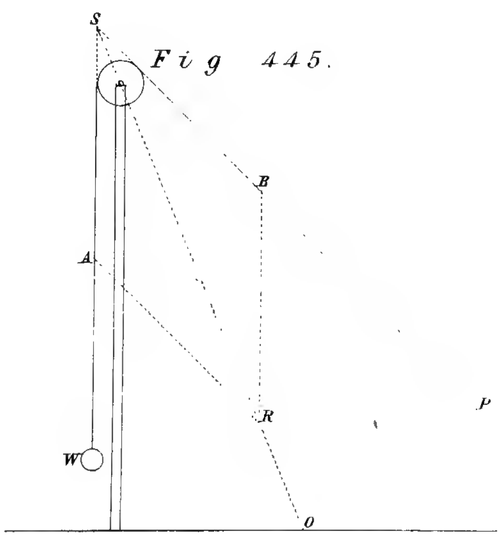
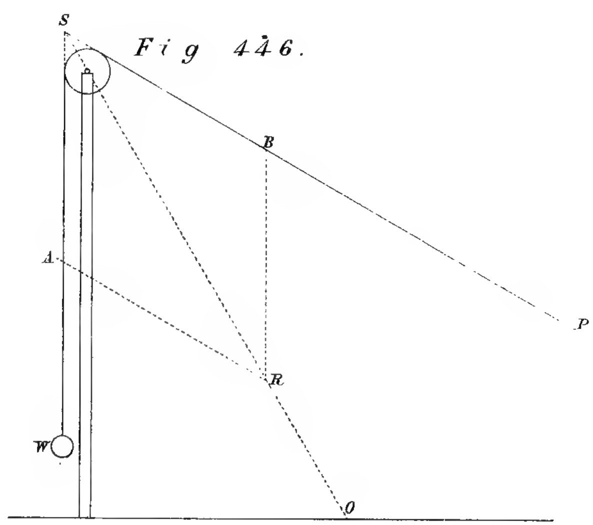


Fig 446.



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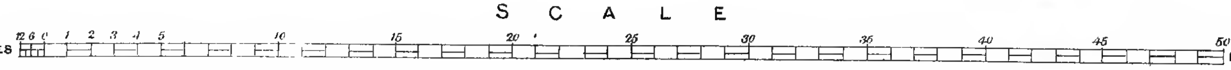

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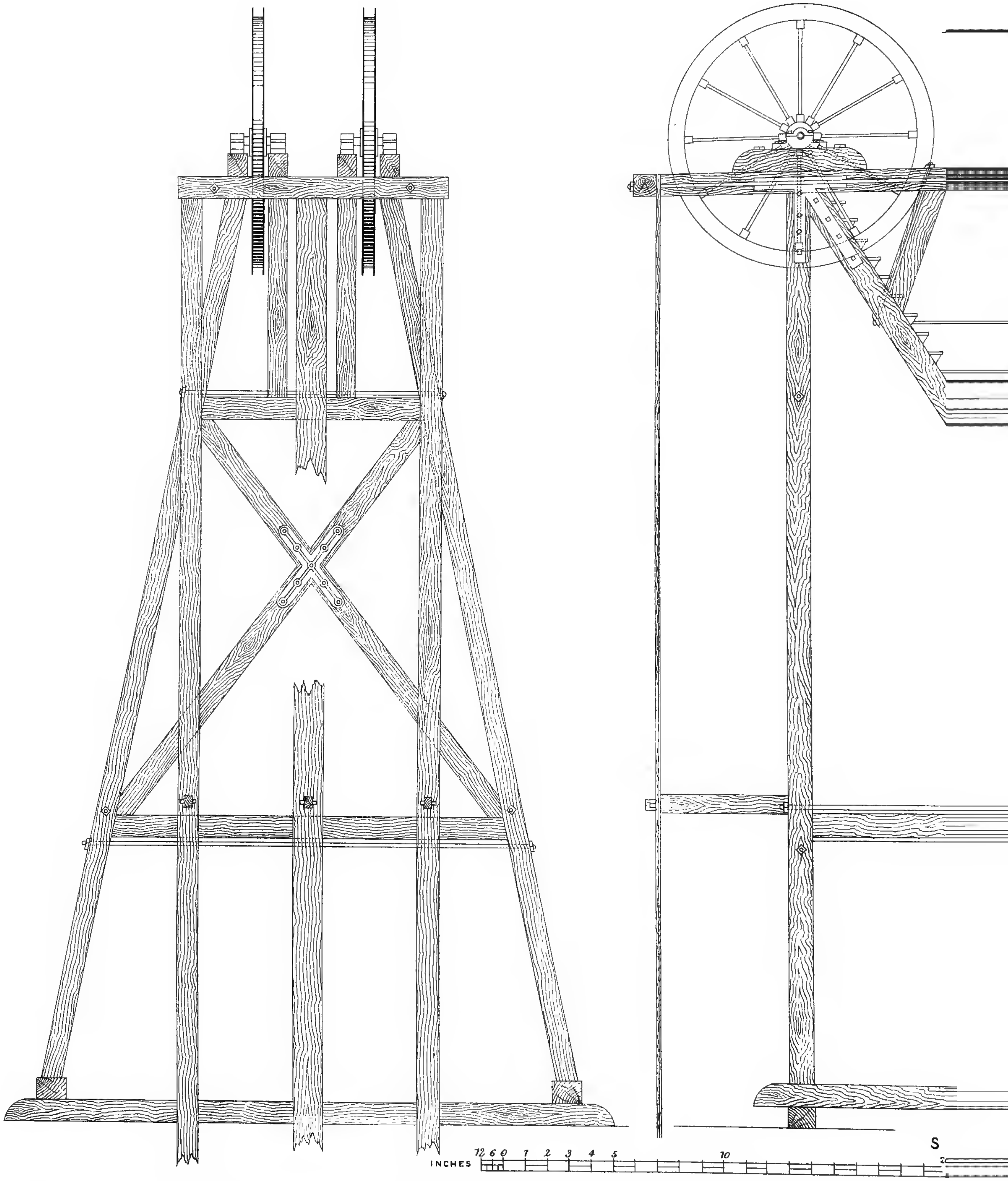
P I T – H E

Fig. 449

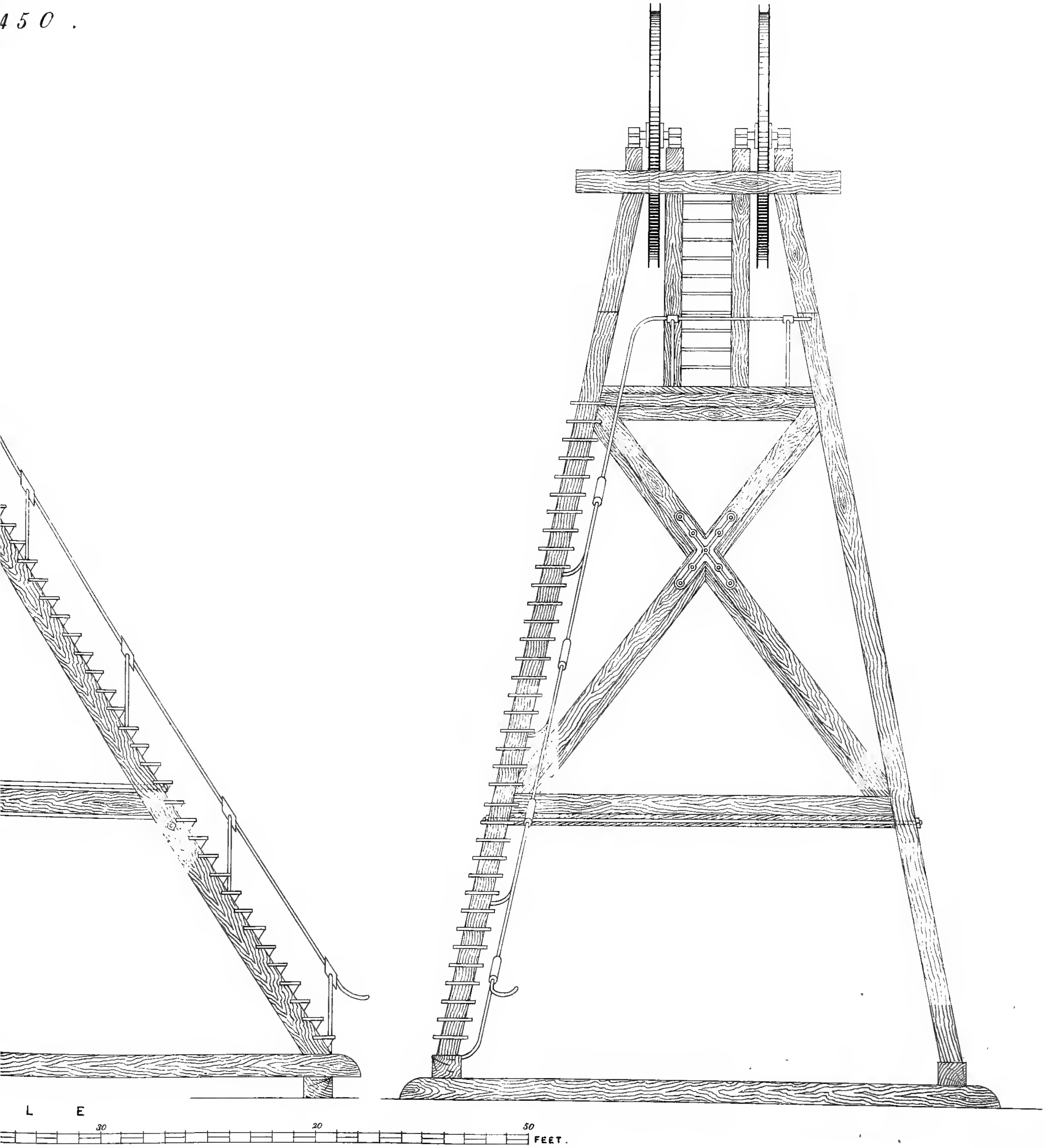


E.

F R A M E S.

Fig. 451.

450.



L E

G. G. ANDRÉ.

ndon & New York.

PIT-HEAD FRA

Fig 452

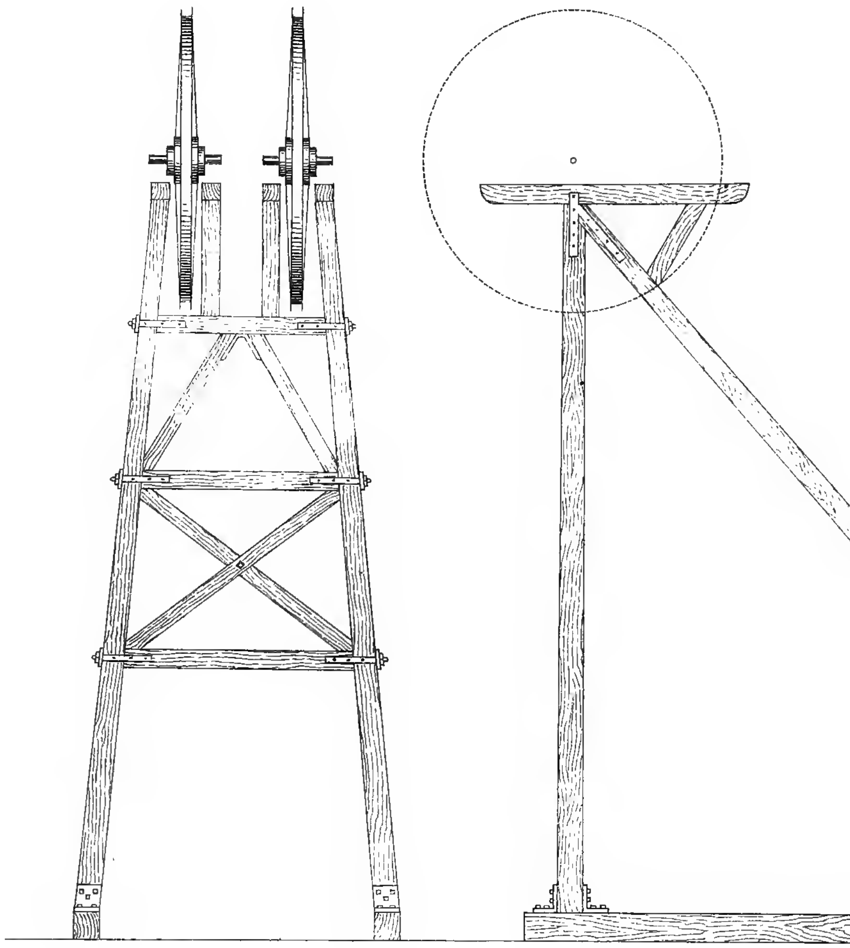


Fig. 456

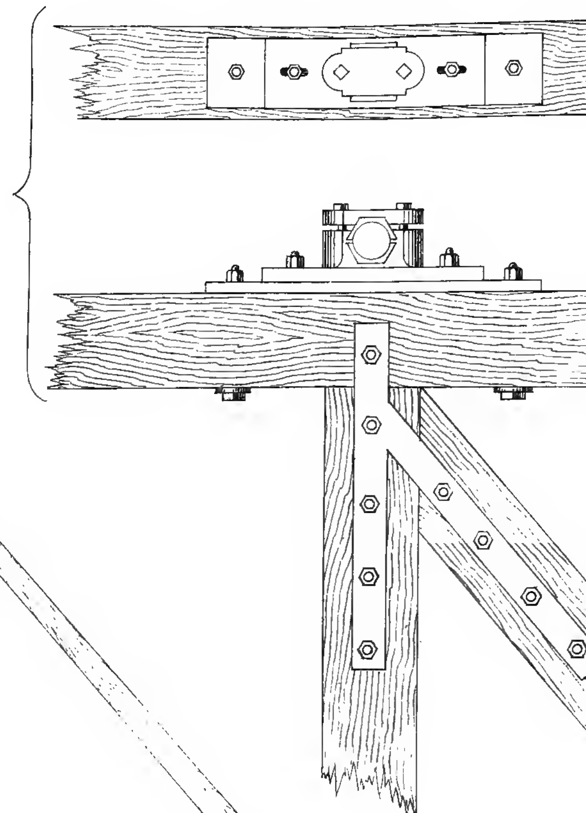


Fig 453.

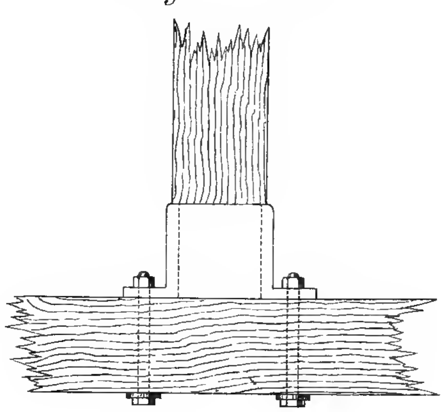
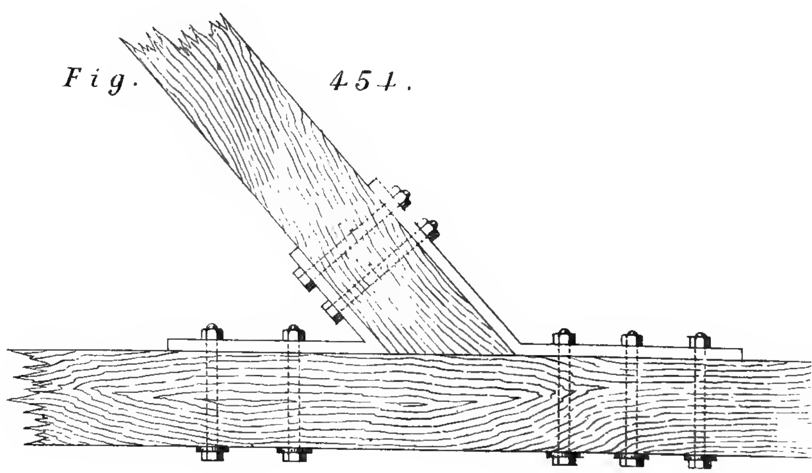


Fig. 454.



S C

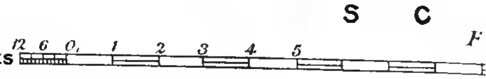
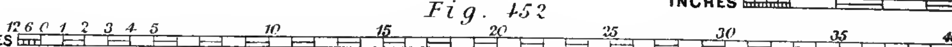


Fig. 452



S AND DETAILS.

Fig. 457

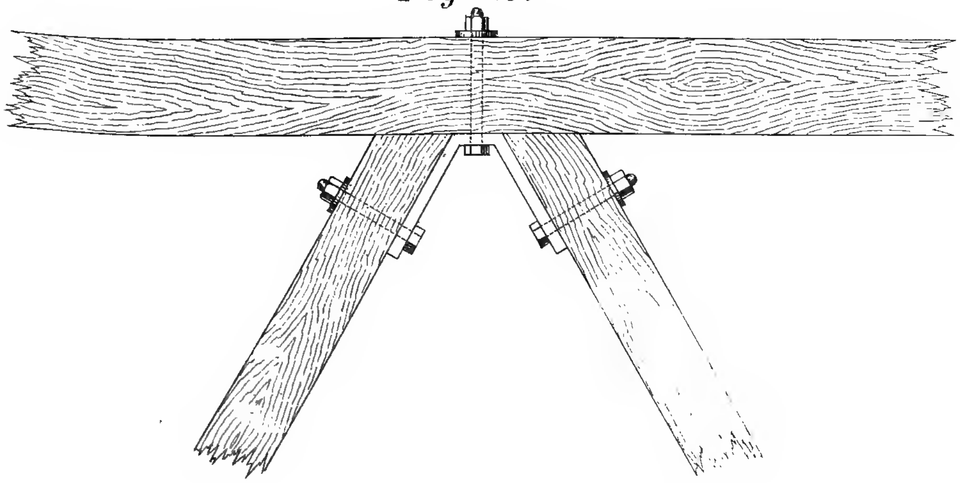


Fig. 460

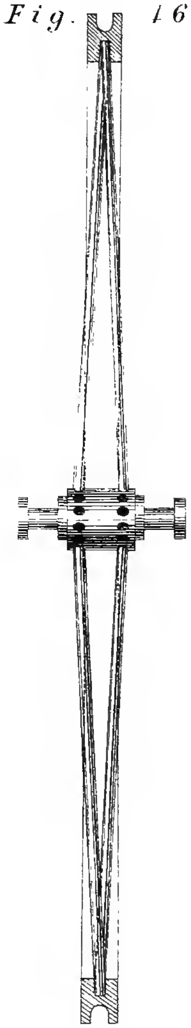


Fig. 458

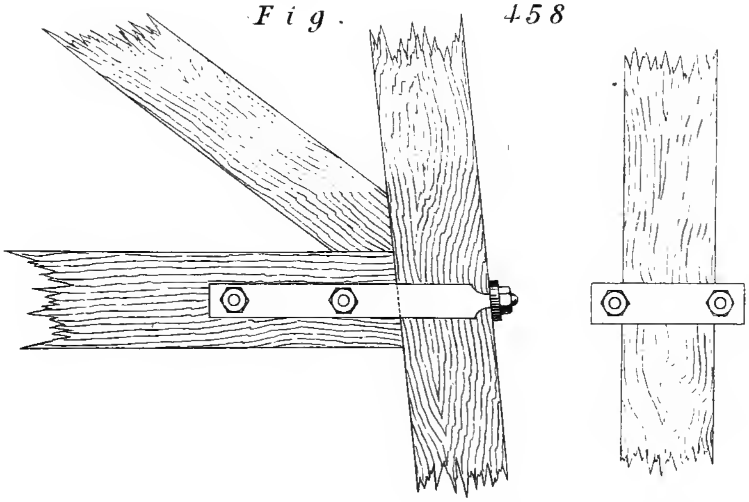


Fig. 455.

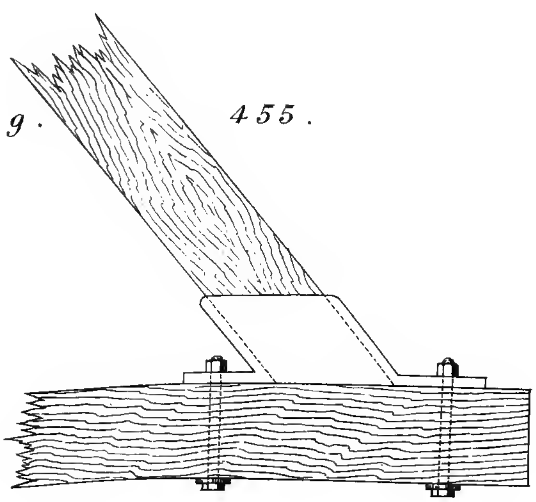
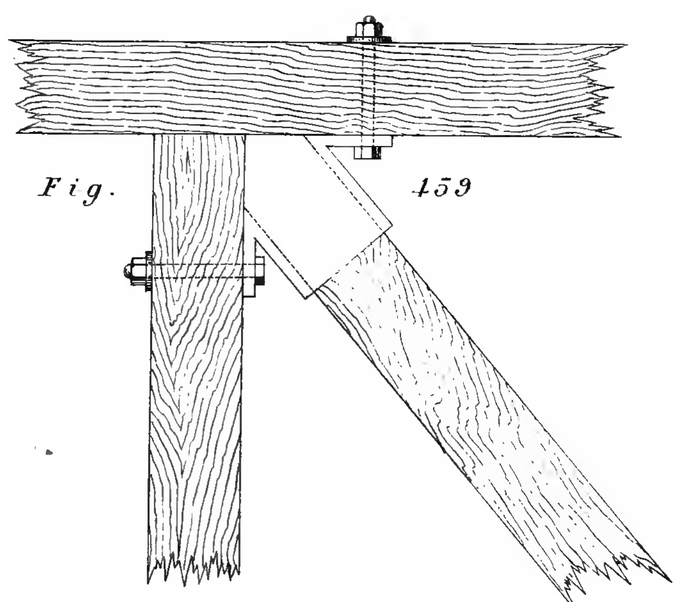


Fig. 459



E S.

15 20 22 FEET

Figs. 453 to 459.

INCHES 12 9 6 3 0 1 2 3 4 5 6 7 8 9 10 FEET

G. G. ANDRÉ

New York.

CORNISH HORSE — WHIM.

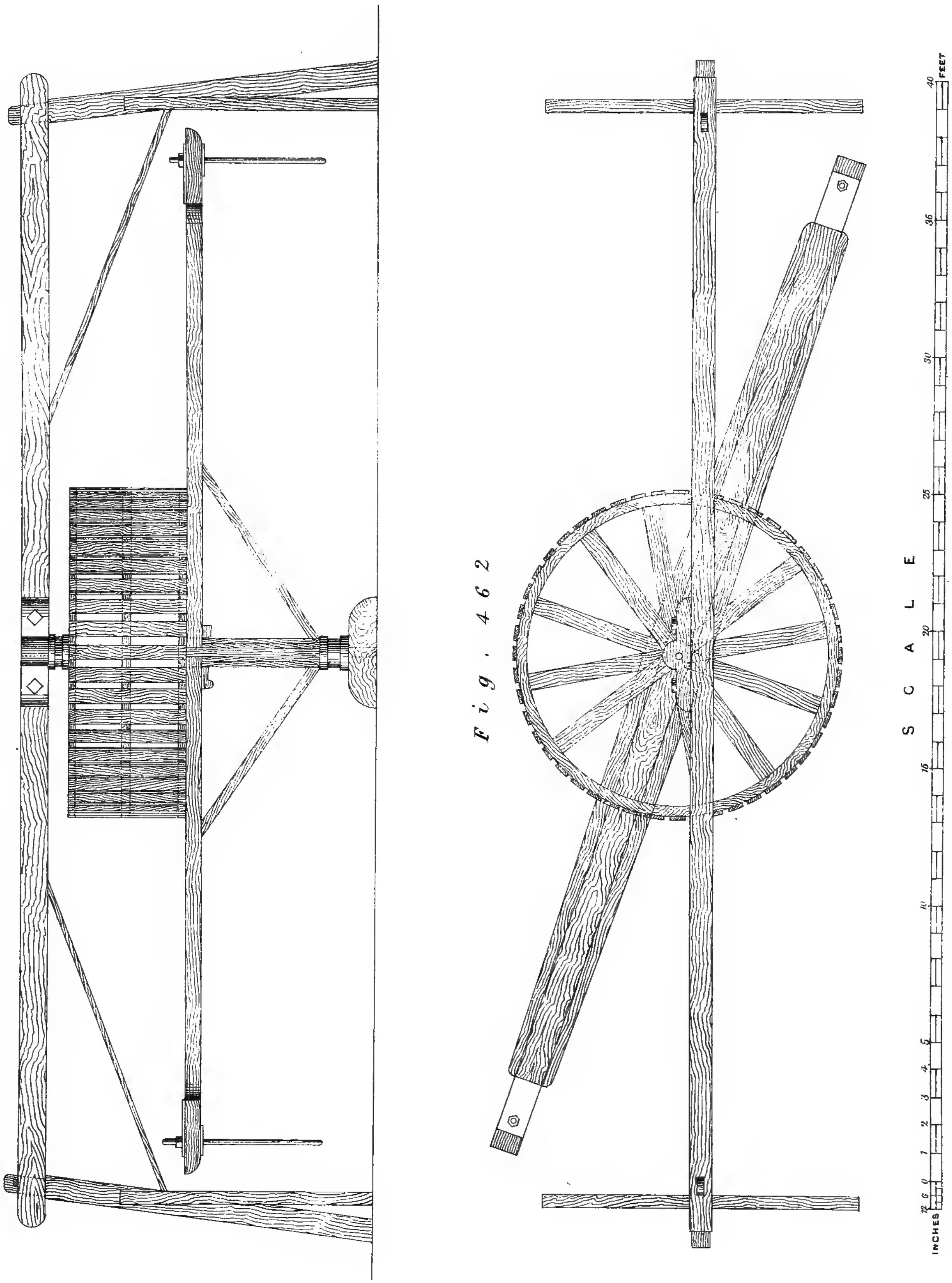


Fig. 461.

Fig. 462

G.G. ANDRÉ.

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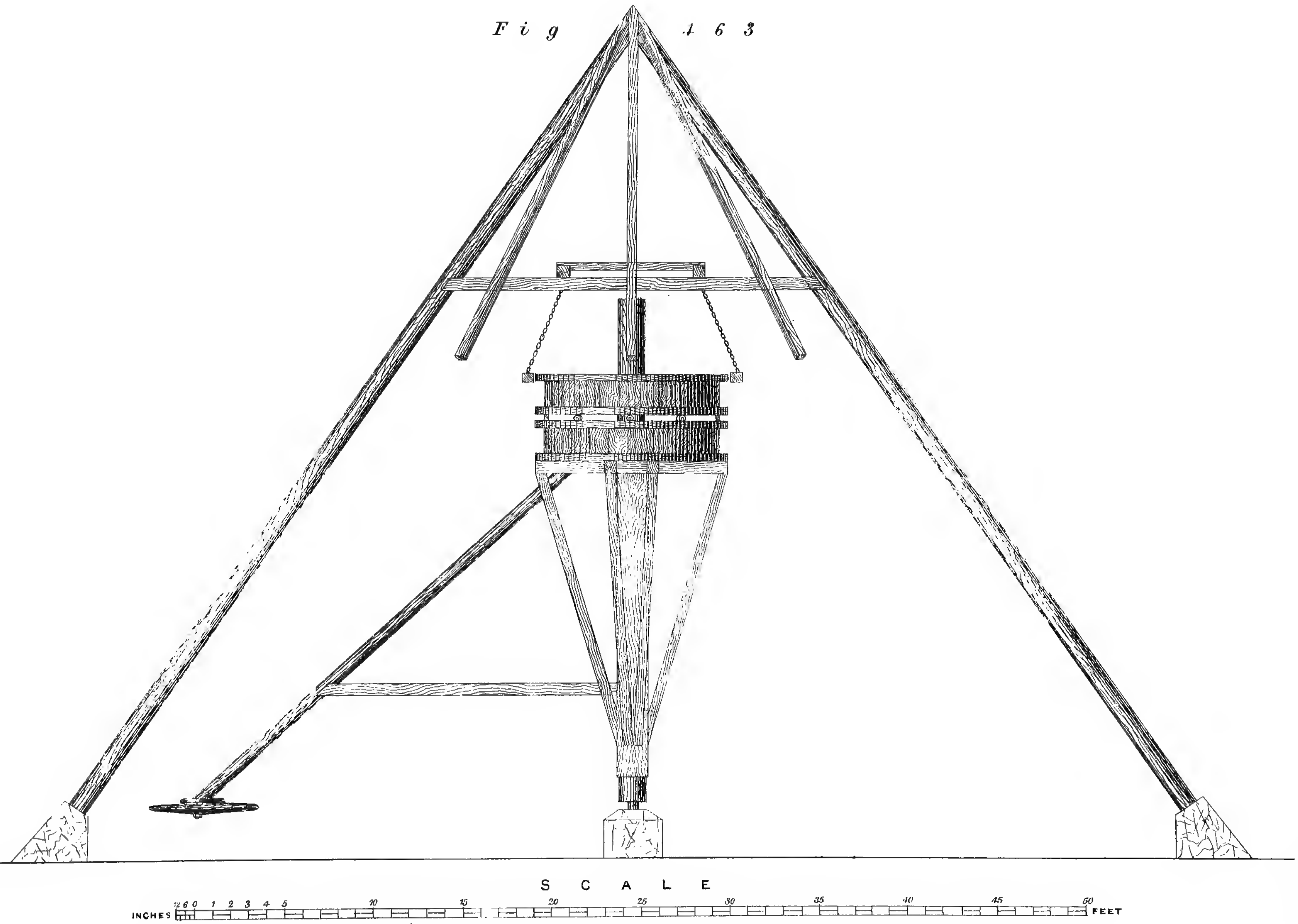
GERMAN HORSE — WHIM

Fig 163



G.G. ANDRÉ.

E & F.N. Spon London & New York

GERMAN HORSE WHIM AND CORNISH WATER WHIM.

Fig. 464.

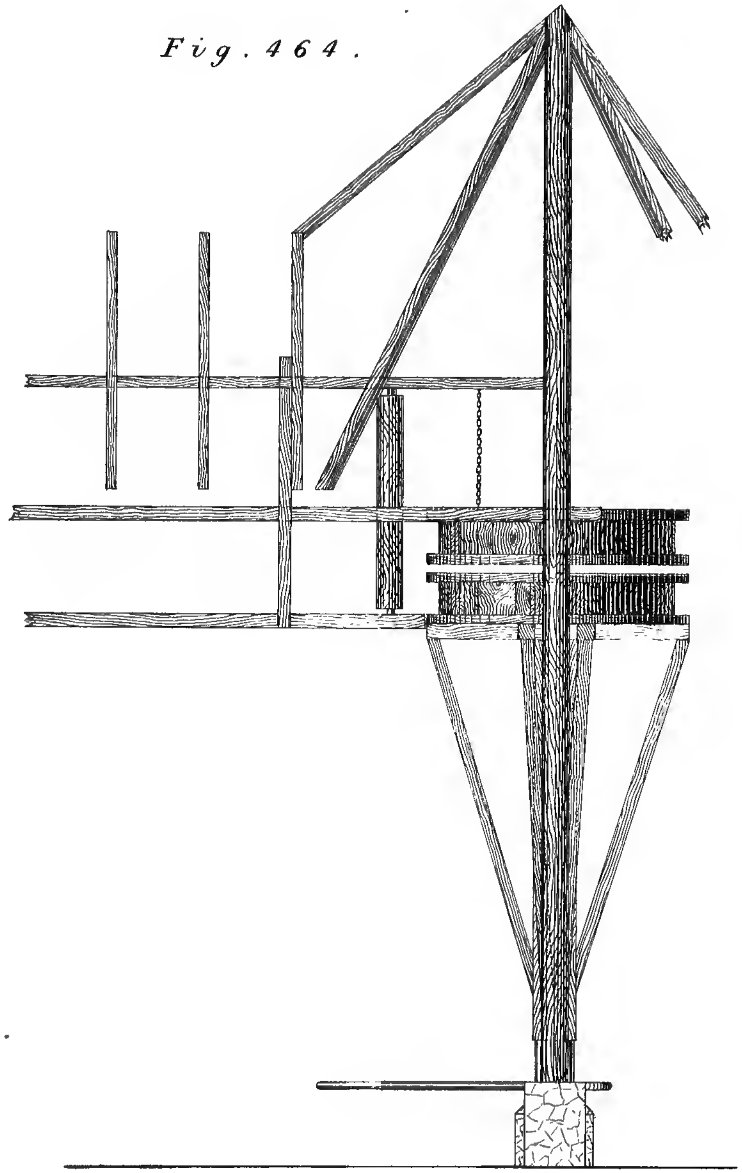
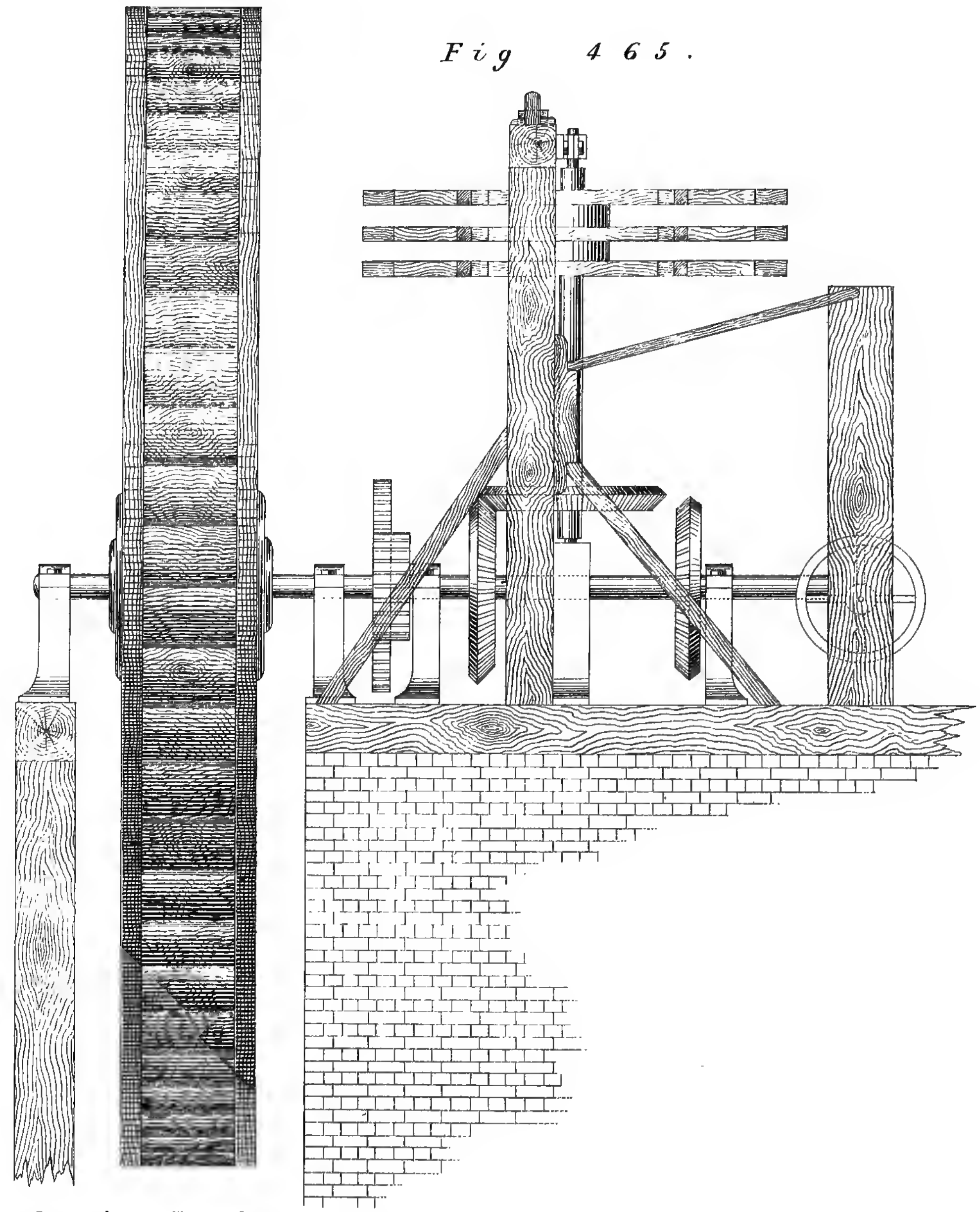


Fig 465.



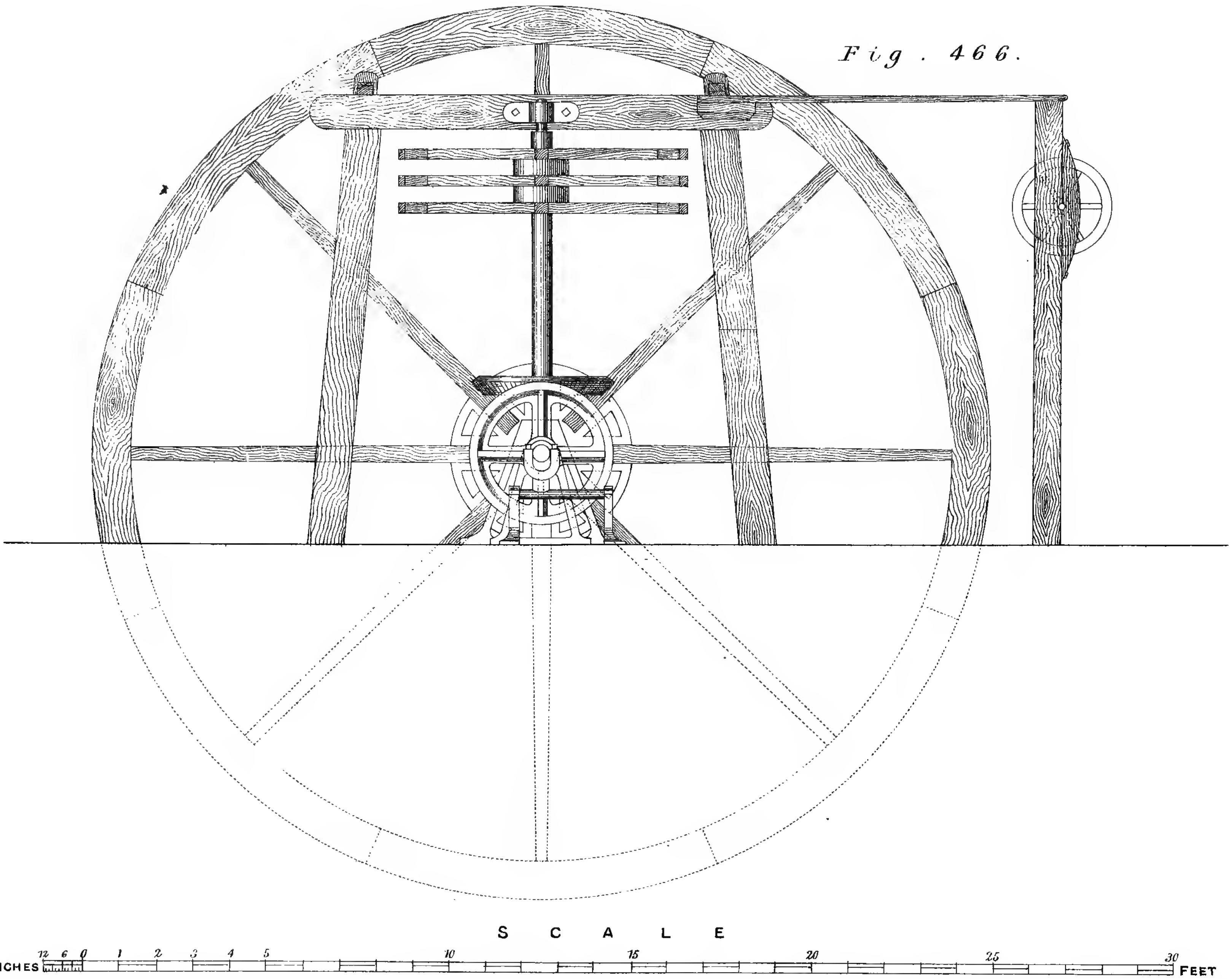
SCALES.

G.G. ANDRÉ

PLATE XCIII.

CORNISH WATER WHIM.

Fig. 466.



G.G. ANDRÉ.

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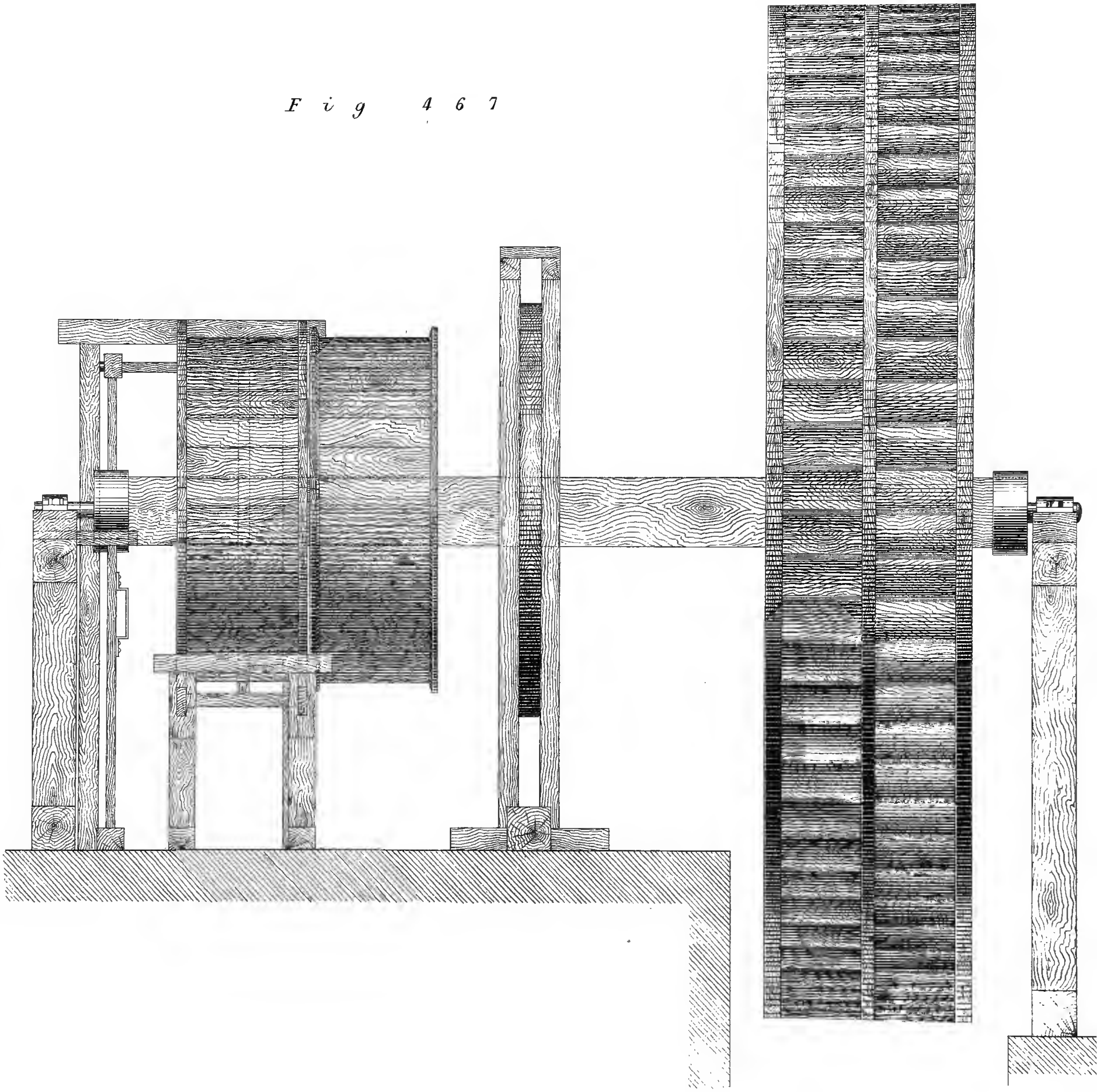
G E R M A N W

Fig 467



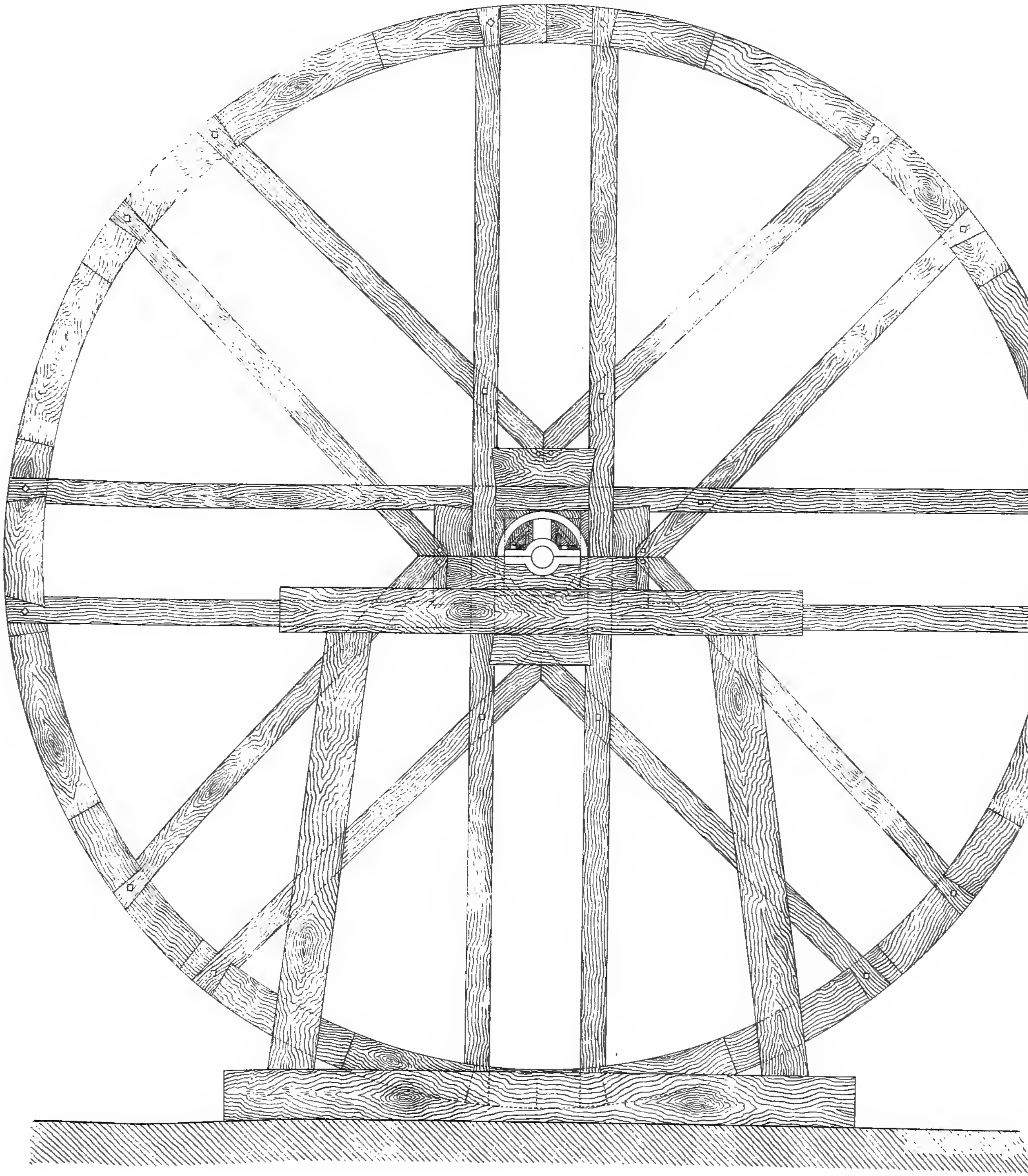
S C

INCHES 12 9 6 3 0 1 2 3 4 5 10

E. & F.N Spon

T E R W H I M .

Fig 468.



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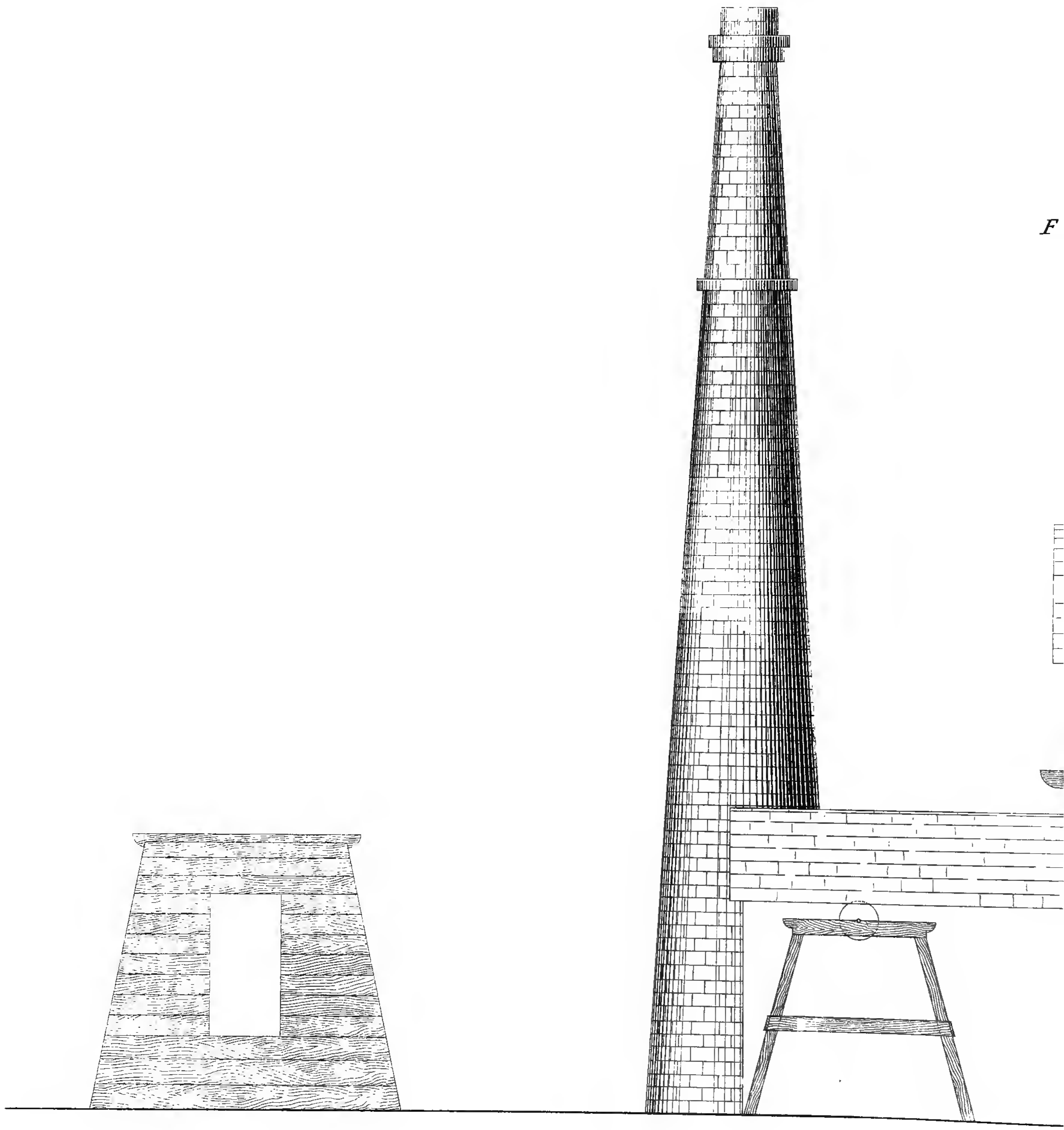
G.G. ANDRÉ.

C O R N I S H



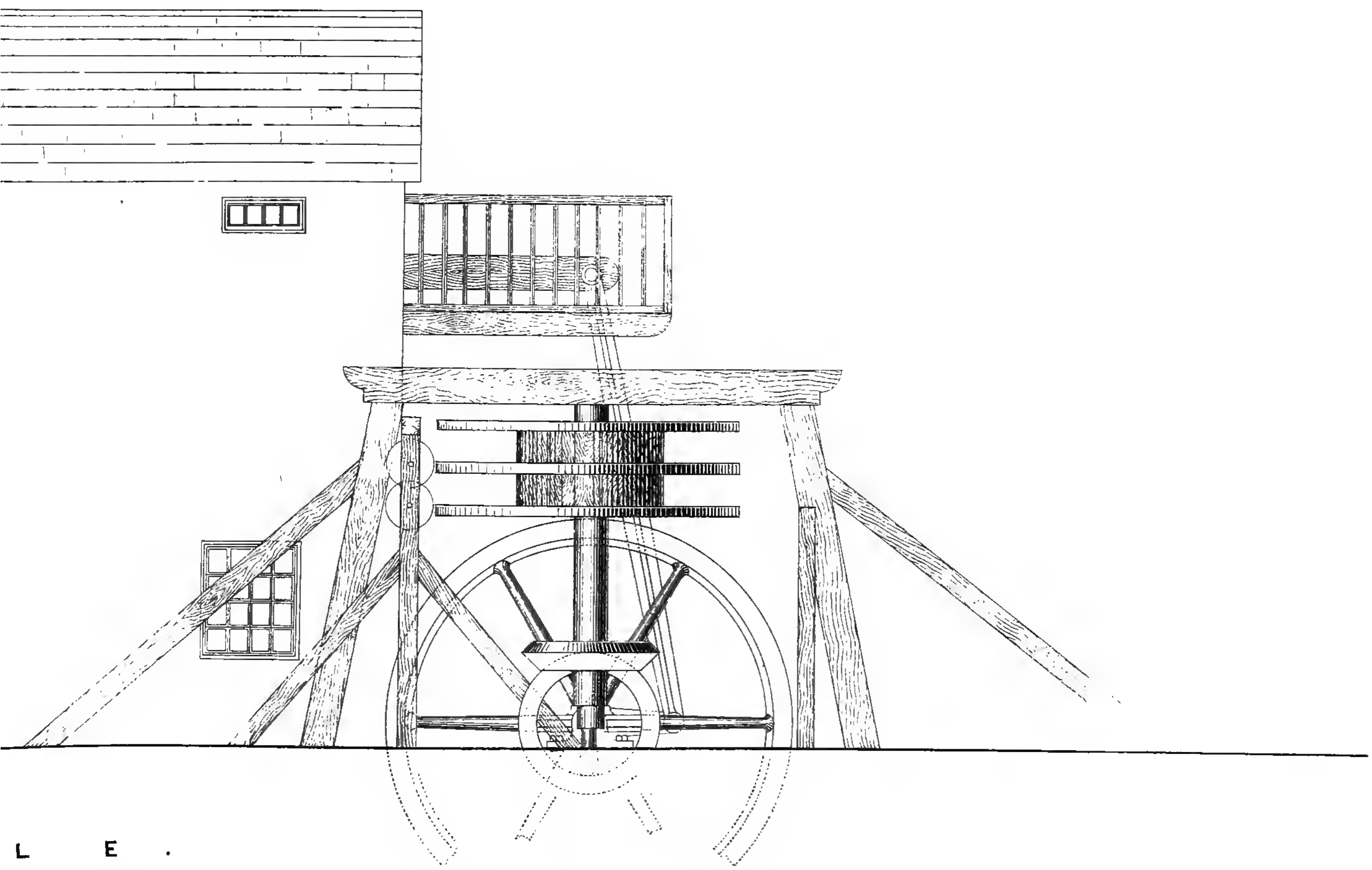
S C

INCHES 12 6 0 1 2 3 4 5 10 15 20

E. & F N

T E A M   W H I M .

4 6 9 .



L E .

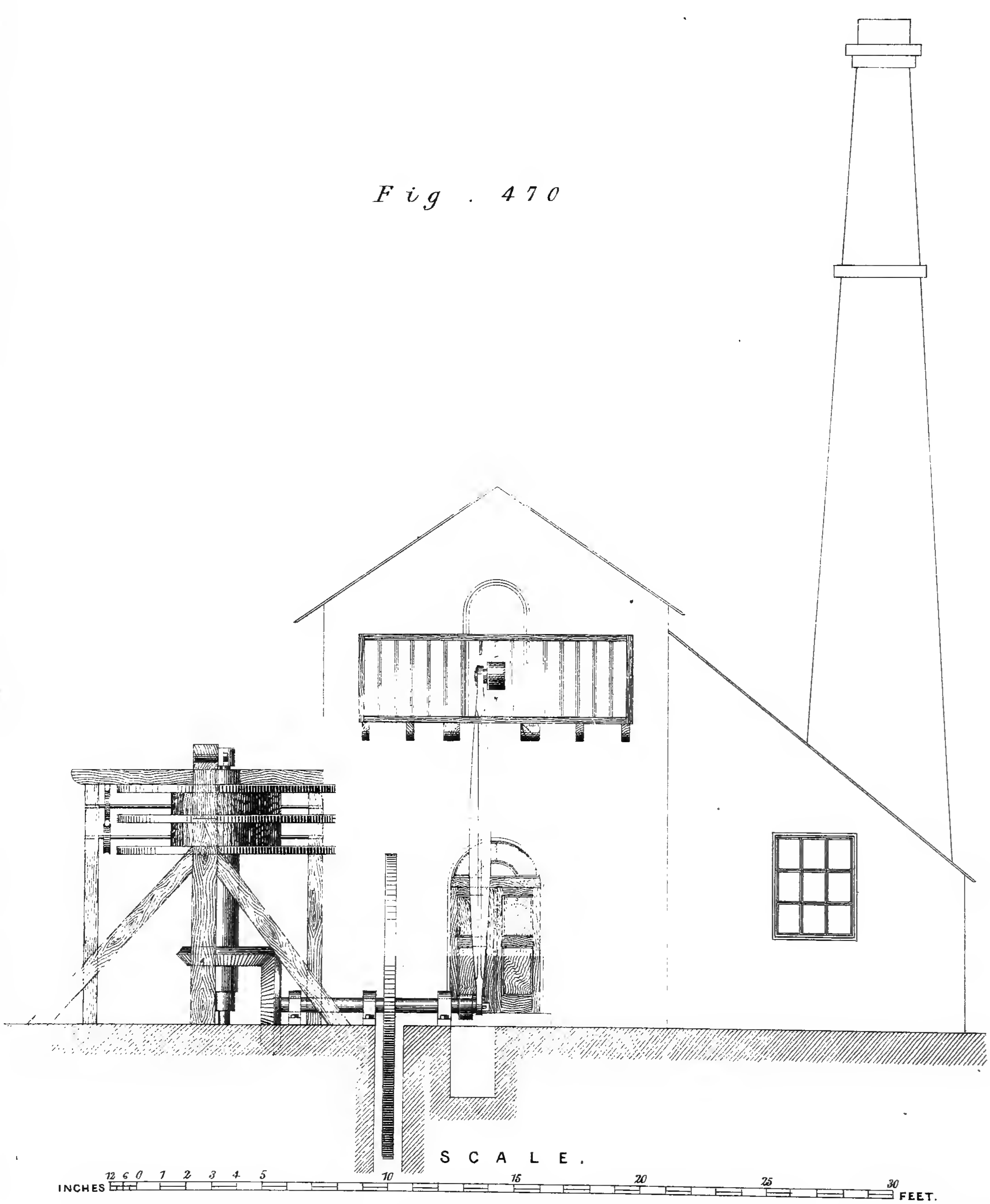
30 35 40 45 50 FEET.

G. G. ANDRÉ

, New York.

CORNISH STEAM WHIM.

Fig. 470



G.G. ANDRÉ.

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HAULING ENGINES — STEVENS SINGLE CYLINDER.

Fig 471. ELEVATION.

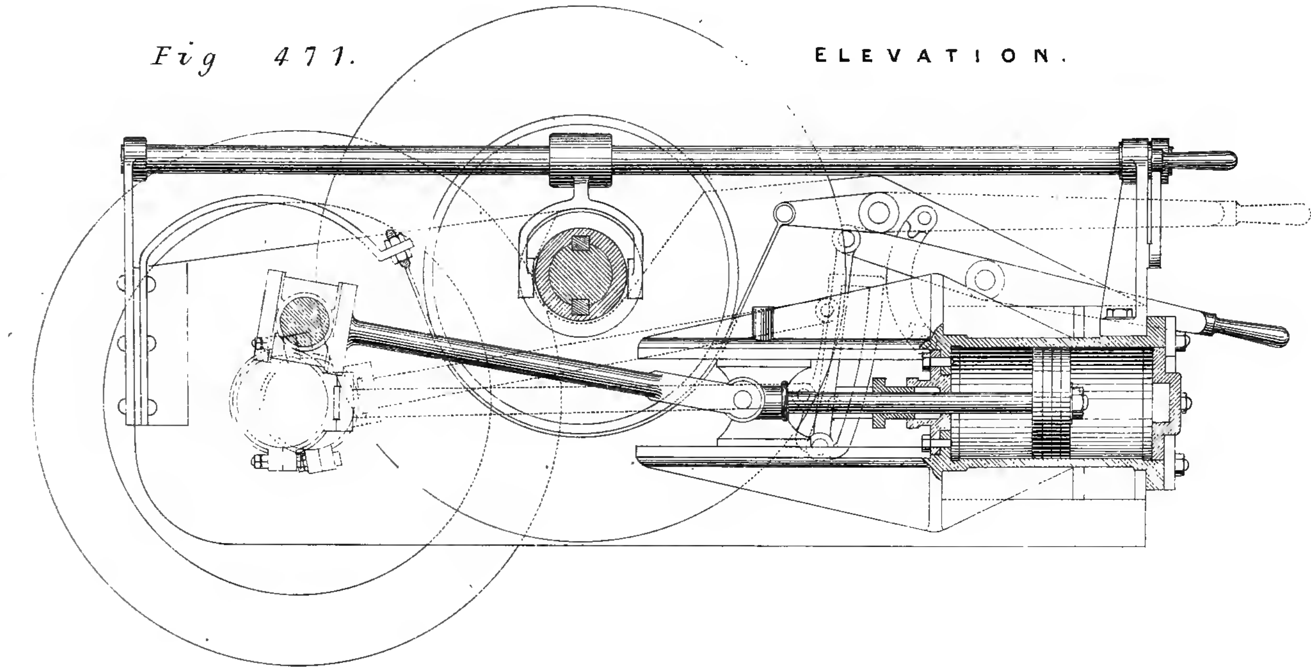
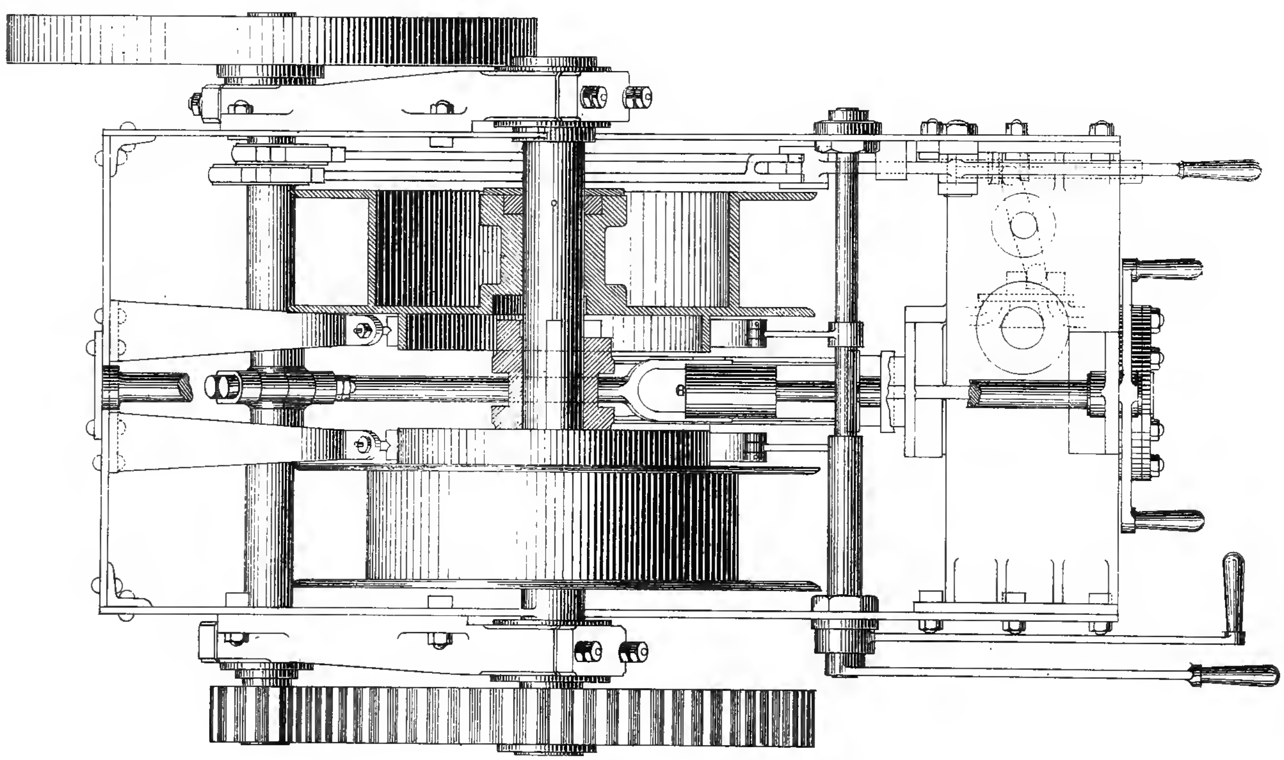


Fig. 471. PLAN.



S C A L E.

INCHES 12 9 6 3 0 1 2 3 4 FEET.

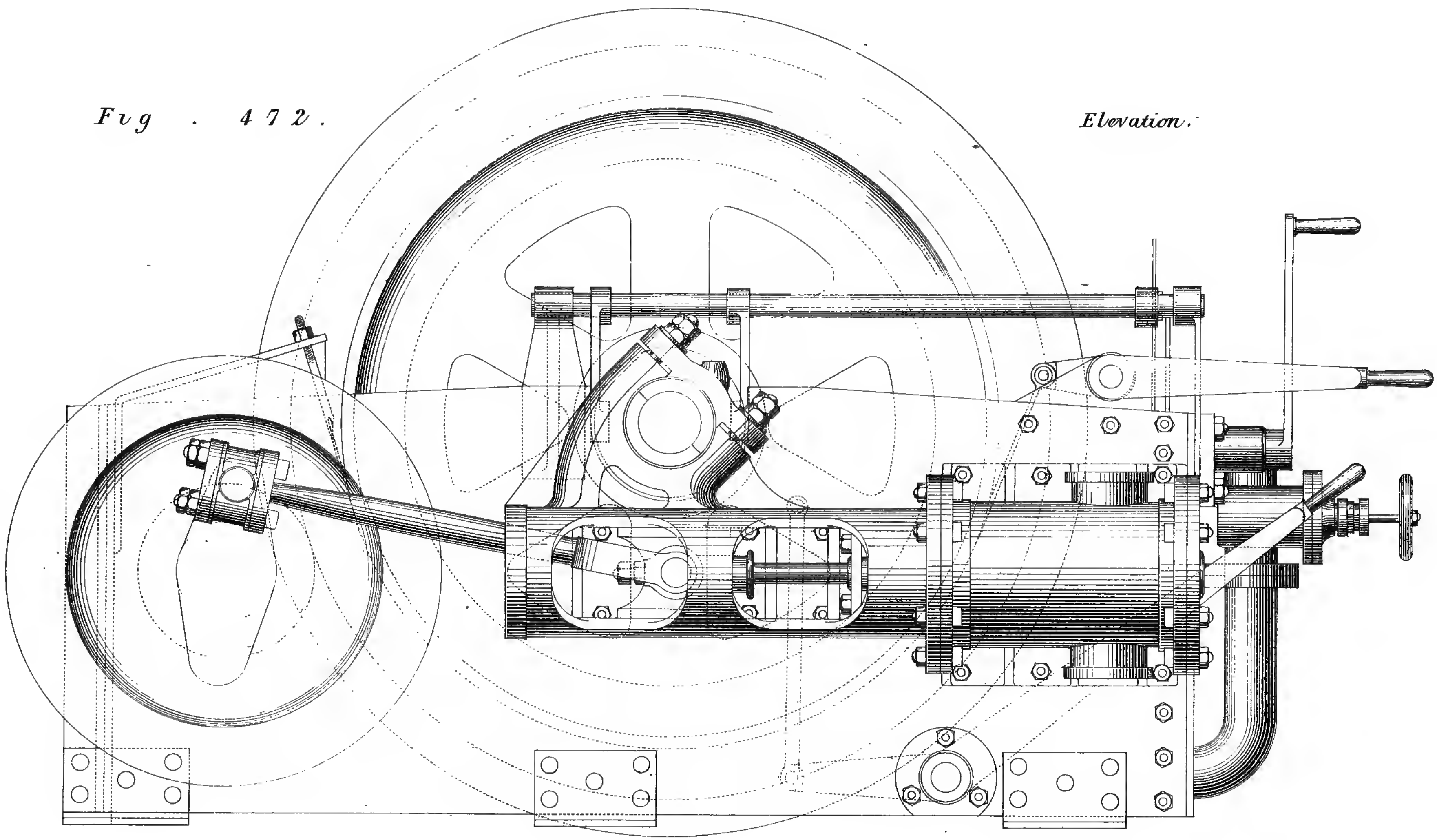
G.G. ANDRÉ

E. & F.N. Spon. London & New York

HAULING ENGINES — STEVENS DOUBLE CYLINDER.

Fig. 472.

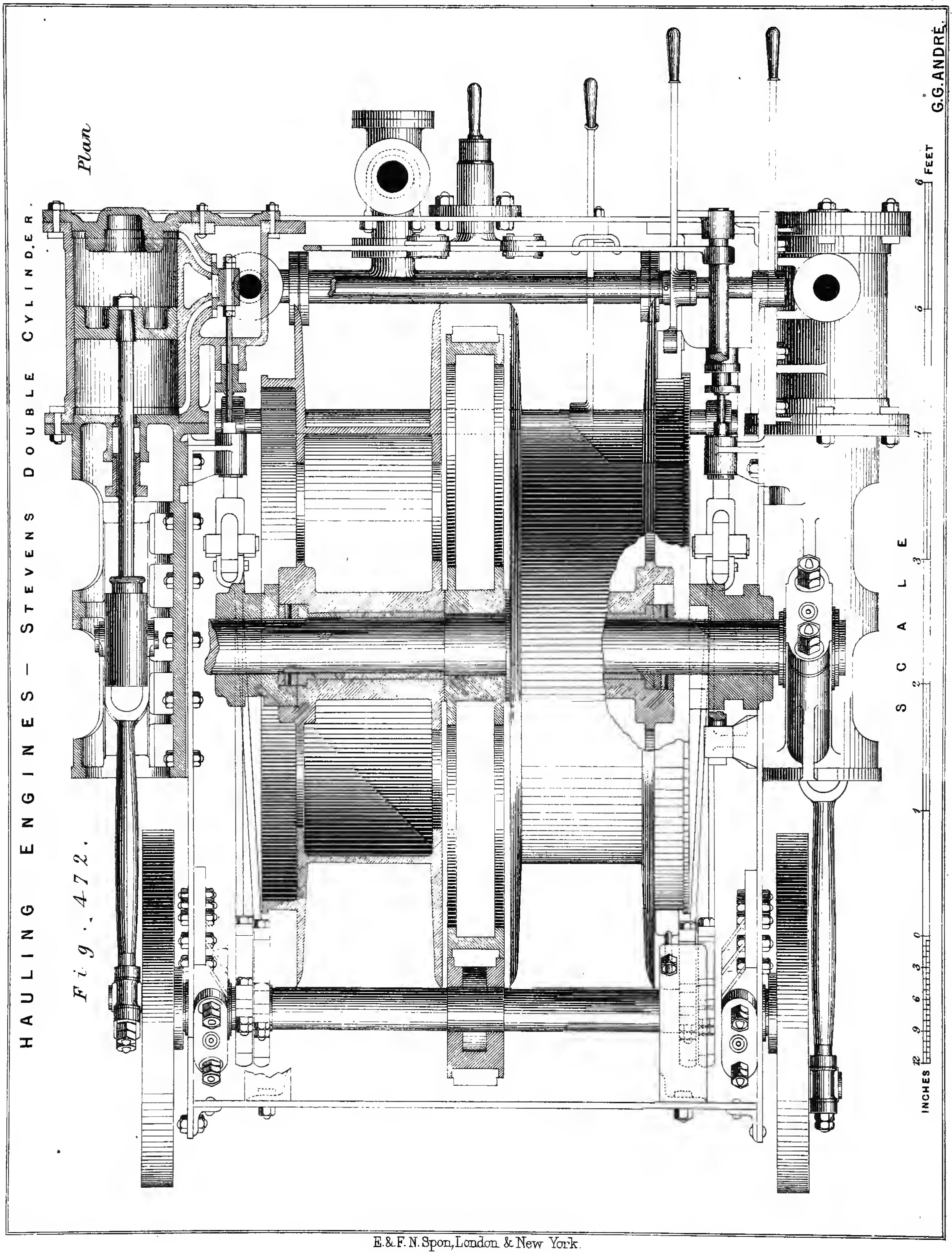
Elevation.



SCALE

INCHES 12 9 6 3 0 1 2 3 4 5 6 FEET

E.&F.N. Spon, London & New York.



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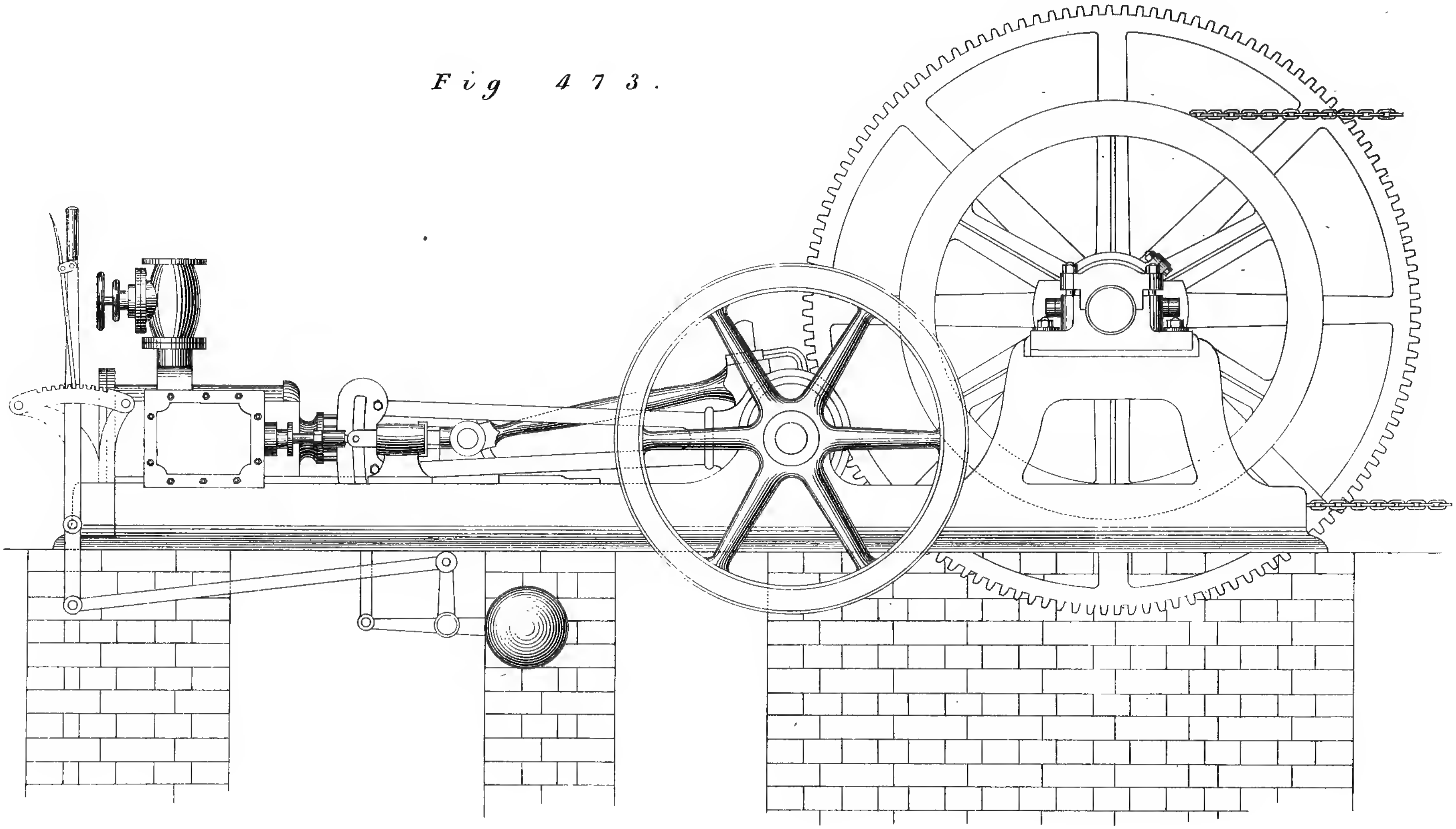
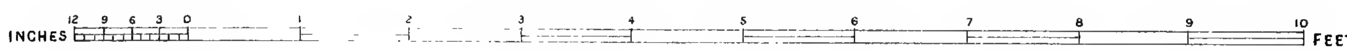
HAULING ENGINES — MATHER AND PLATT.

Fig 473.



SCALE.



G. G. ANDRÉ.

E & F N Spon London & New York.

HAULING ENGINES – MATHER AND PLATT.

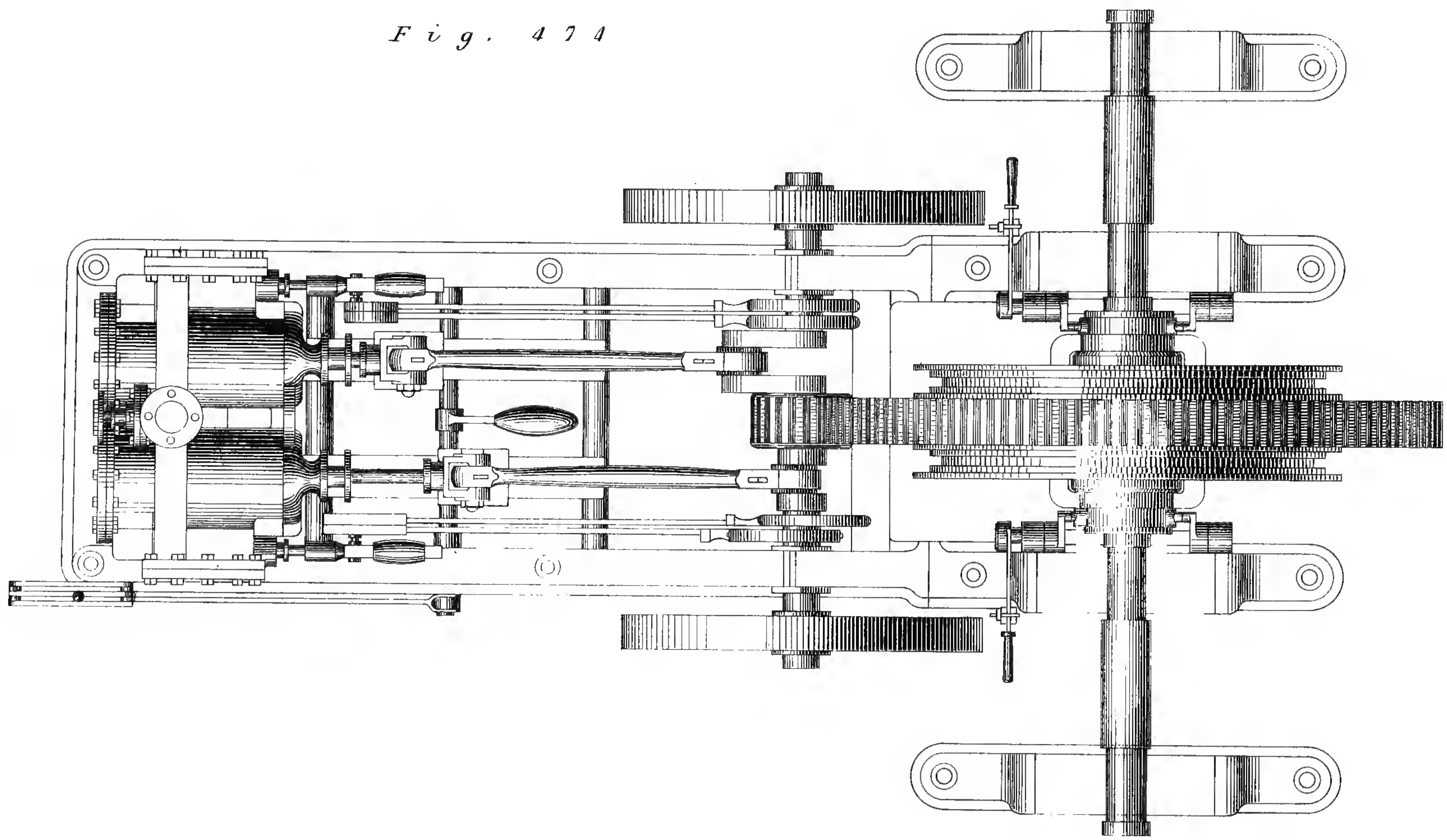


Fig. 474

SCALE.

G.G. ANDRÉ.

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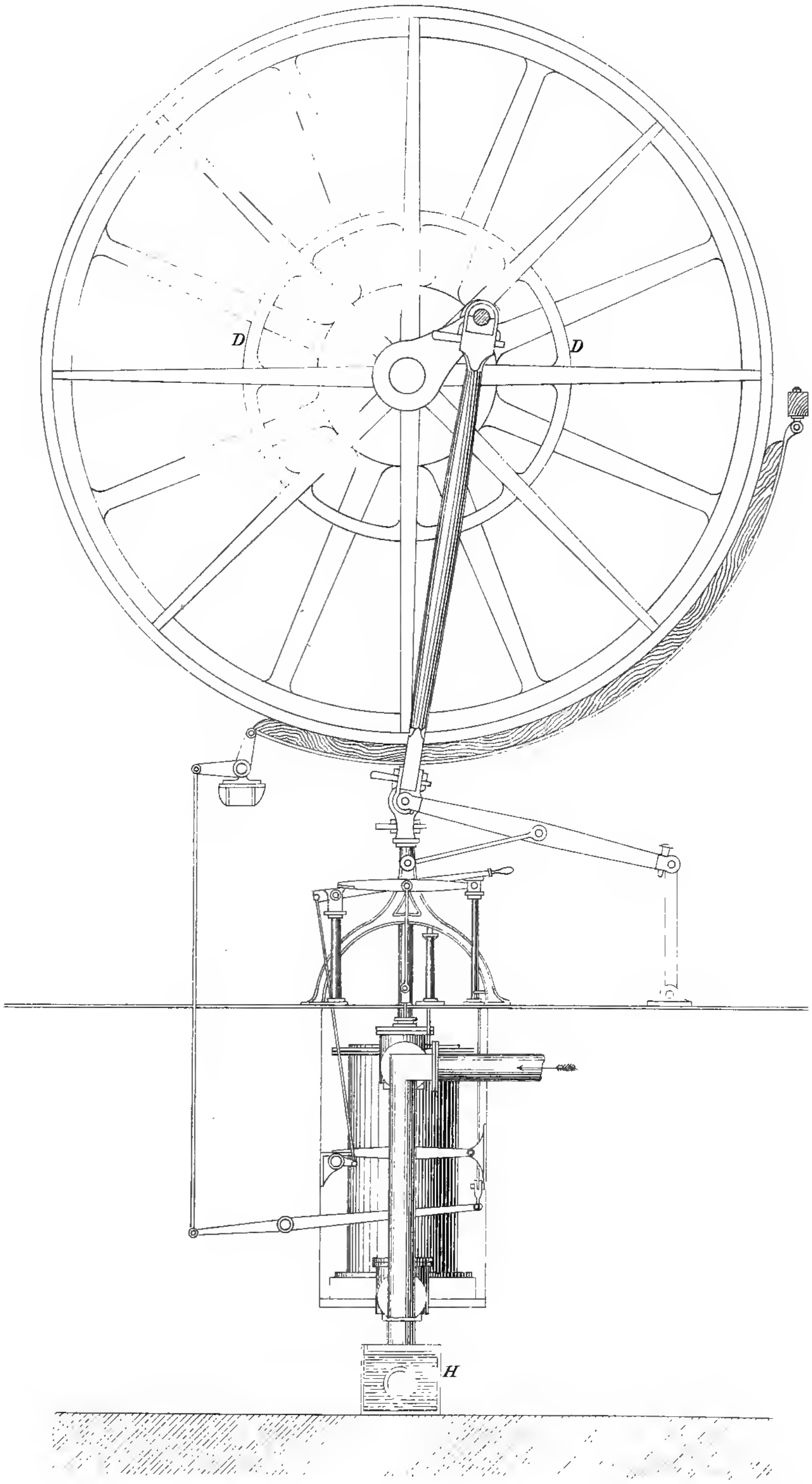
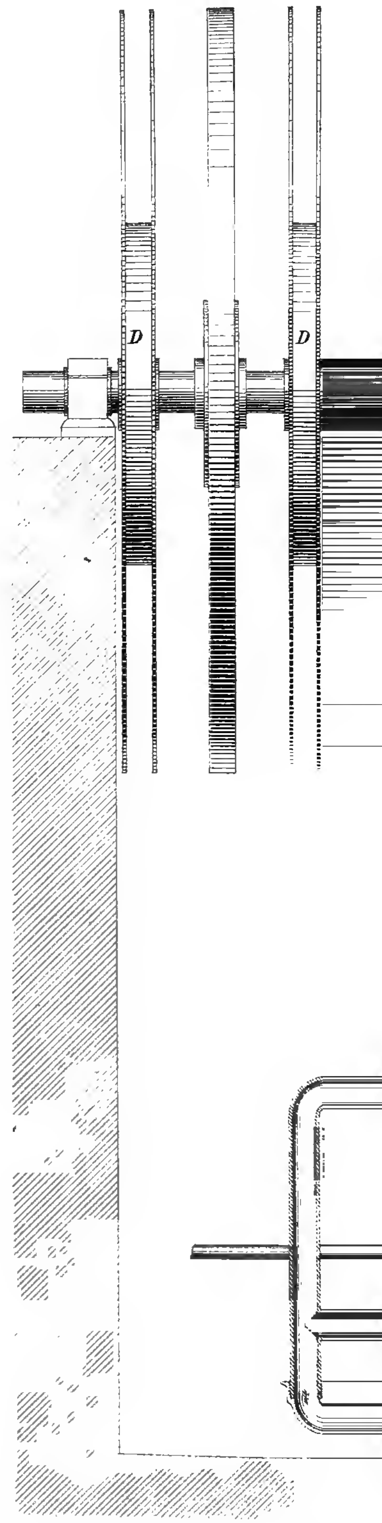
WINDING ENGINES

Fig. 475.





S C

INCHES 12 6 0 1 2 3 4 5 10 15 20

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VERTICAL — DIRECT ACTING

Fig. 476.

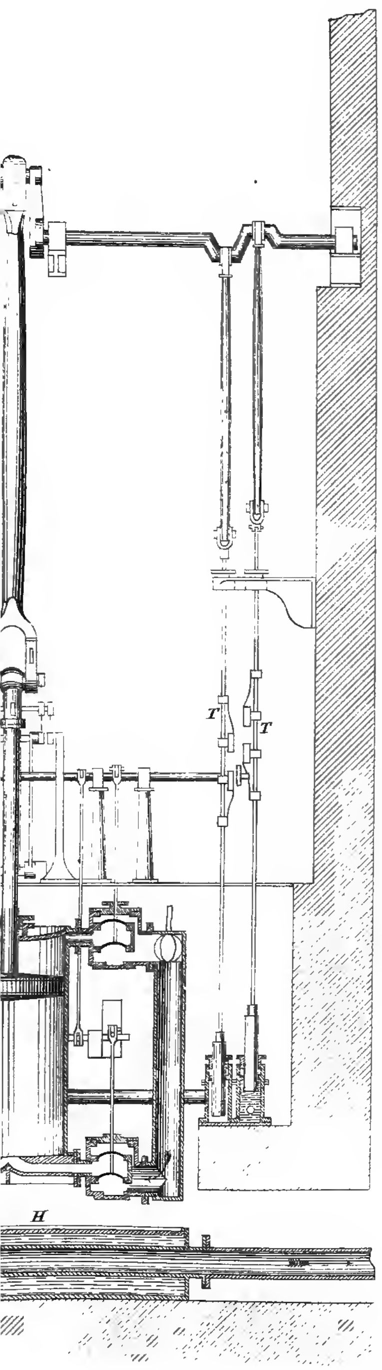
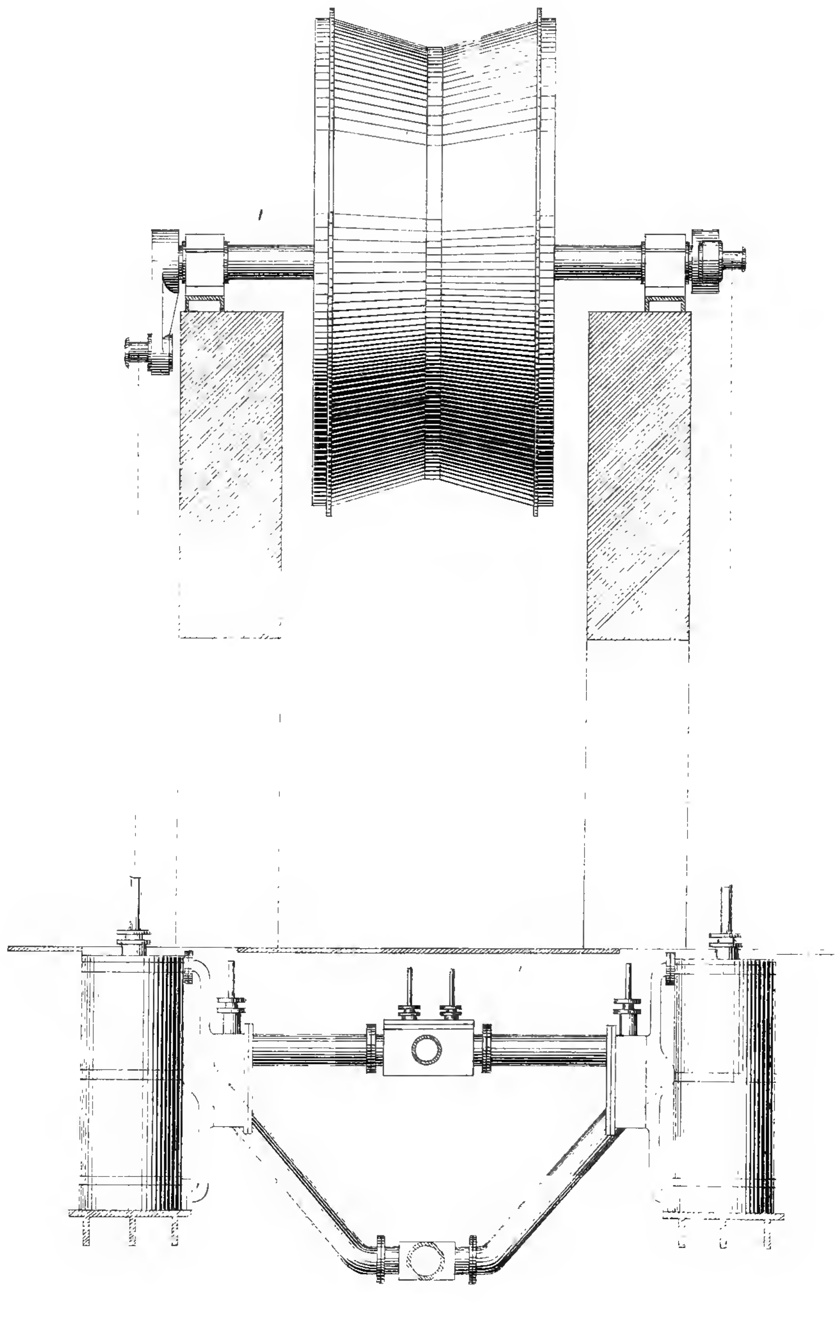


Fig. 477.



30 35 40 45 50 FEET

G.G. ANDRE

WINDING ENGINES

Fig 478.

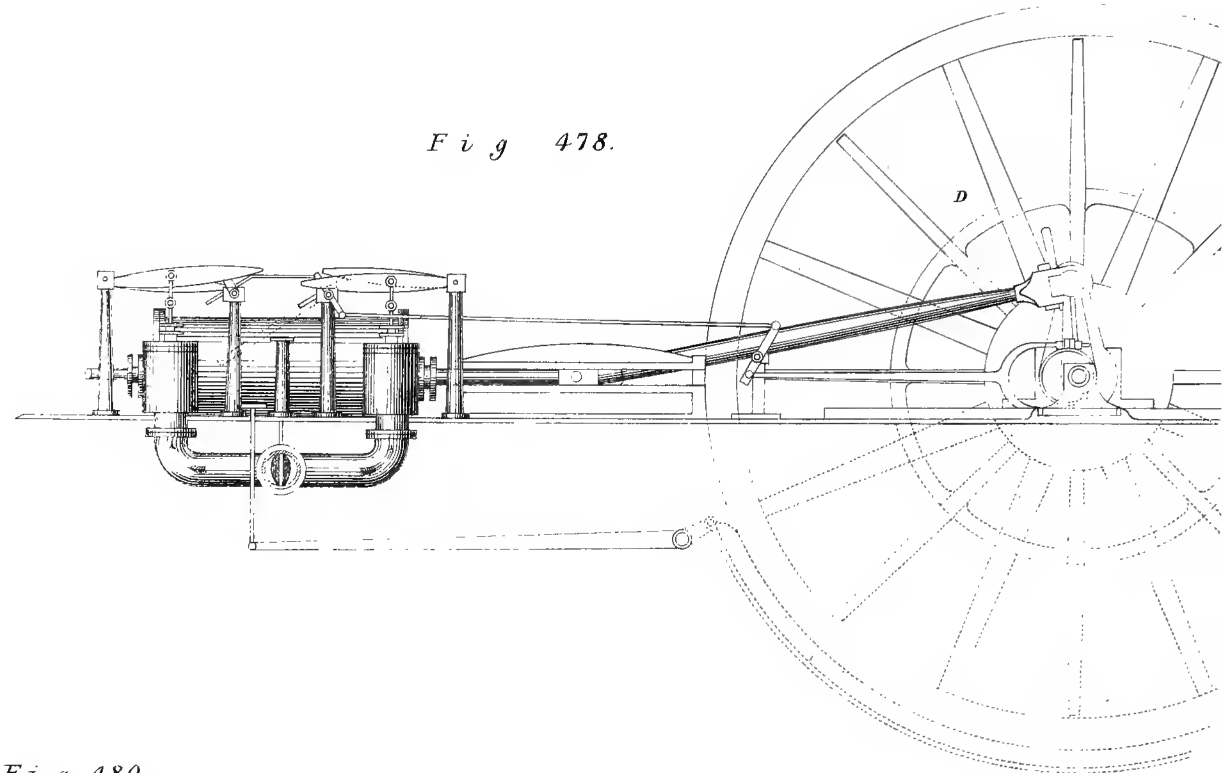


Fig. 480.

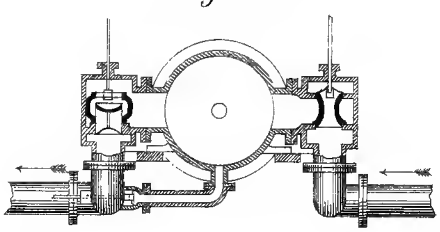
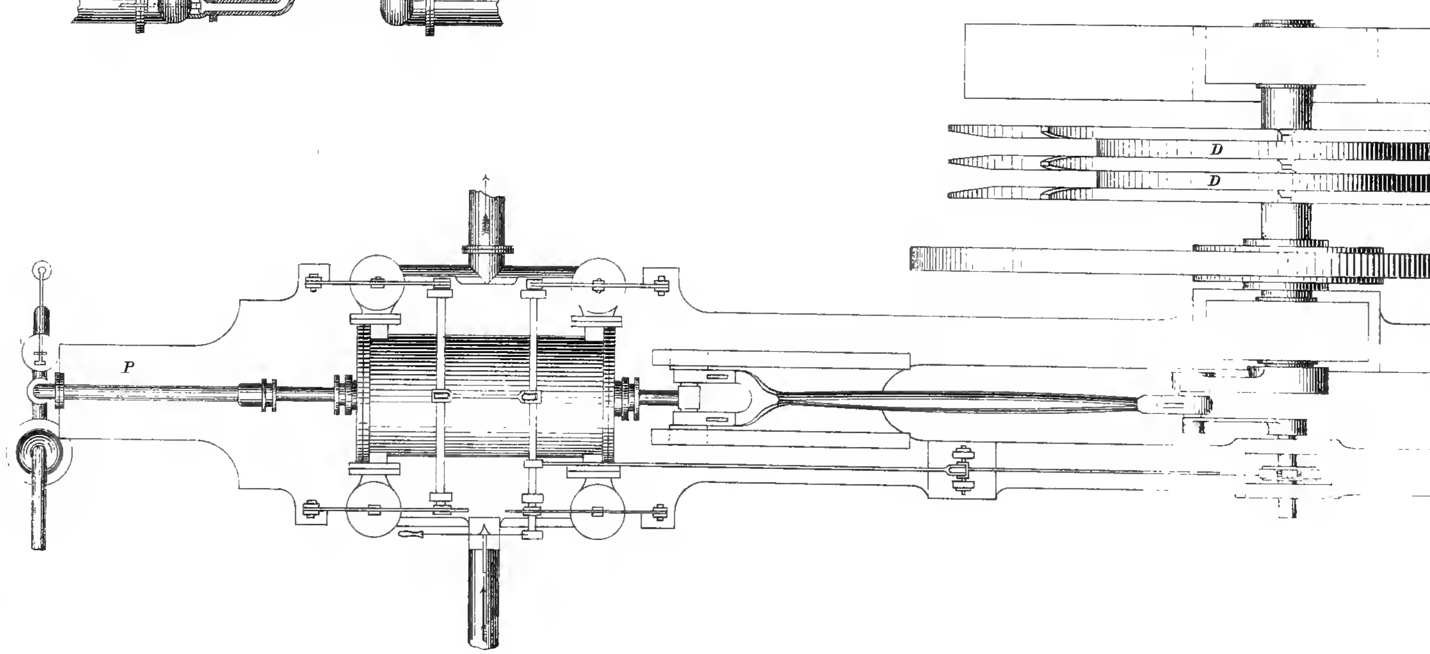


Fig. 479.



FIGS 478 _ 480.

INCHES 12 6 0 1 2 3 4 5 10 15 20 24 FEET

S C

ORIZONTAL — DIRECT ACTING.

Fig. 481

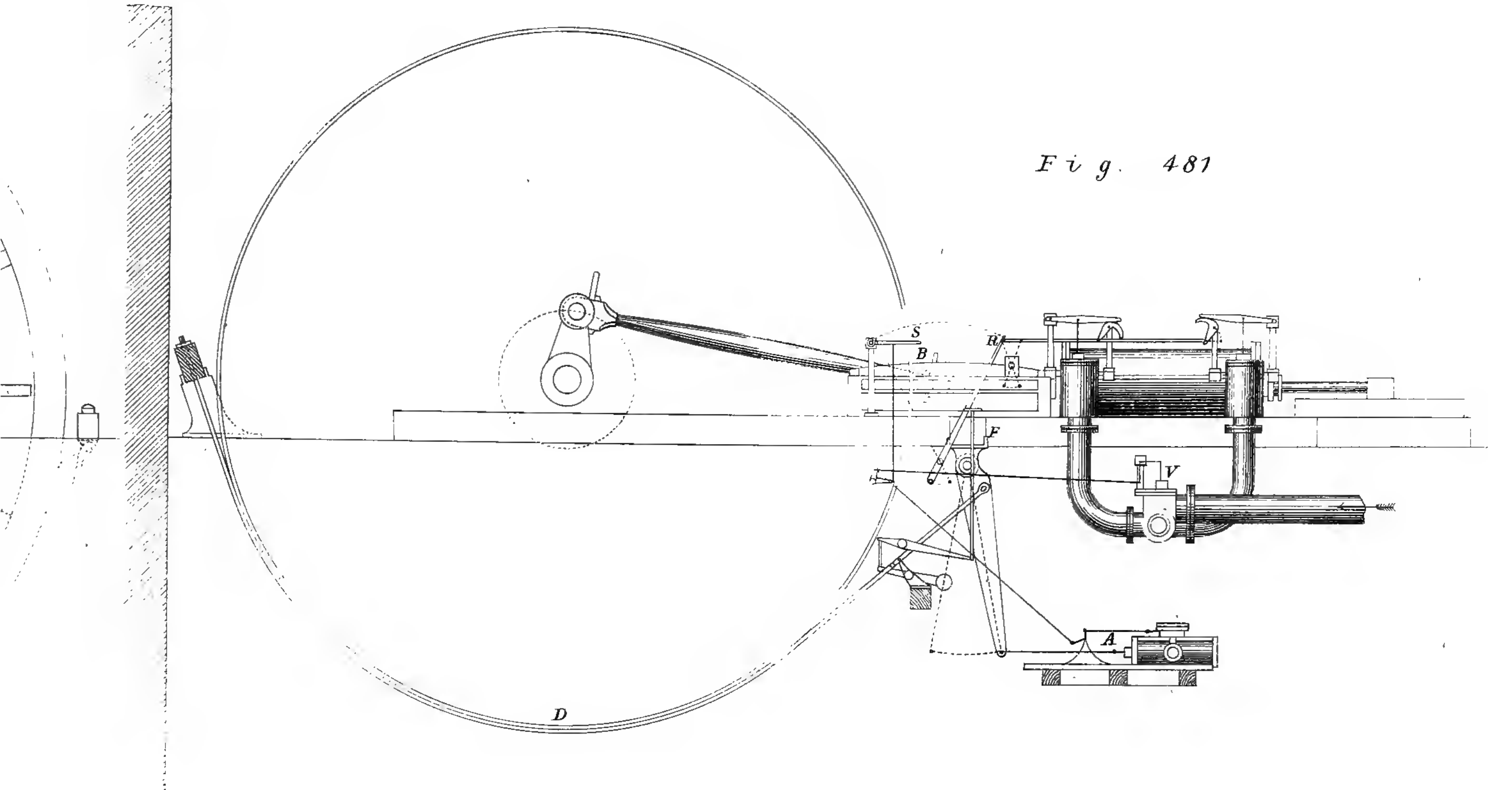
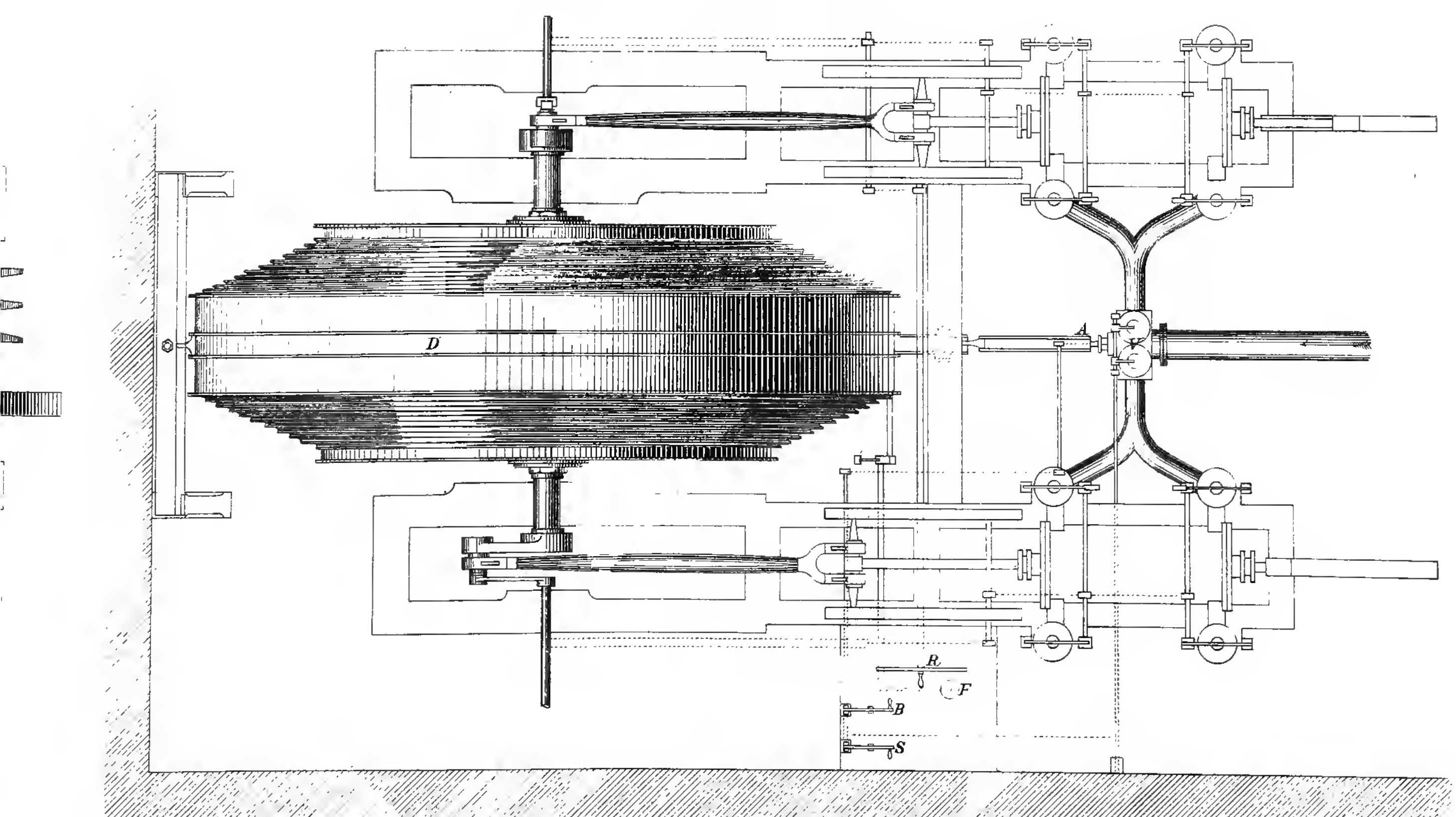


Fig 482.



E S

FIGS 481_482.

INCHES 12 6 0 1 2 3 4 5 10 15 20 25 30 35 40 FEET

G.G.ANDRÉ

ewYork

FRICTION GEARING AND WINDING INDICATOR.

Fig. 483.

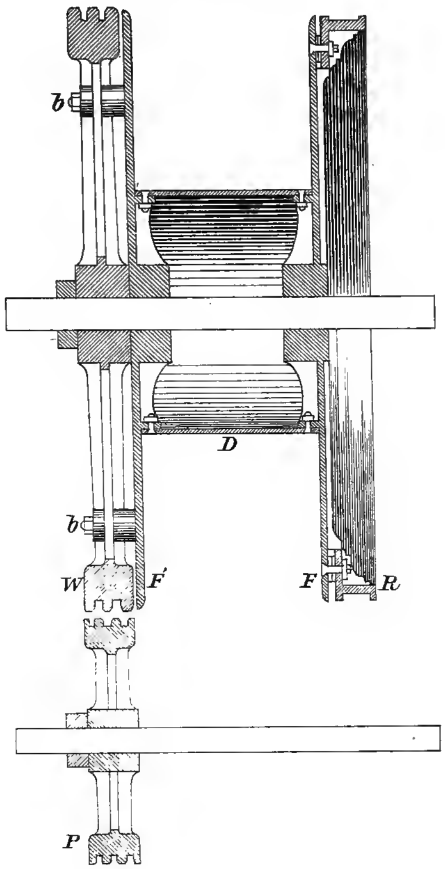


Fig 489.

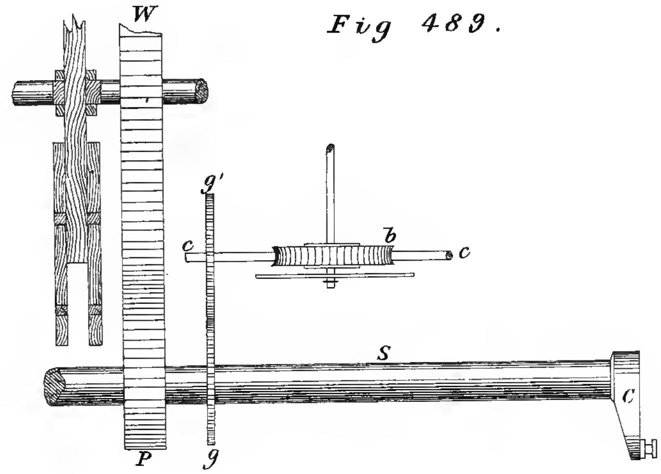


Fig 490.

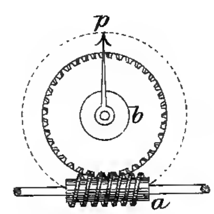


Fig. 484.

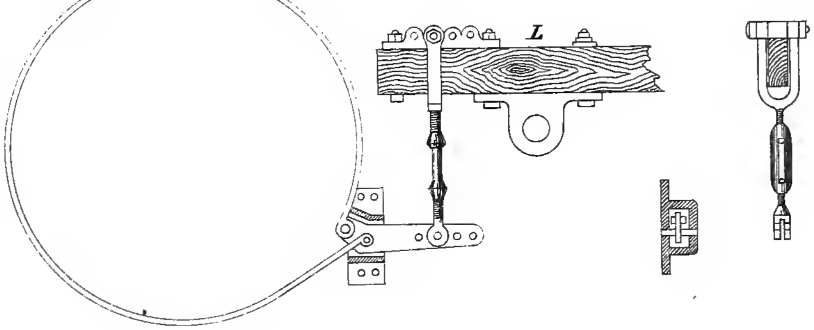
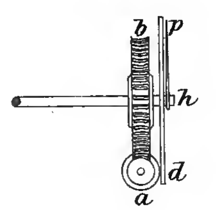


Fig. 491.



S C A L E S

FIGS 483 – 489 – 491.

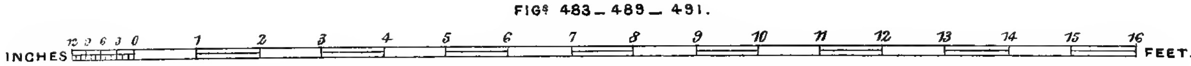
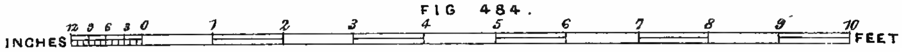


FIG 484.



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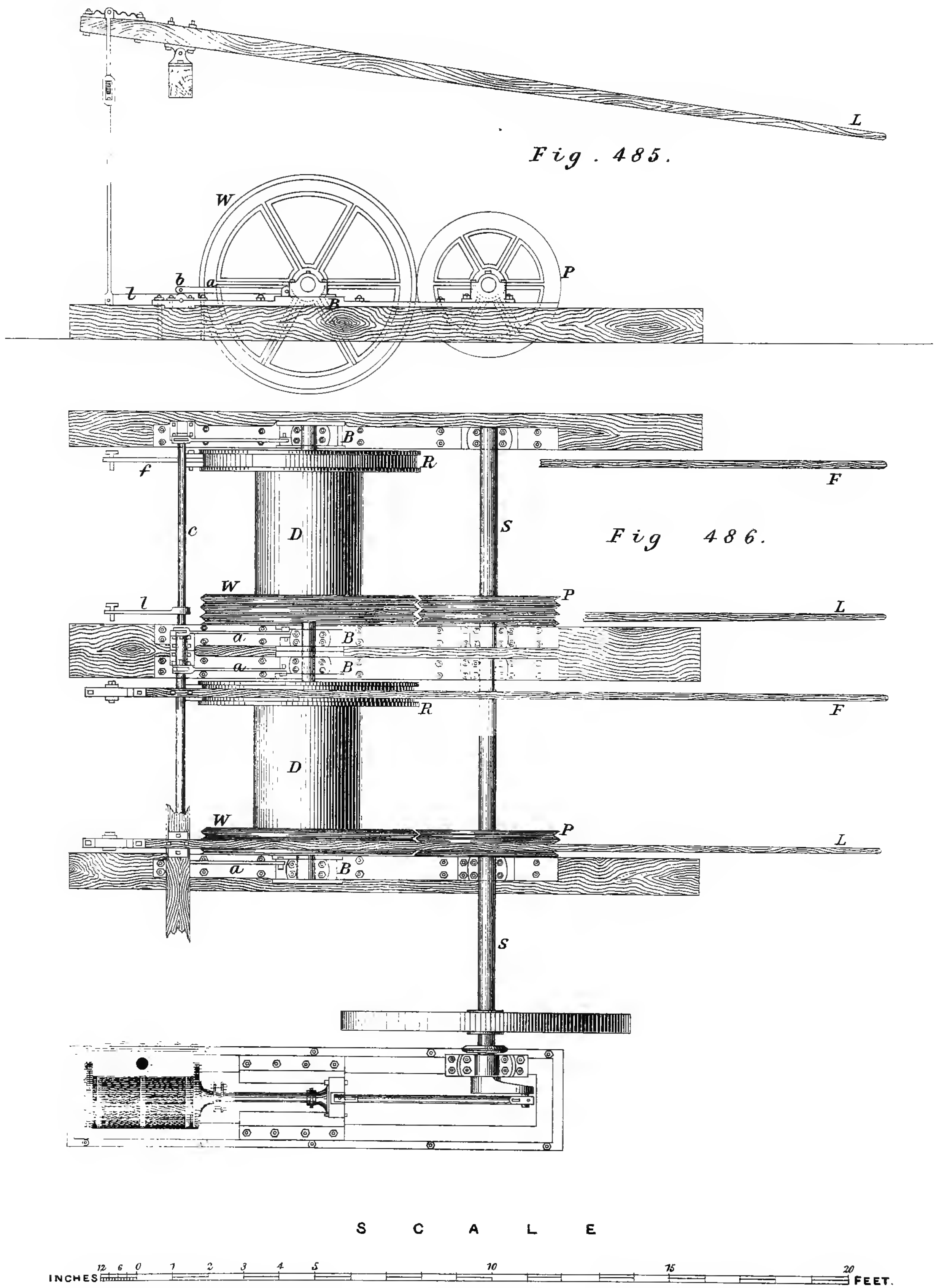
WINDING ENGINES — FRICTION GEARING

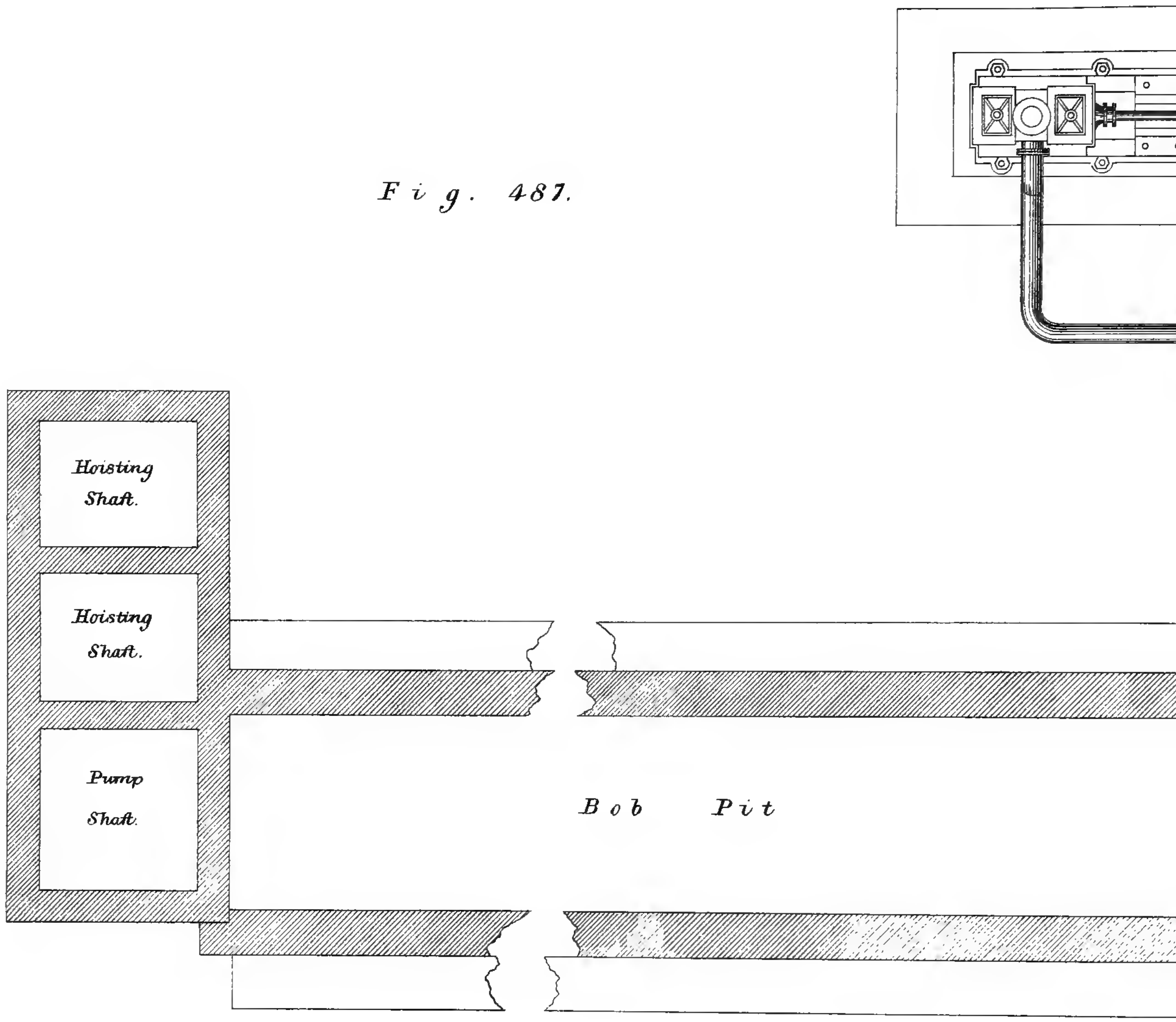


G. G. ANDRÉ.

E & F. N. Spon. London & New York

W I N D I N G   E N

Fig. 487.



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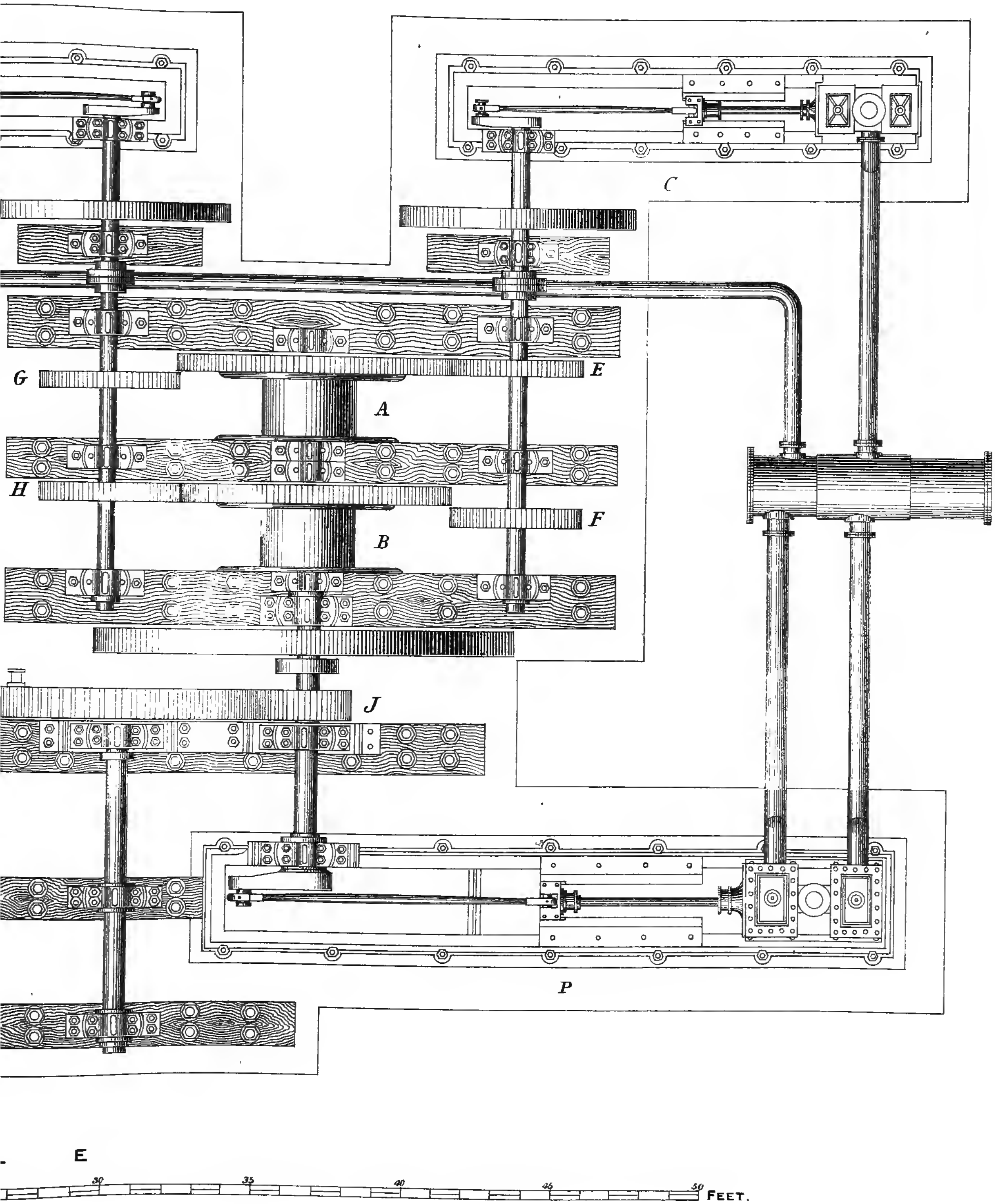
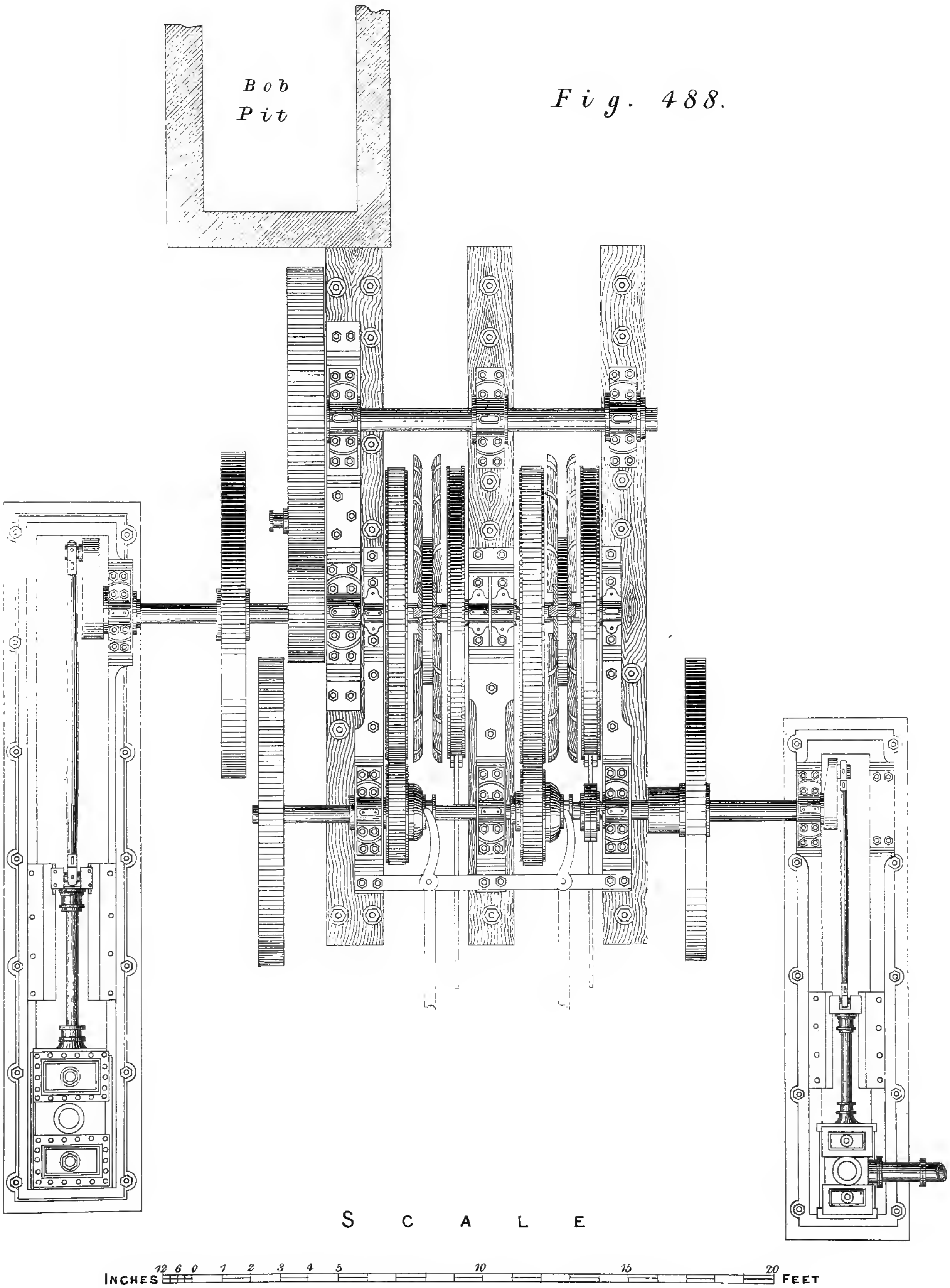
N E S. —— COG GEARING



y York.

G. G. ANDRÉ.

WINDING ENGINES — COG GEARING.



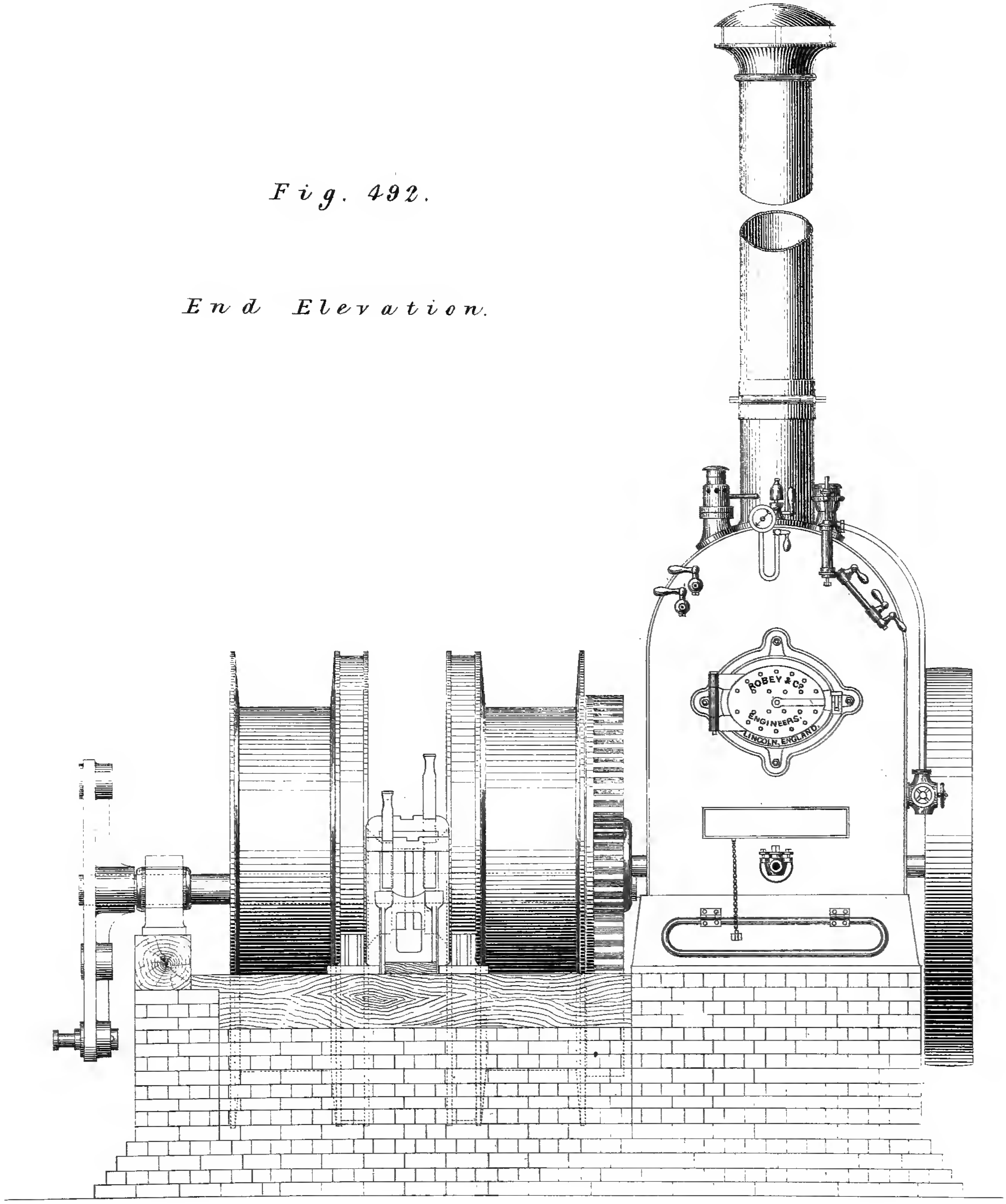
G. G. André.

E & F N Spon, London & New York

WINDING ENGINES — ROBEY'S PATENT.

Fig. 492.

End Elevation.



SCALE

INCHES 12 9 6 3 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 FEET.

G. G. ANDRÉ.

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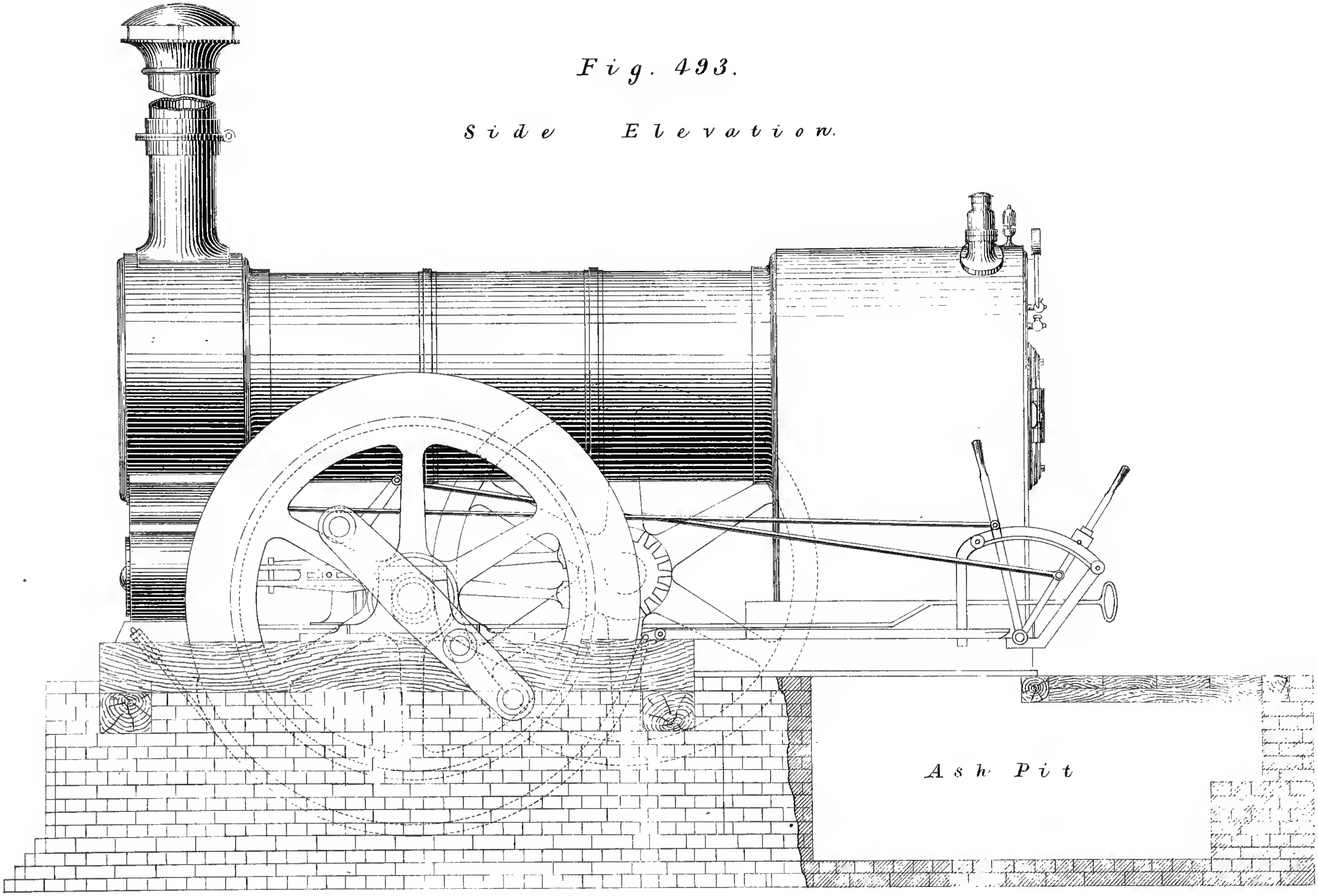
WINDING ENGINES — ROBEY'S PATENT

Fig. 493.

Side Elevation.



SCALE

INCHES 12 9 6 3 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 FEET.

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MAN–ENGINES DRAINING BUCK

Fig. 494.

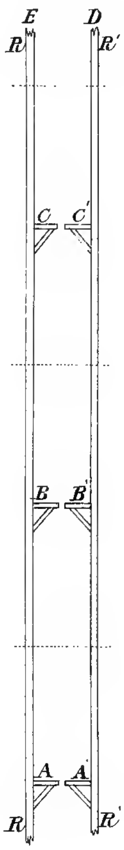


Fig. 495.

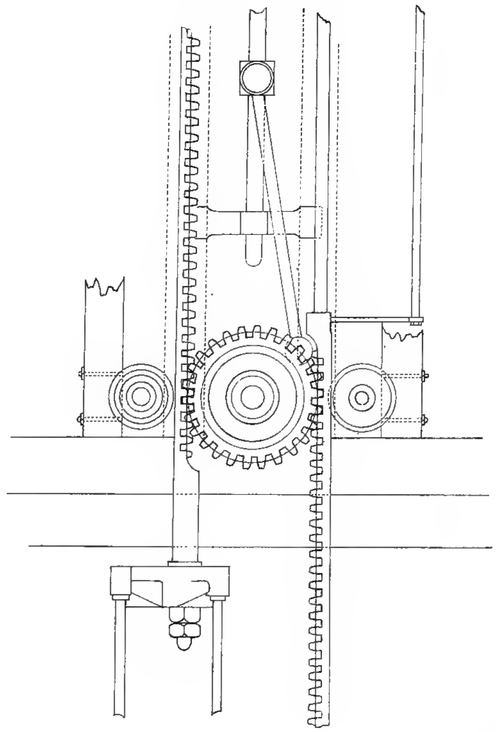


Fig. 496.

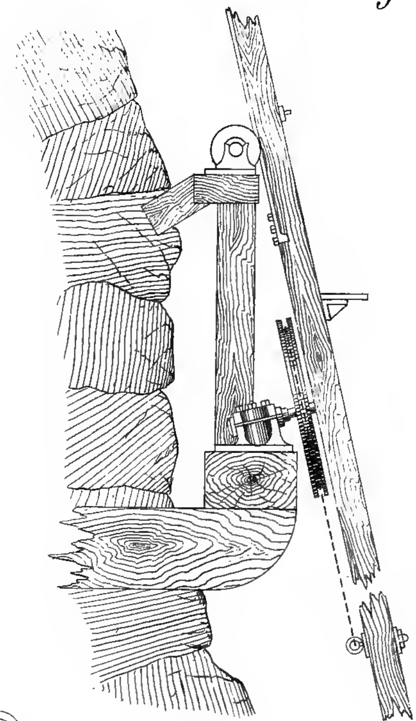


Fig. 497.

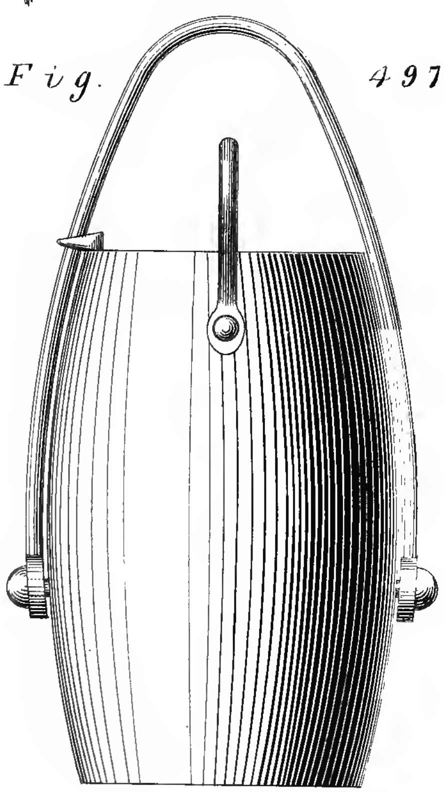


Fig. 498.

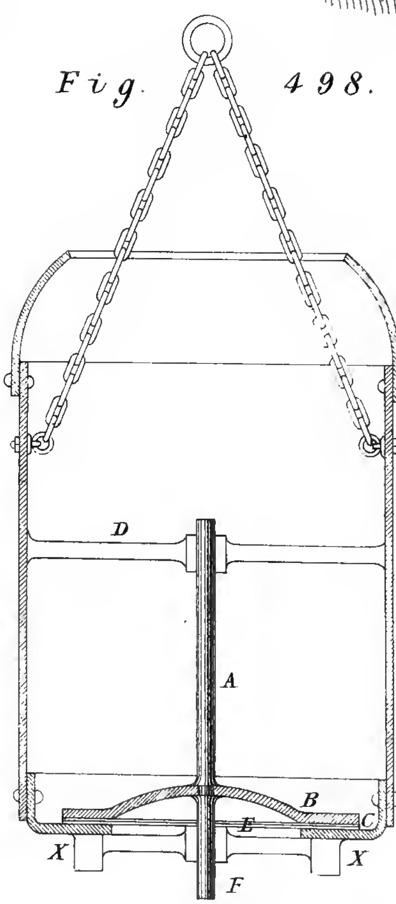
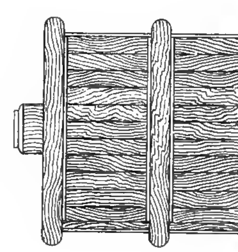


Fig. 5



INCHES 12 6 0 1 2 3 4 5 6

BALANCE BOB V. BOB AND VIBRATING RODS.

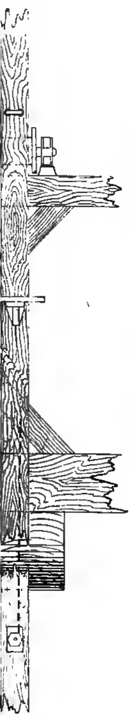


Fig. 499.

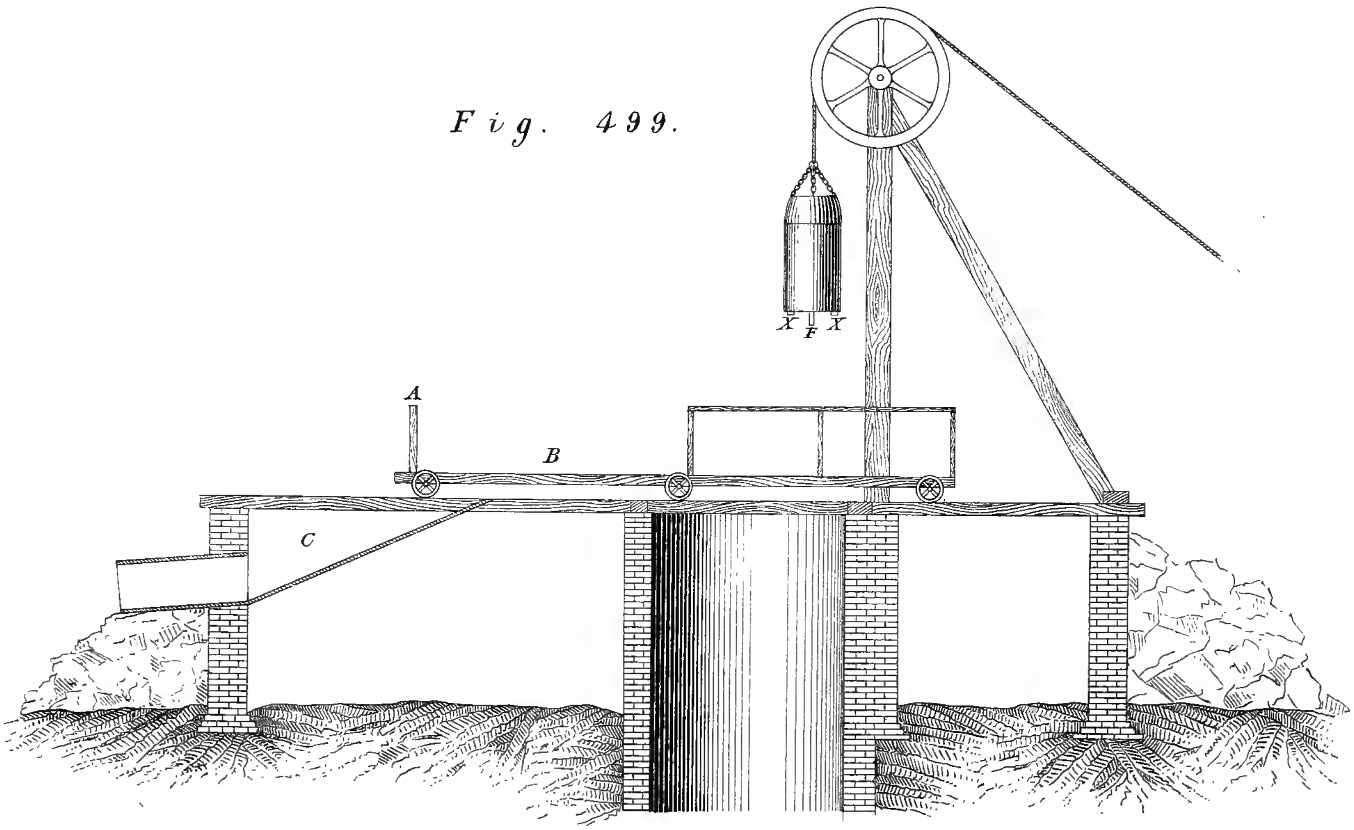
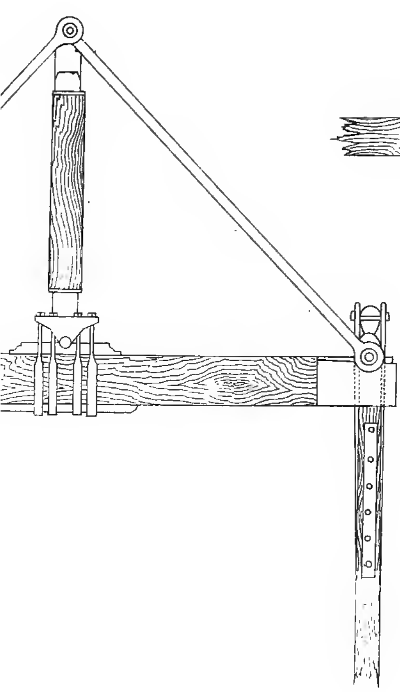


Fig. 502.



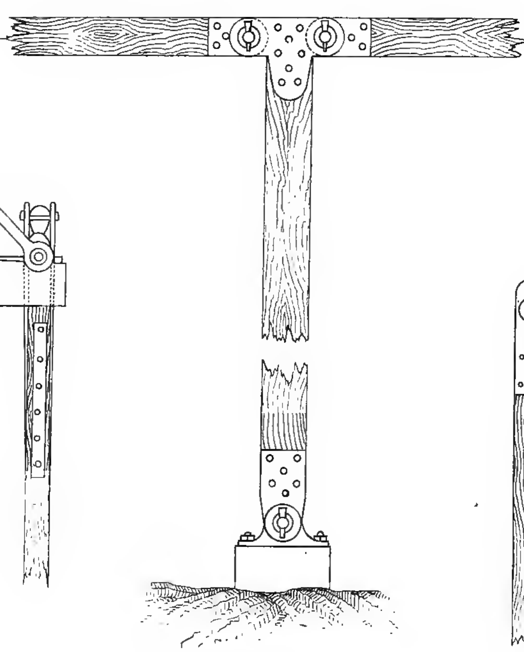
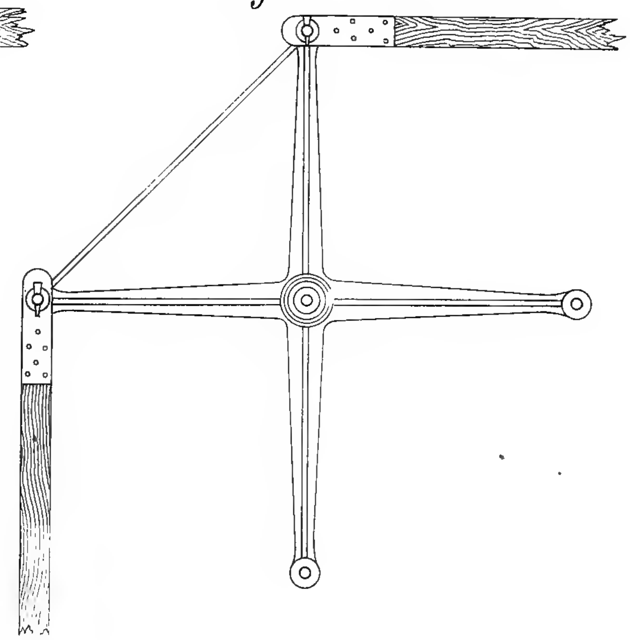


Fig. 501.



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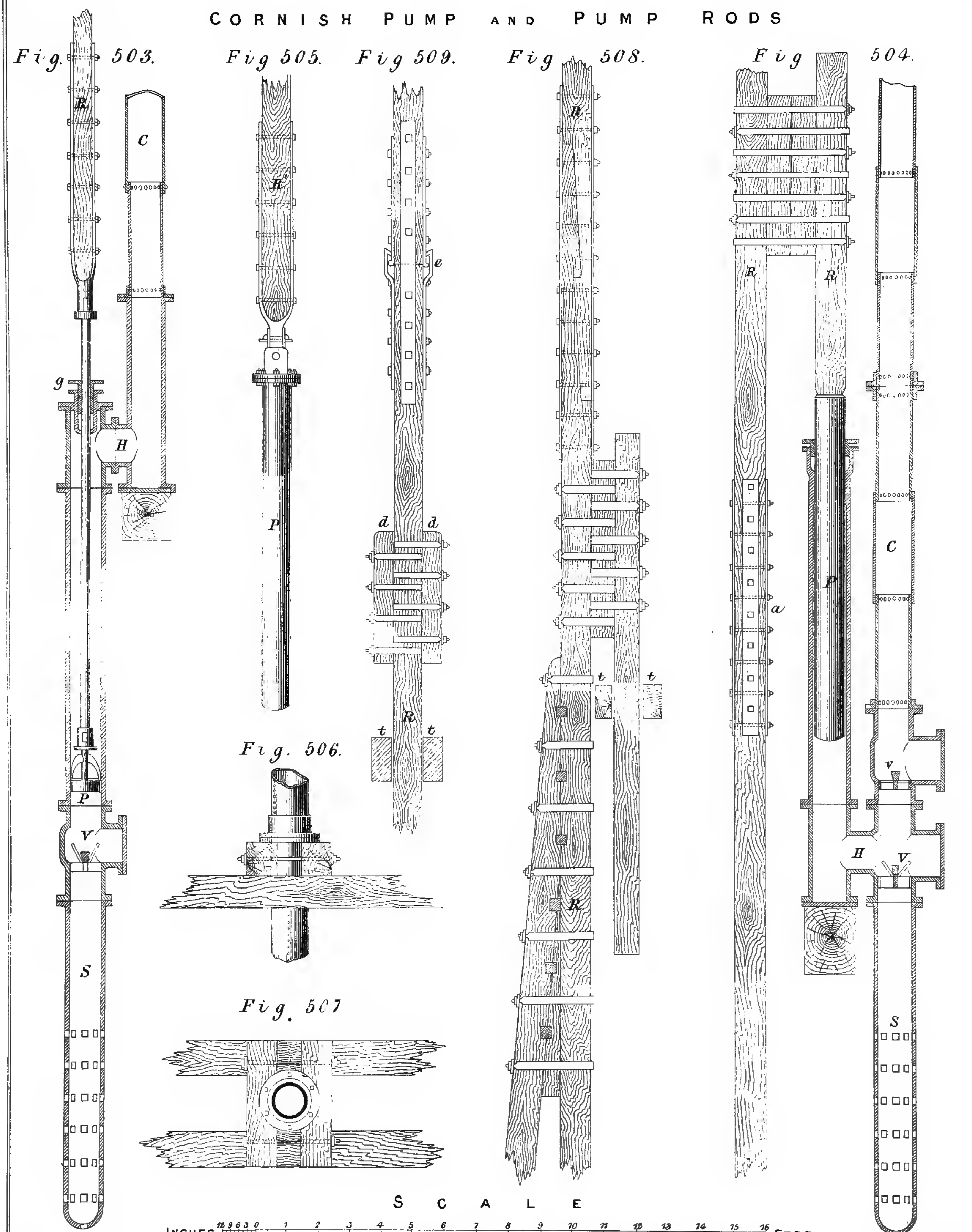
CORNISH PUMP AND PUMP RODS



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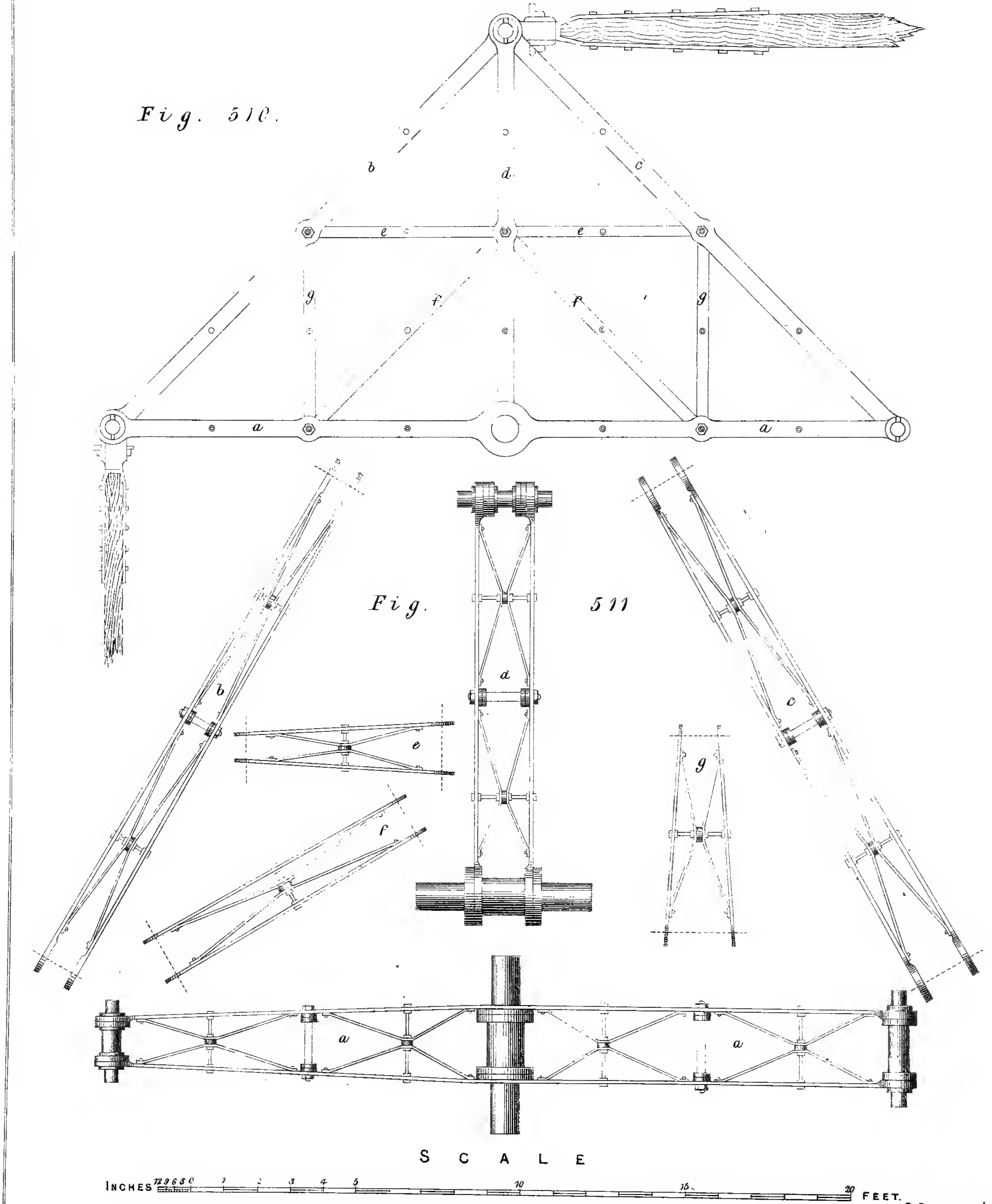
CORNISH PUMP — WROUGHT IRON BOB.



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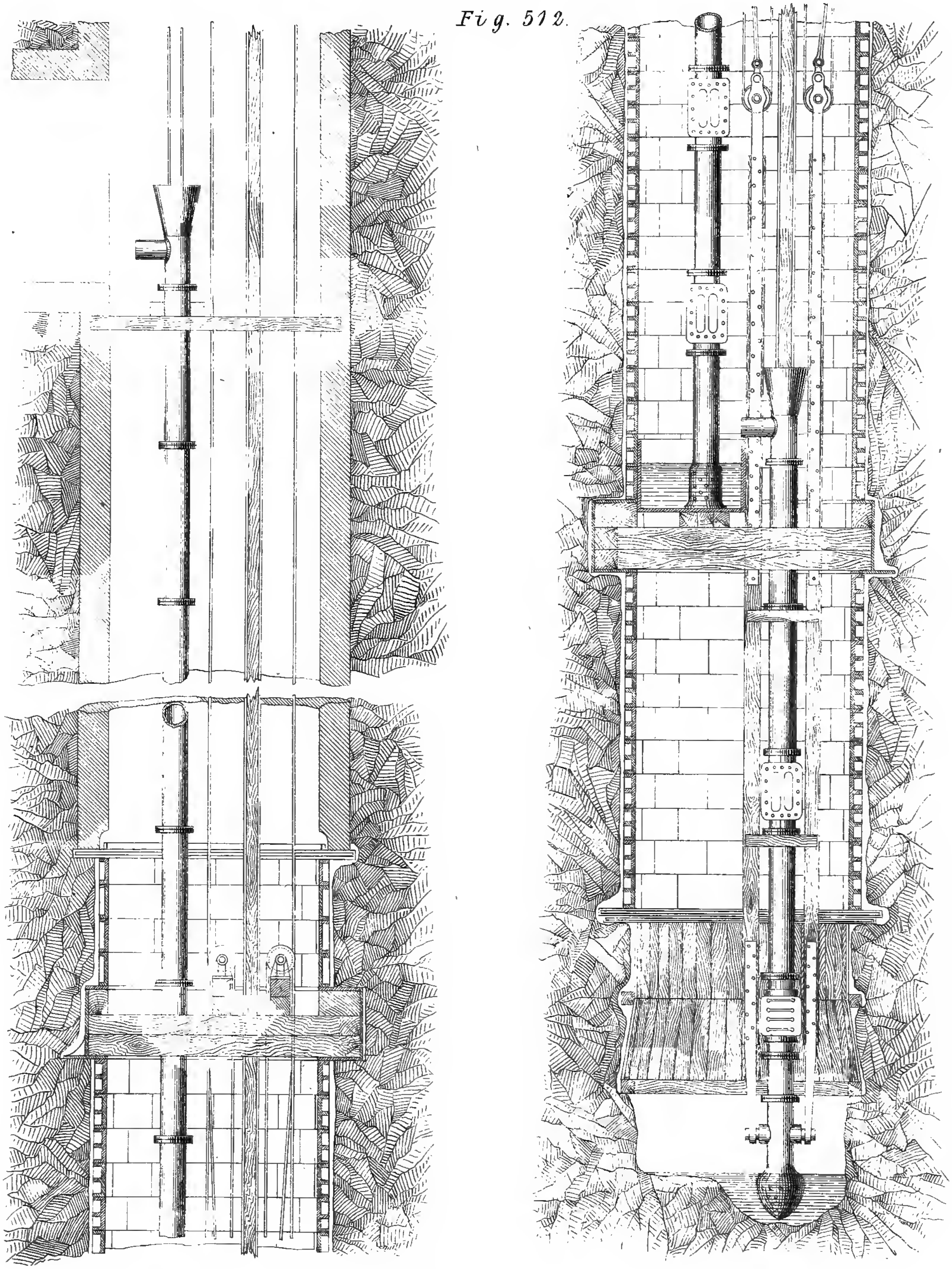
CORNISH PUMP — SUSPENDED BOTTOM SET — SEGEBERG.

Fig. 512.



SCALE

INCHES 12 6 0 1 2 3 4 5 10 15 20 25 30 35 40 FEET.

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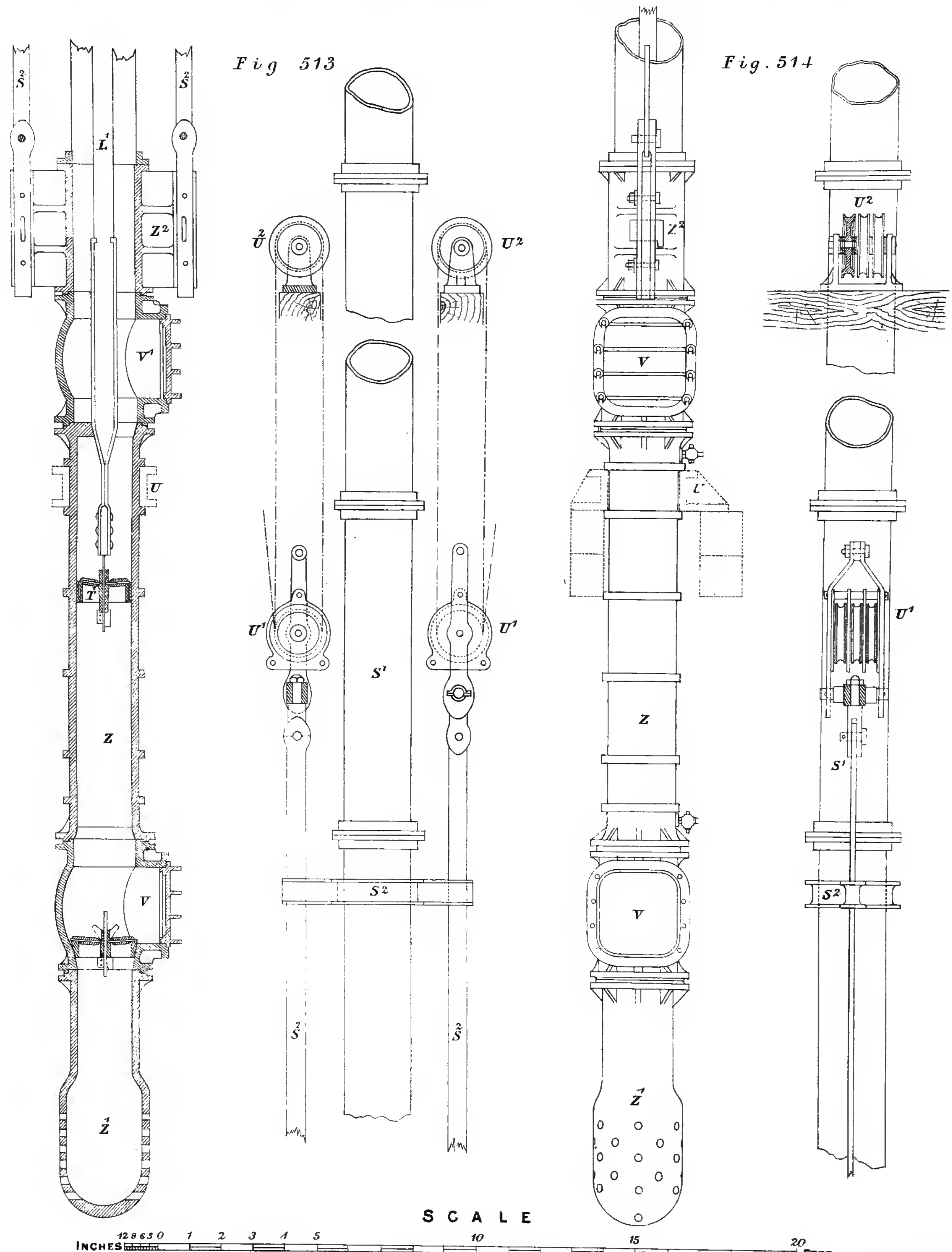
CORNISH PUMP — SUSPENDED LIFTING SET — SEGEBERG.



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CORNISH PUMP — FORCING SET — SEGEBERG — 28 IN. FORCIN

Fig. 515.

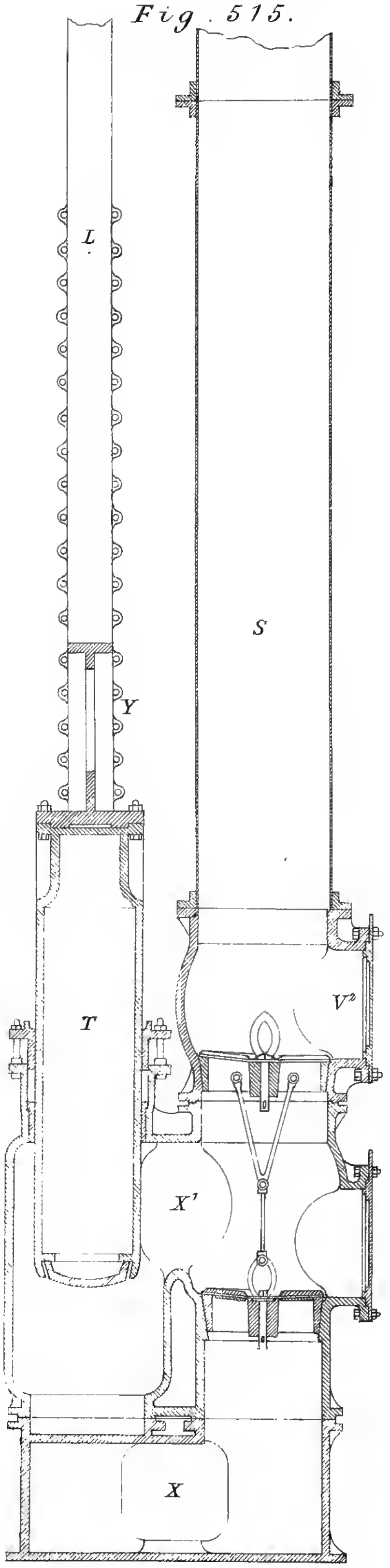
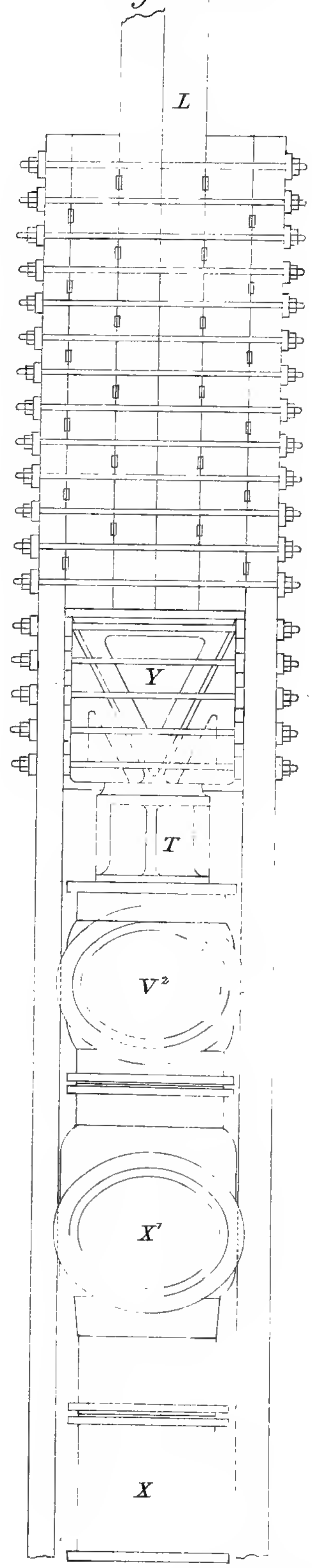
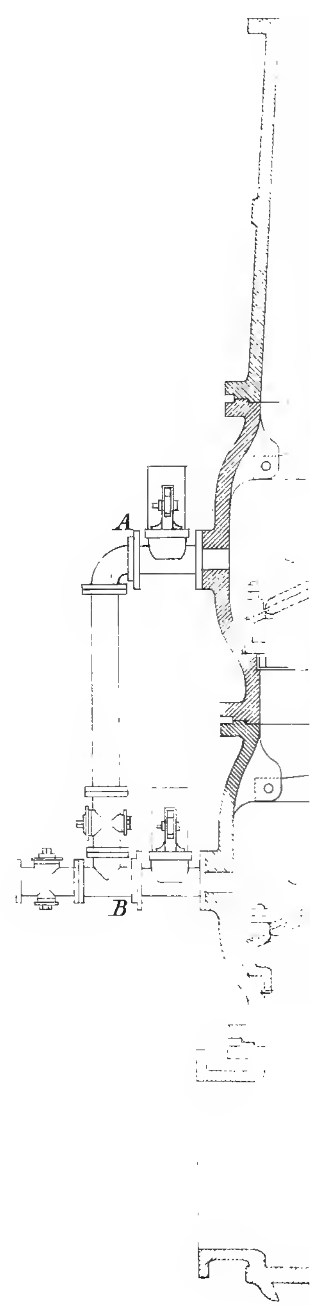


Fig. 516.



Fig



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FIGS 515-516-519.

INCHES 12 6 0 1 2 3 4 5 10 15 20 FEET.

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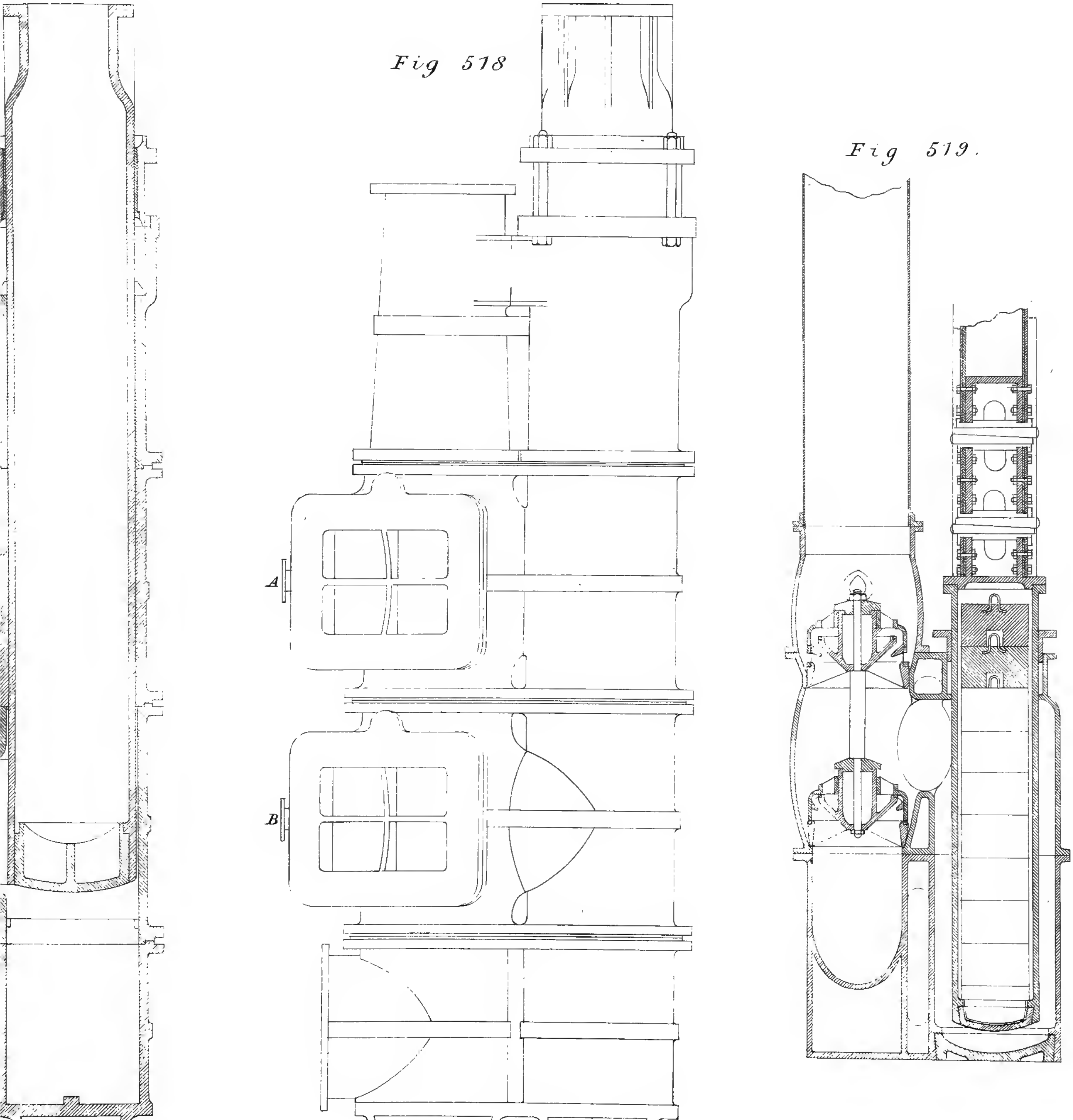
SAARBRÜCKEN — FORCING SET, WEIGHTED PLUNGER — RUDERSDORF



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FIGS – 517 – 518.

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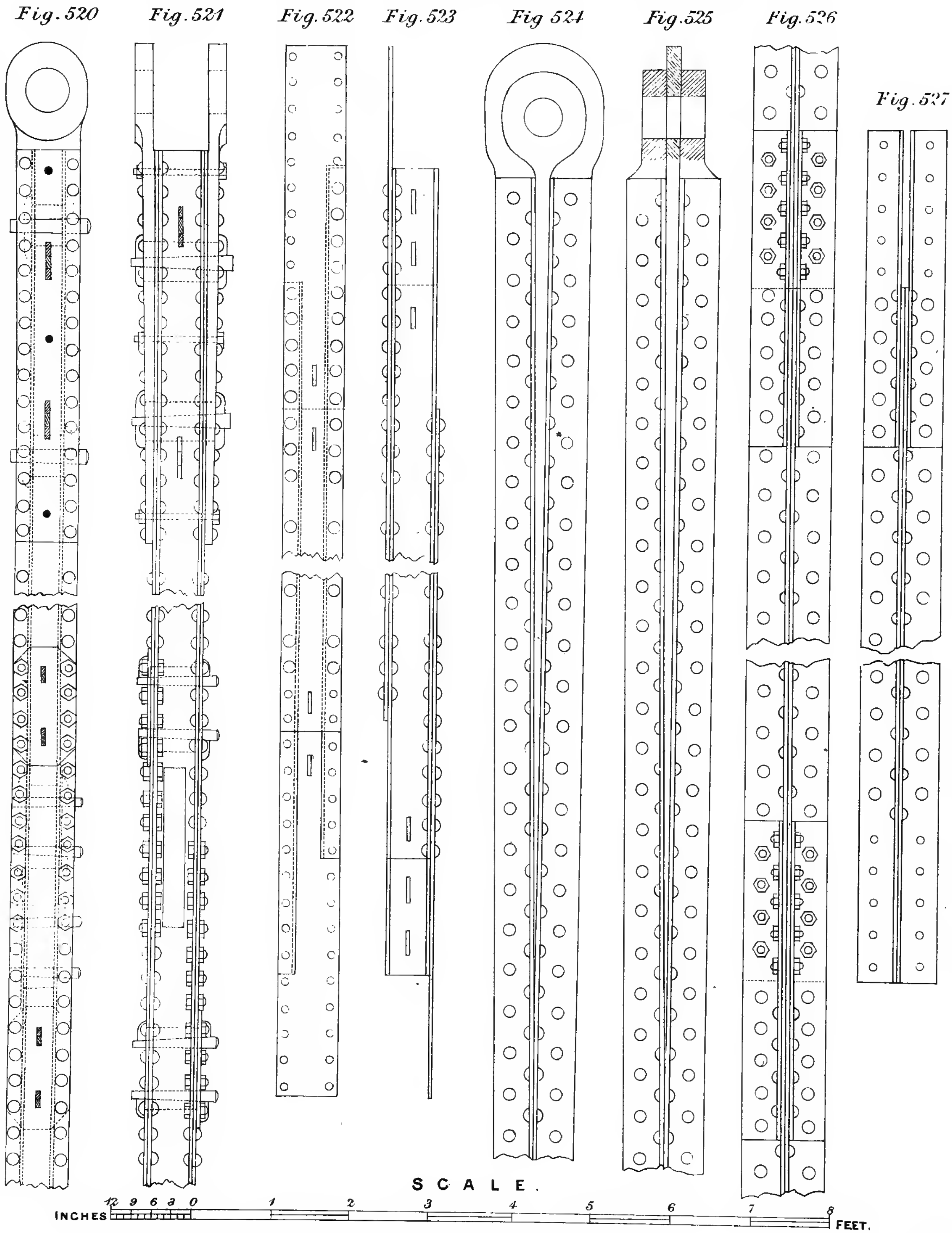
CORNISH PUMP WROUGHT IRON PUMP RODS.



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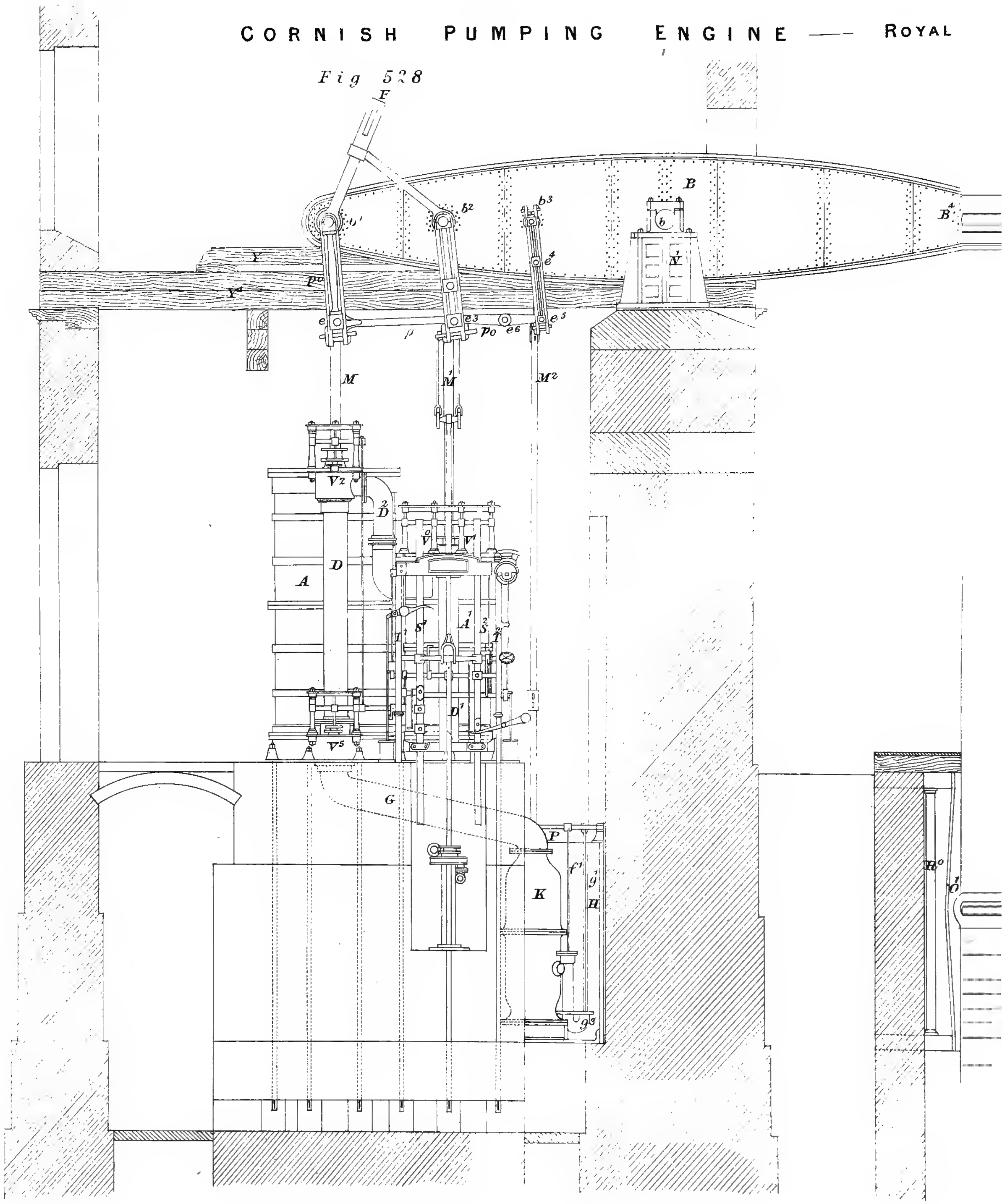
CORNISH PUMPING ENGINE — ROYAL

Fig 528



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INCHES 12 6 0 1 2 3 4 5 10 15 20

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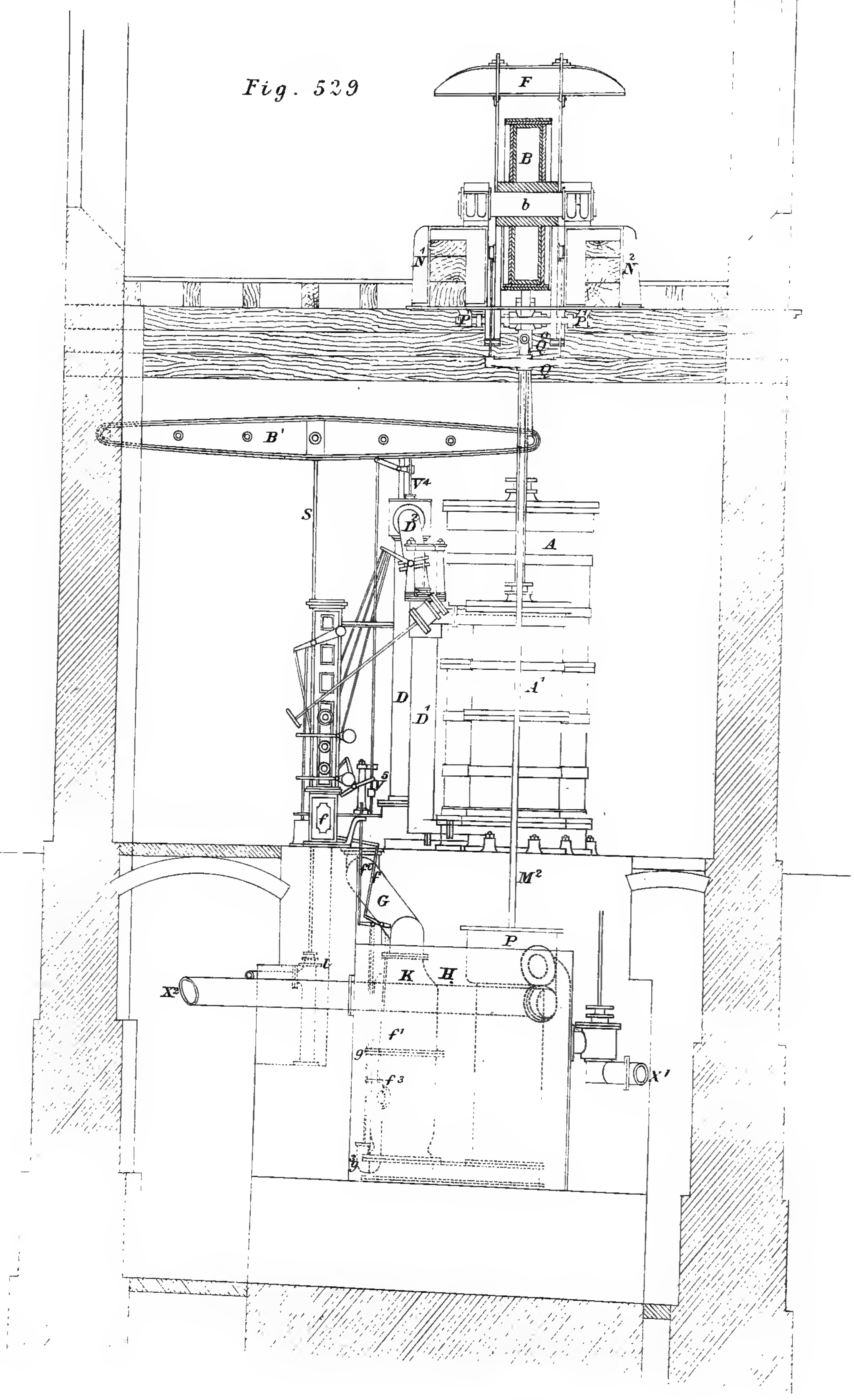
ERIES SAARBRÜCKEN —— *Side and Front Elevations.*



30 35 40 45 50 FEET.

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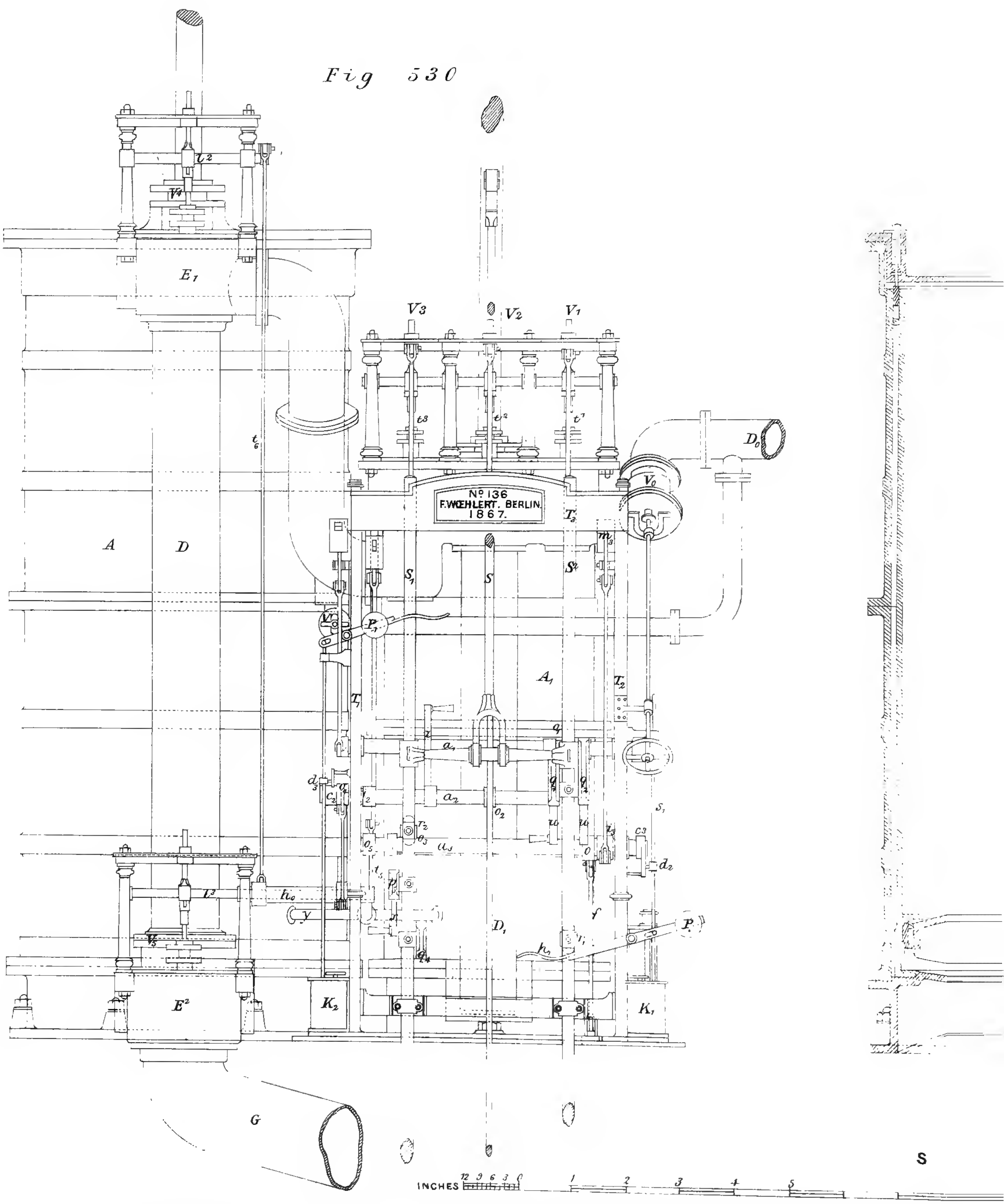
G.G. ANDRÉ.

CORNISH PUMPING ENGINE —— ROYAL CO

Fig 530



E & F

ES SAARBRÜCKEN —— *Details of Cylinders and Valve Gear.*

Fig 531.

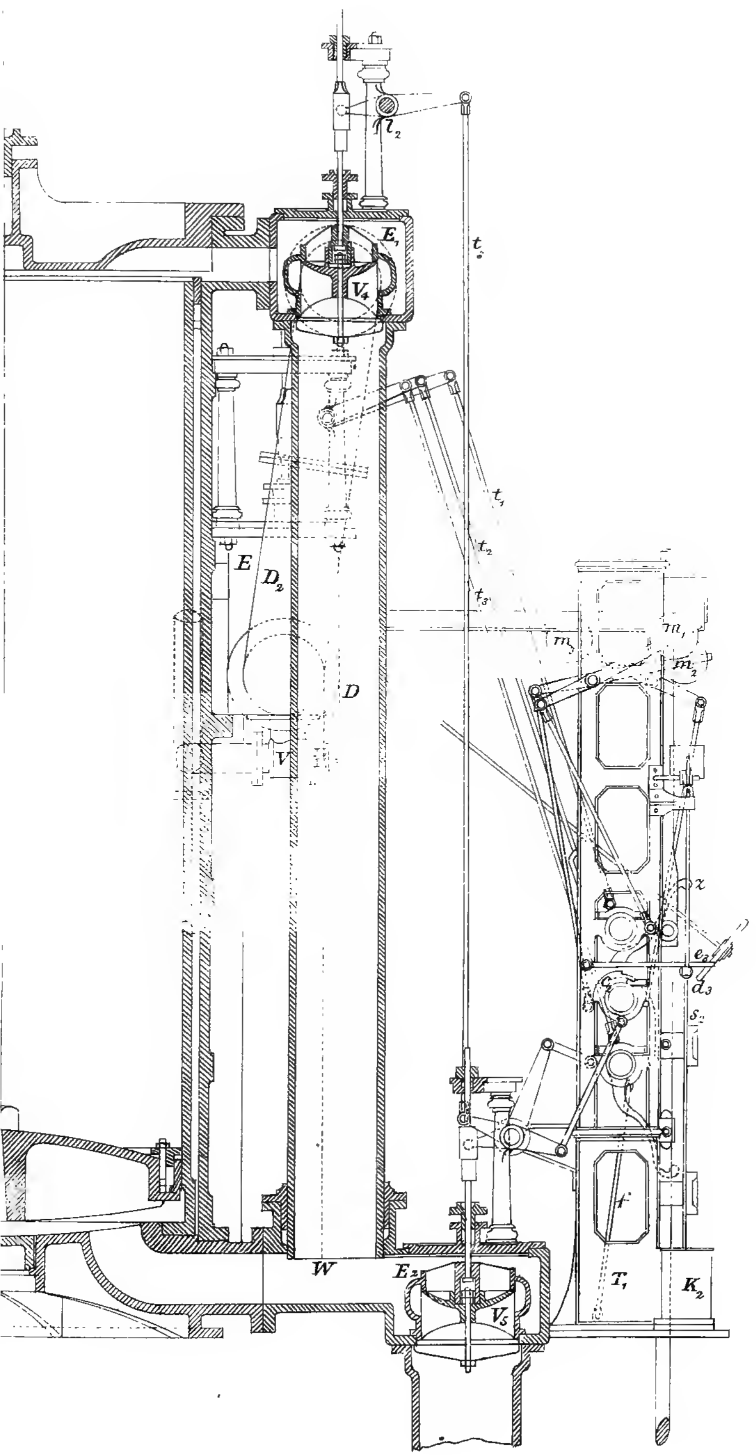
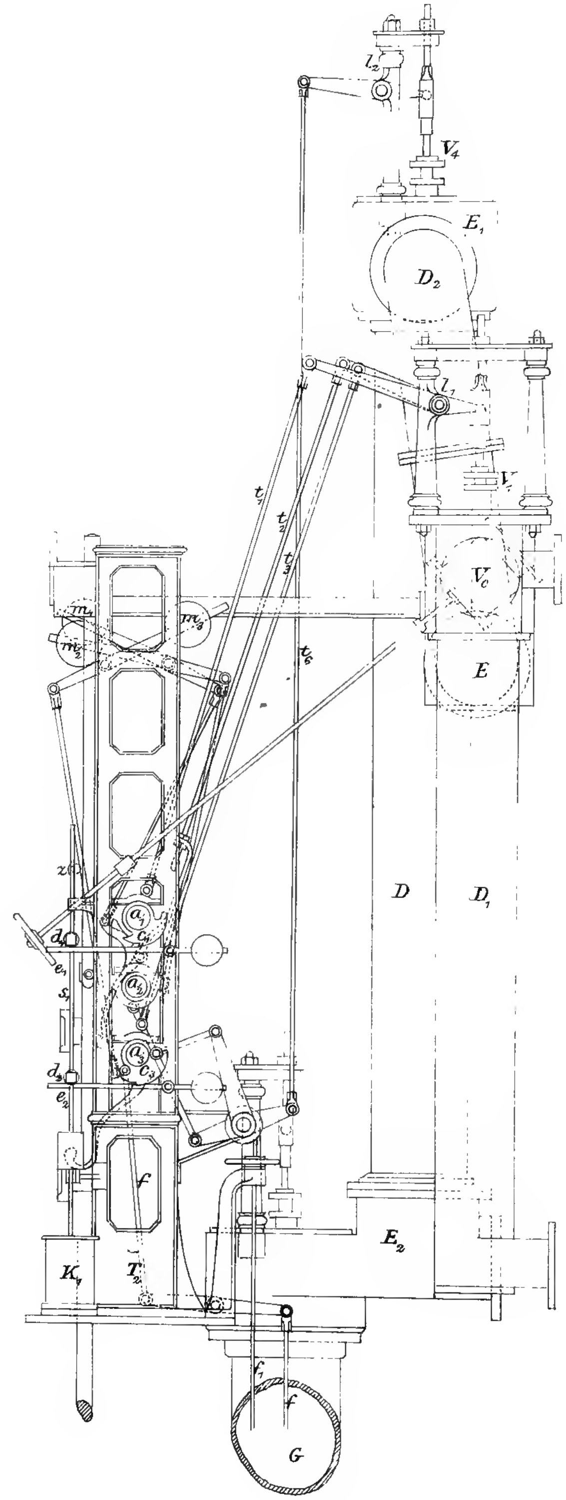


Fig 532.



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G.G. ANDRÉ.

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CORNISH PUMPING ENGINE —— ROYAL COL

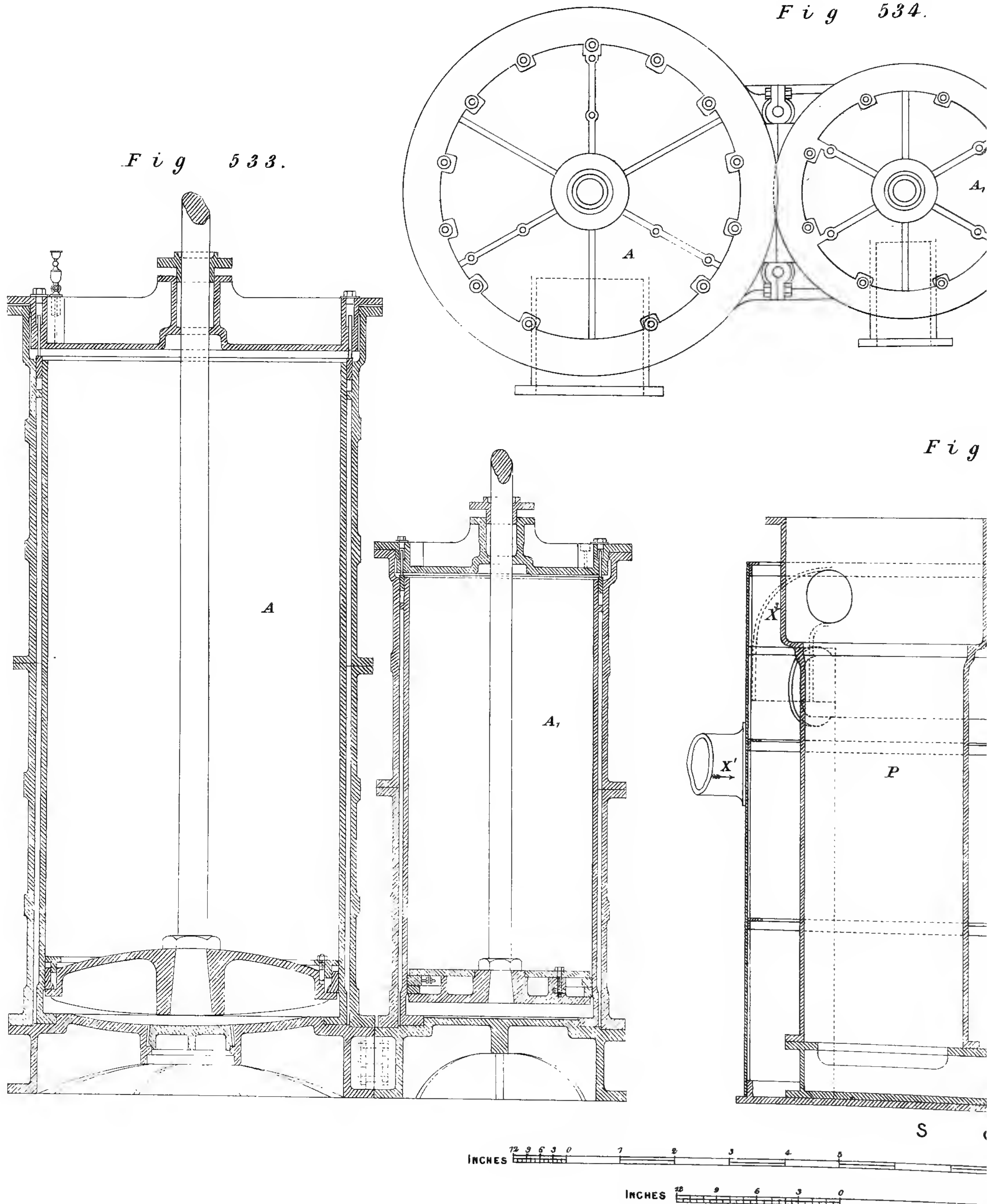

Fig 533.

Fig 534.

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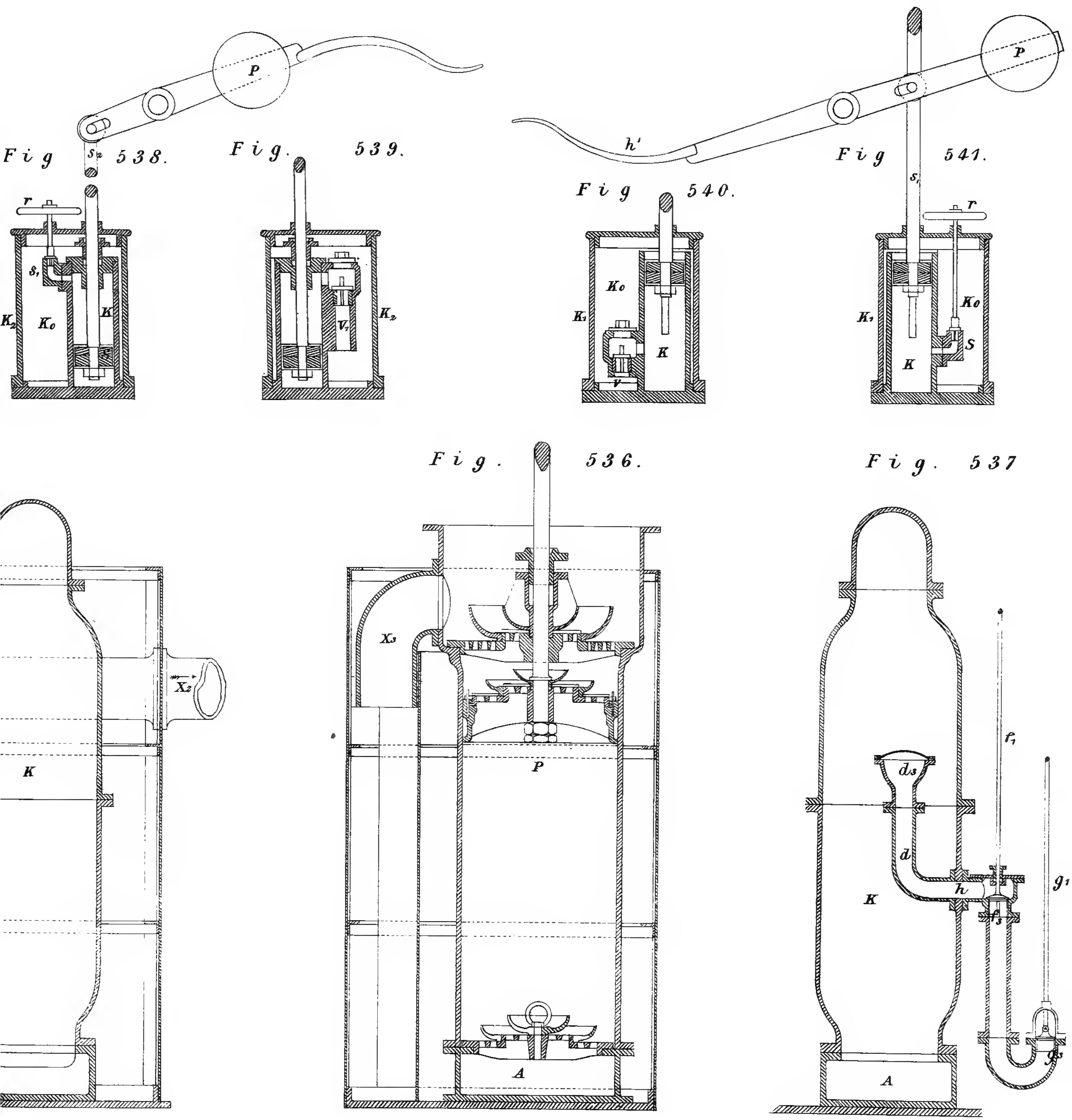
E & F

SAARBRÜCKEN — *Details of Cylinders, Air-Pump, Cataract, etc.*



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2 3 4 FEET

n & New York.

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Cornish Pumping Engine with Fly Wheel.

Fig 542.

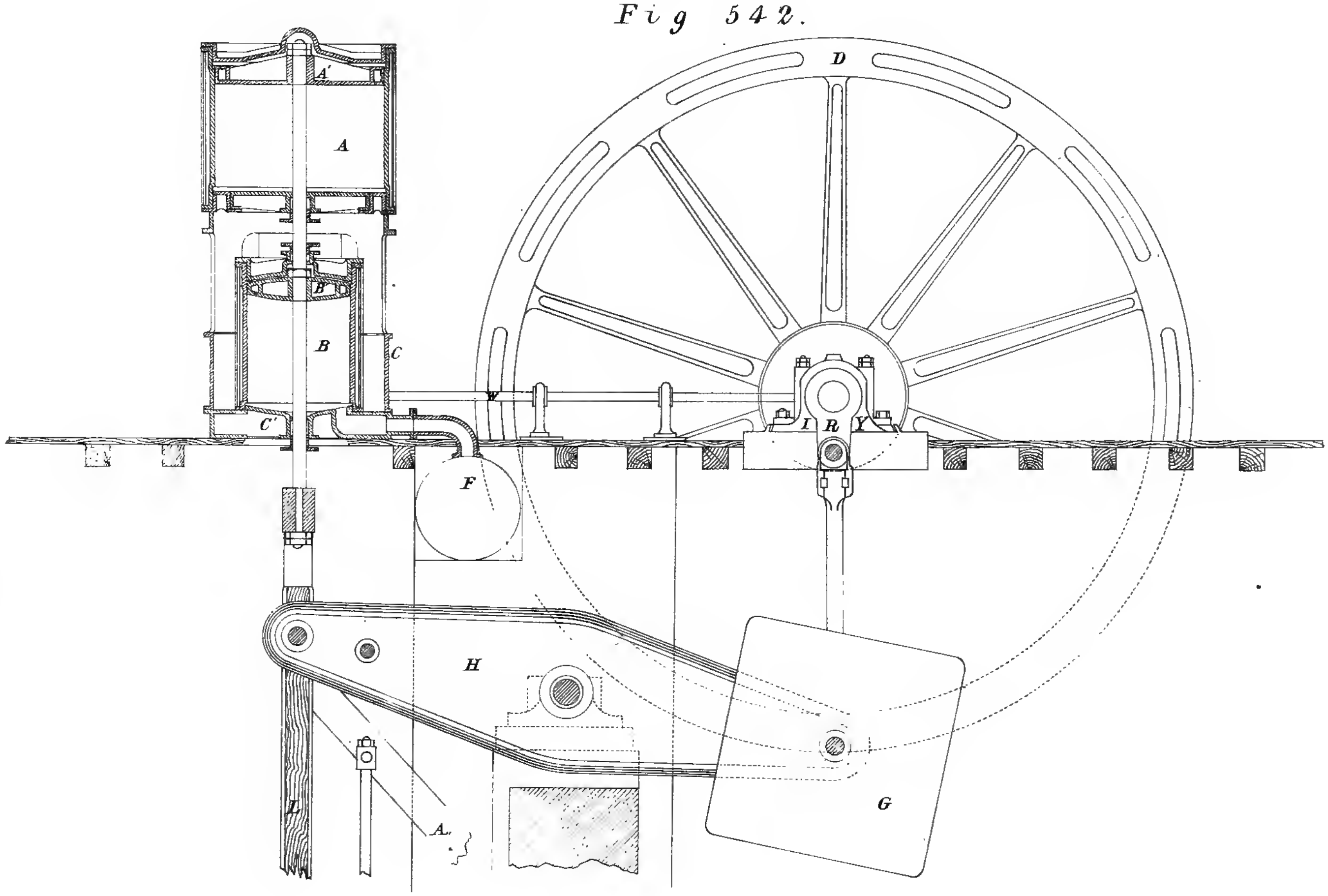
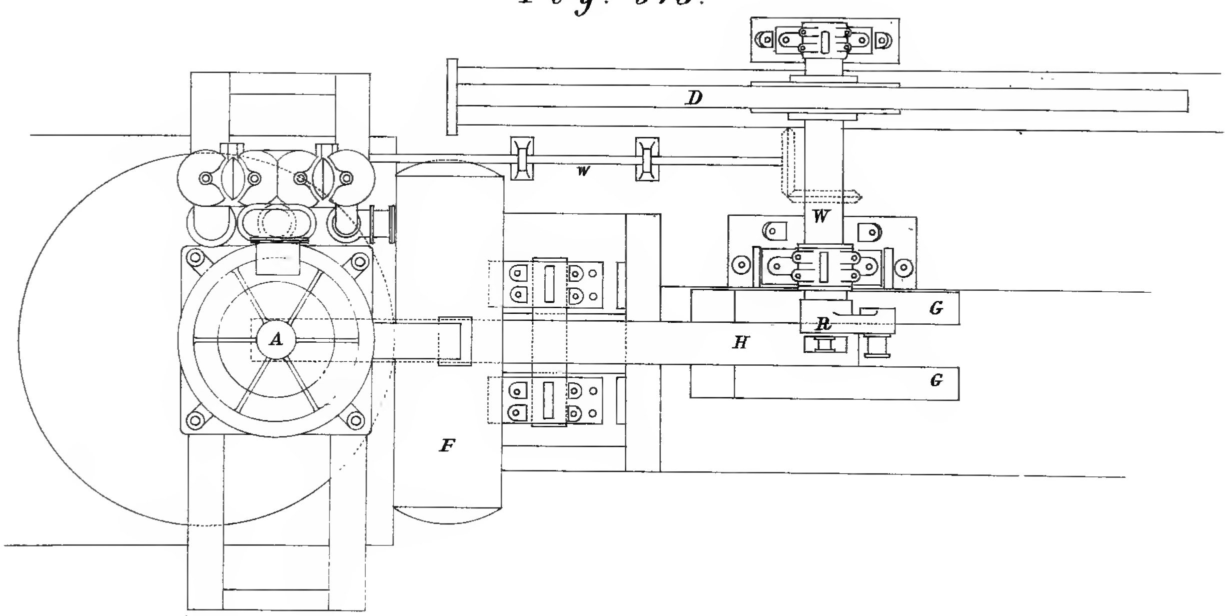


Fig. 543.



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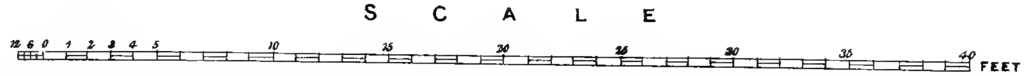

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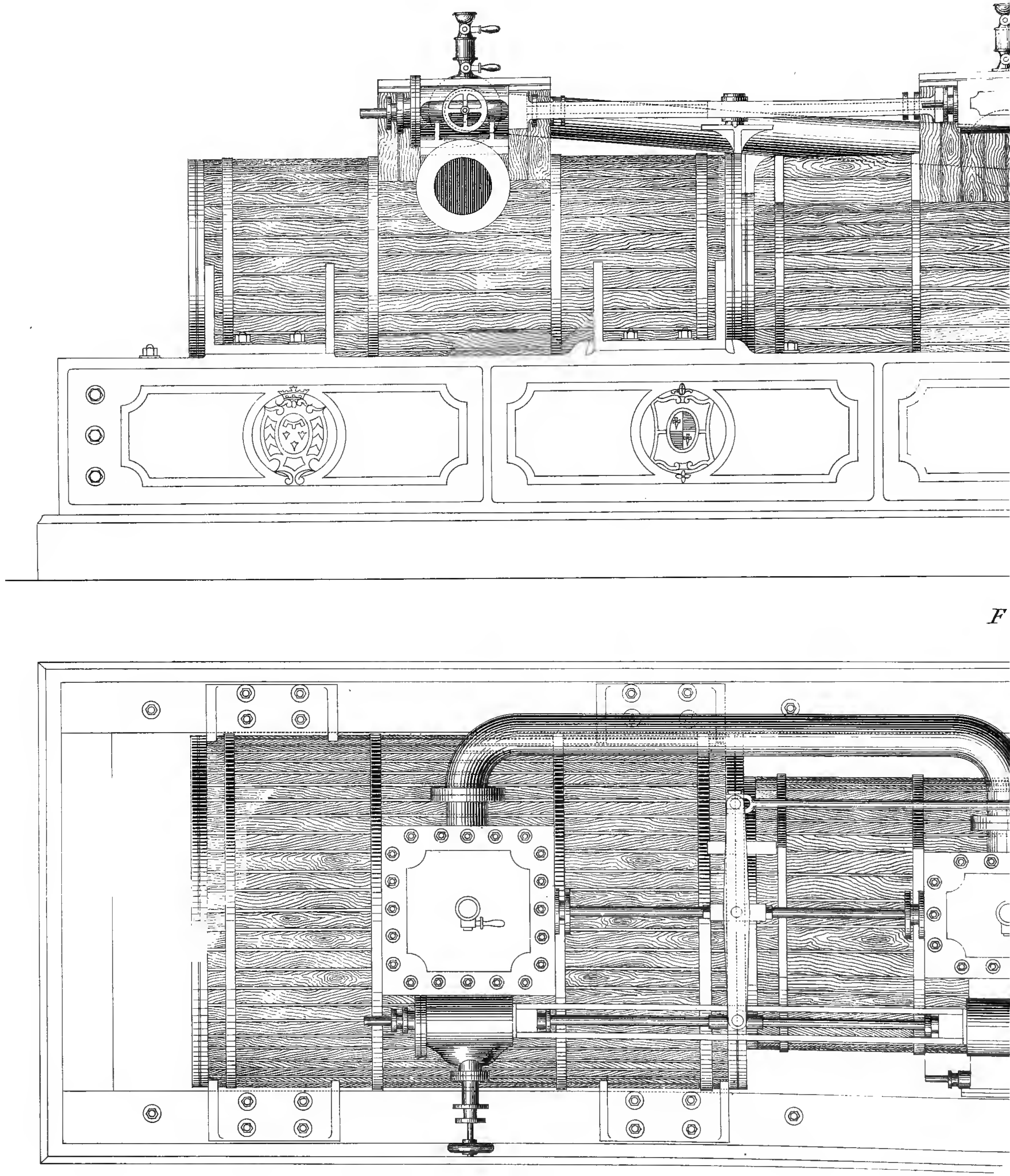
HORIZONTAL PUMPING ENGIN



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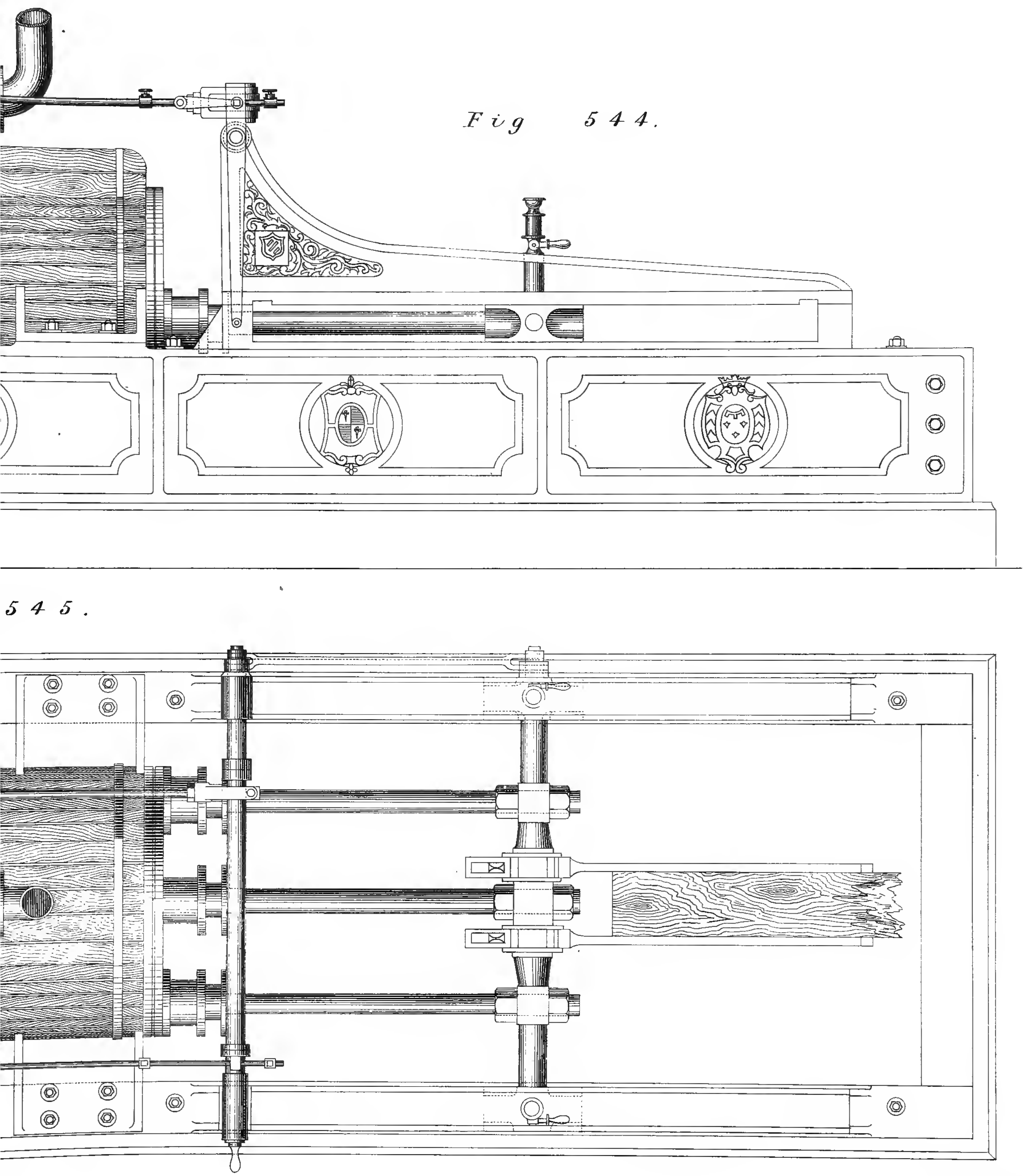
E & F.N

DAVEY'S PATENT DIFFERENTIAL

Fig 544.

545.



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New York.

HORIZONTAL PUMPING ENGINES — DAVEY'S PATEN[T]

Fig. 546

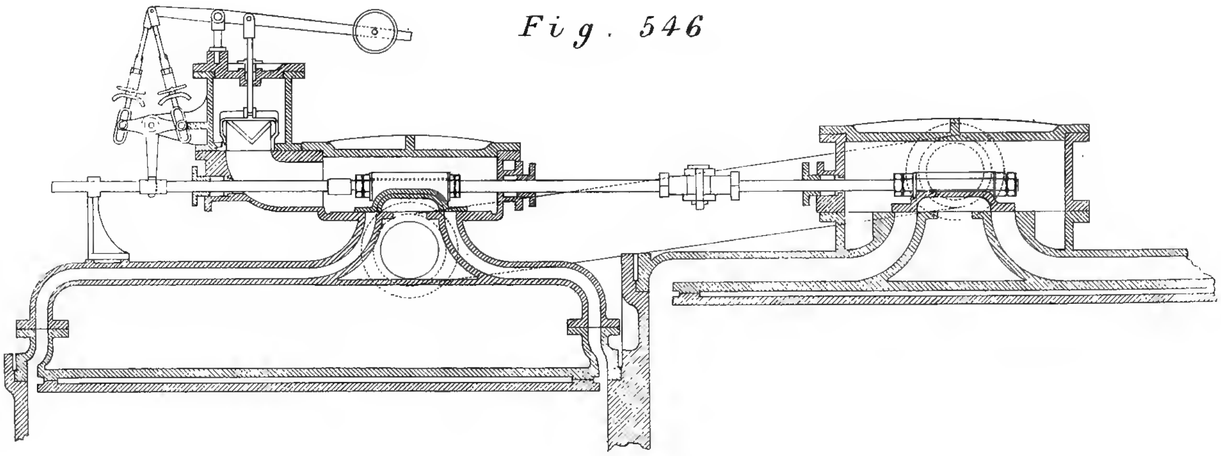


Fig. 5

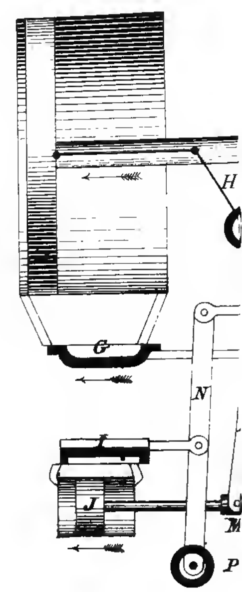


Fig. 547.

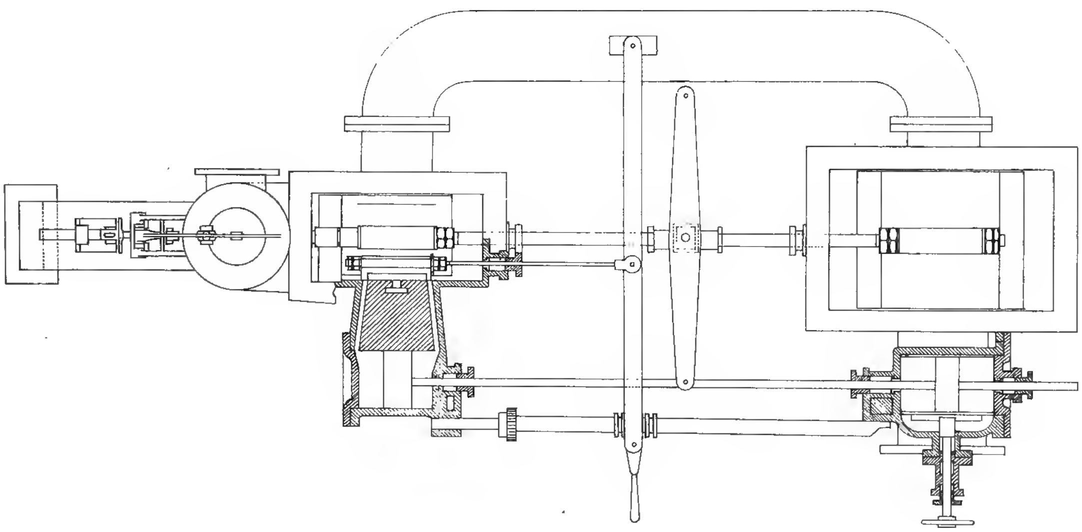


Fig. 5

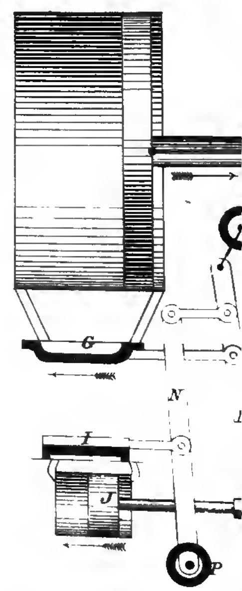


Fig. 548.

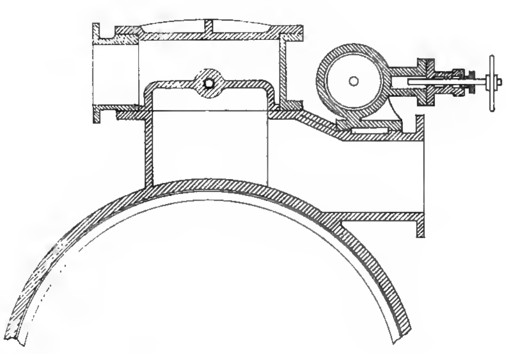
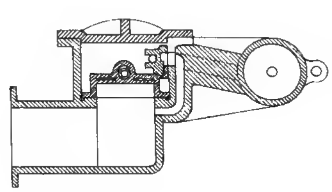


Fig. 509.



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... Differential—*Details*—and—Woolf's Direct Acting.

...50.

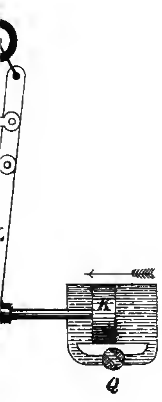


Fig. 551

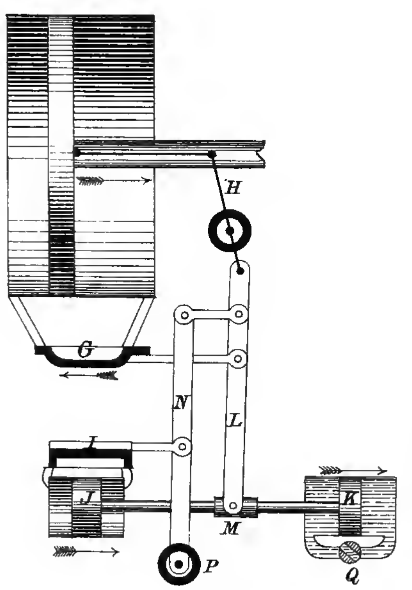


Fig. 555

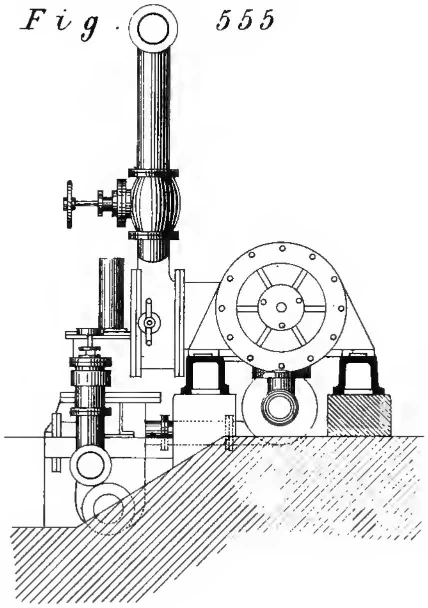
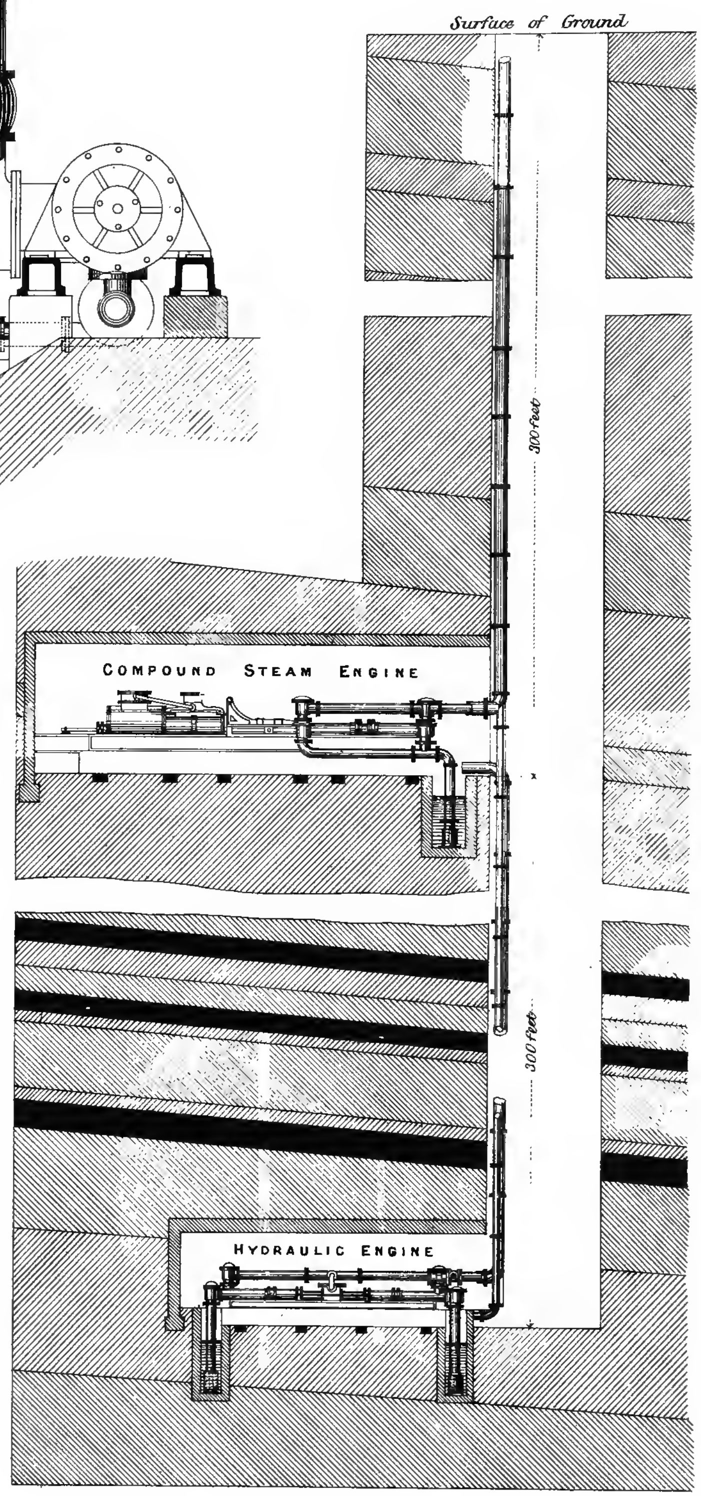
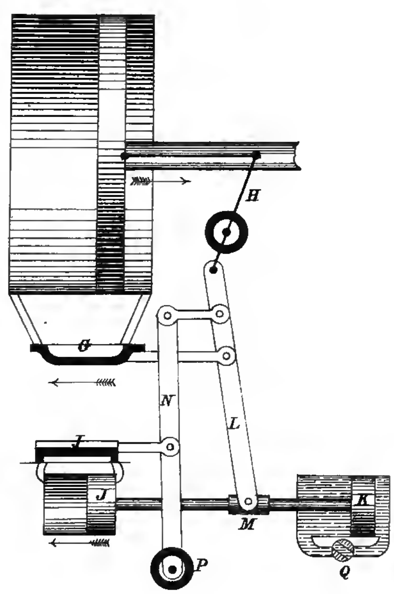


Fig 554.



...52

Fig 553.



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...6–549

8 9 10 11 12 13 14 15 16 FEET

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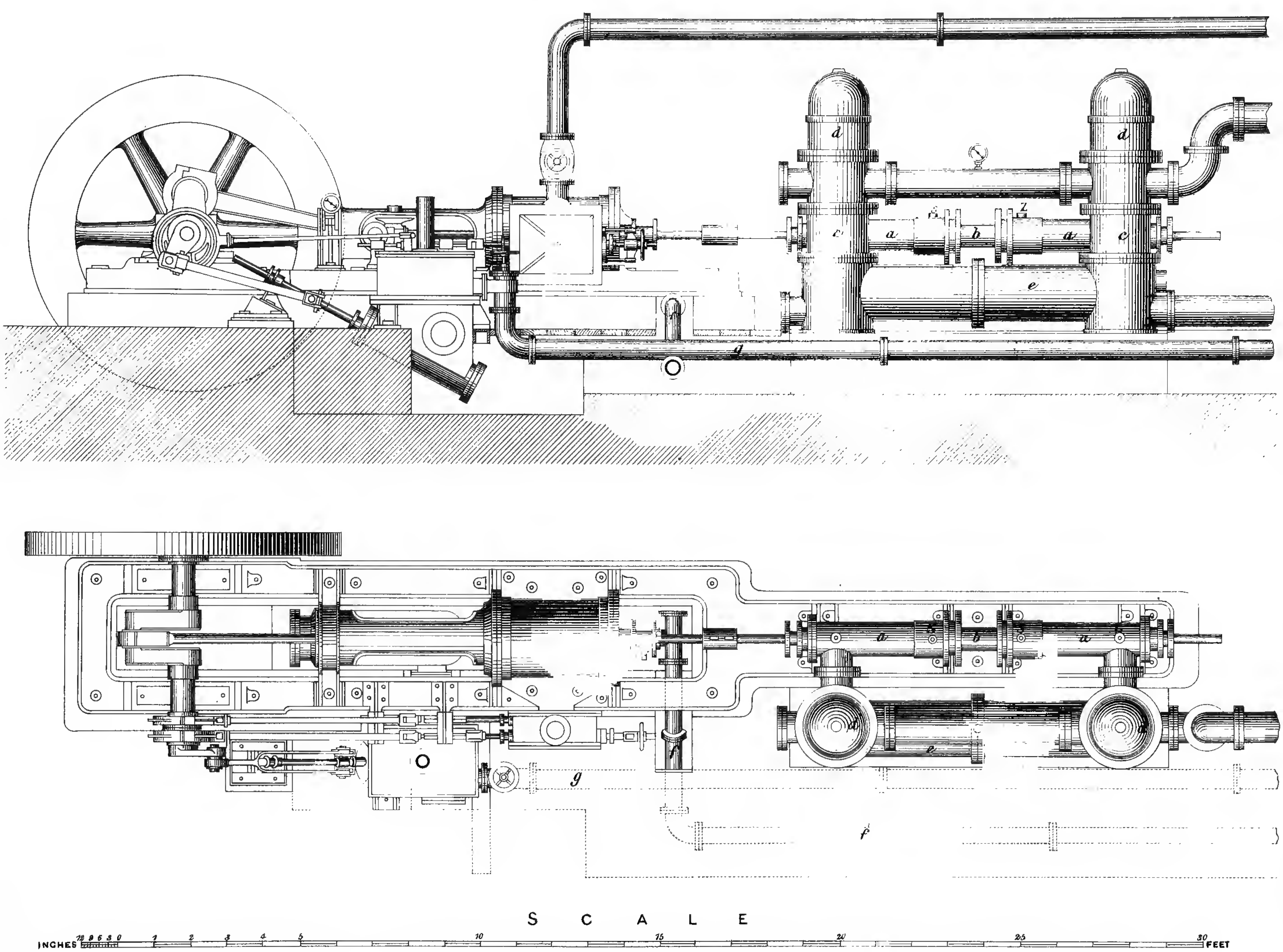
...ndon & New York.

DIRECT-ACTING PUMPING ENGINES — WOOLF — *Silesian Kohlenwerks – actien Gesellschaft.*



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DIRECT ACTING PUMPING ENGINE

Fig. 558.

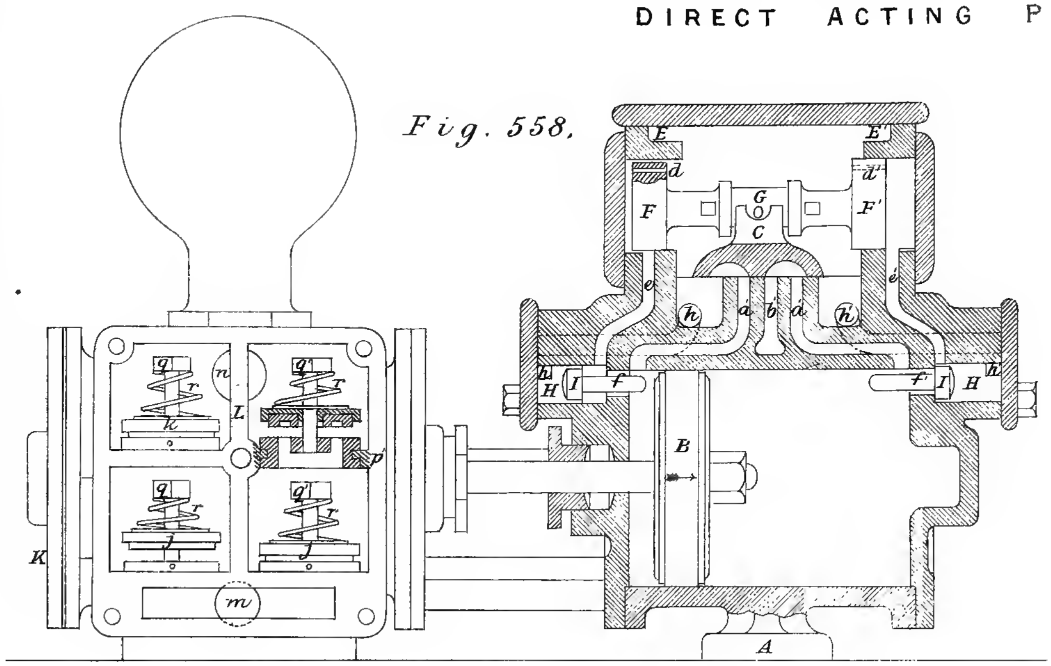


Fig. 563.

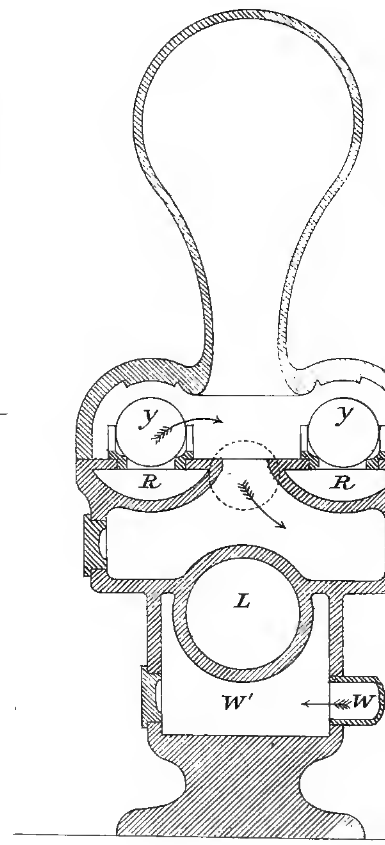


Fig. 562

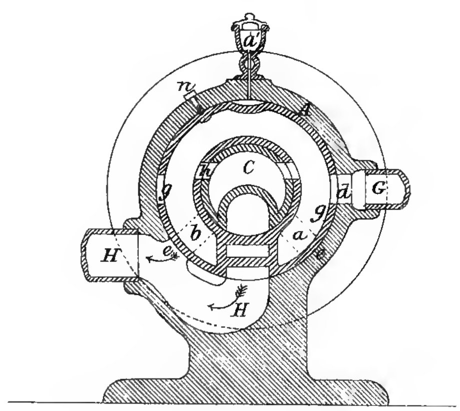
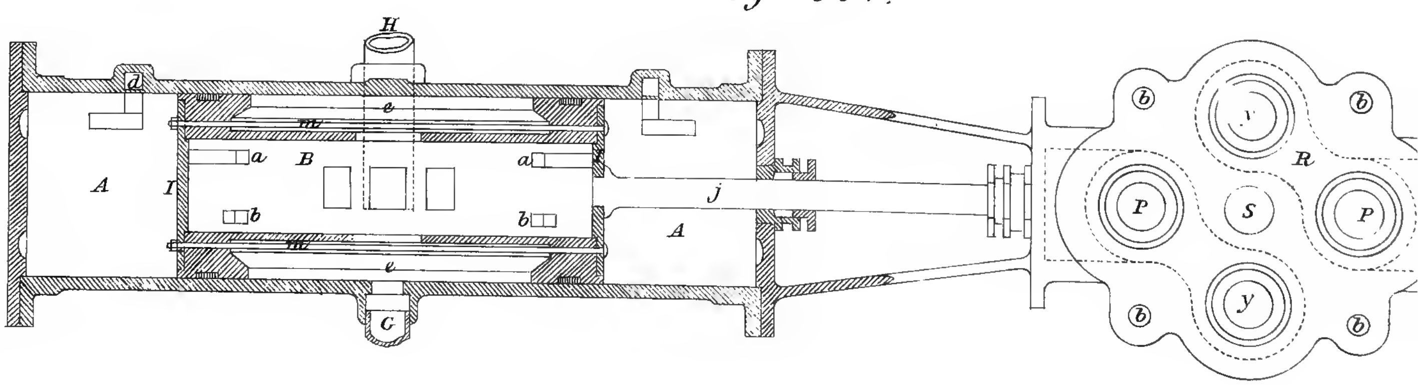


Fig 561.



E & F.N

TANGYE'S "SPECIAL"— HAYWARD, TYLER & C^{os} "UNIVERSAL"

Fig 559.

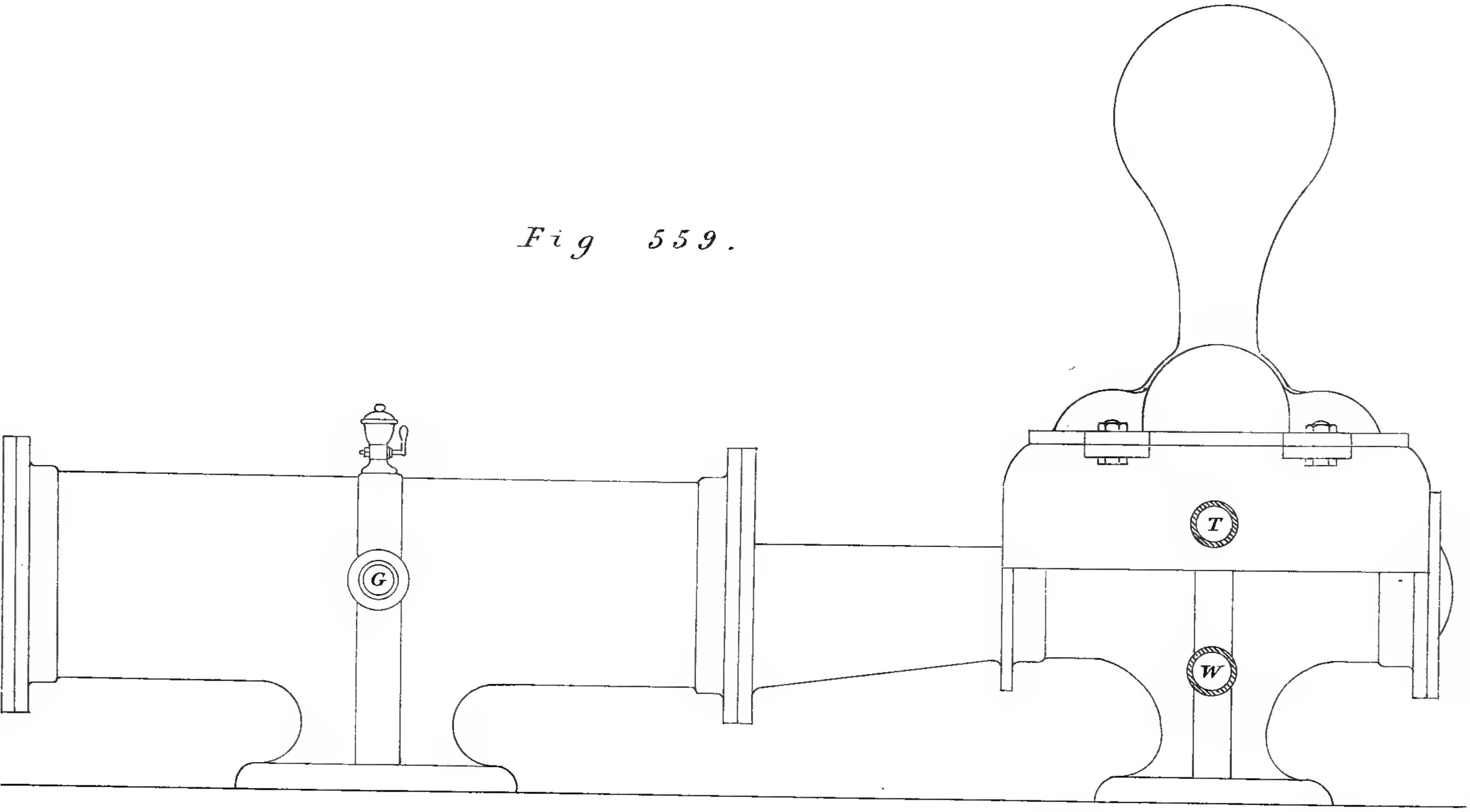
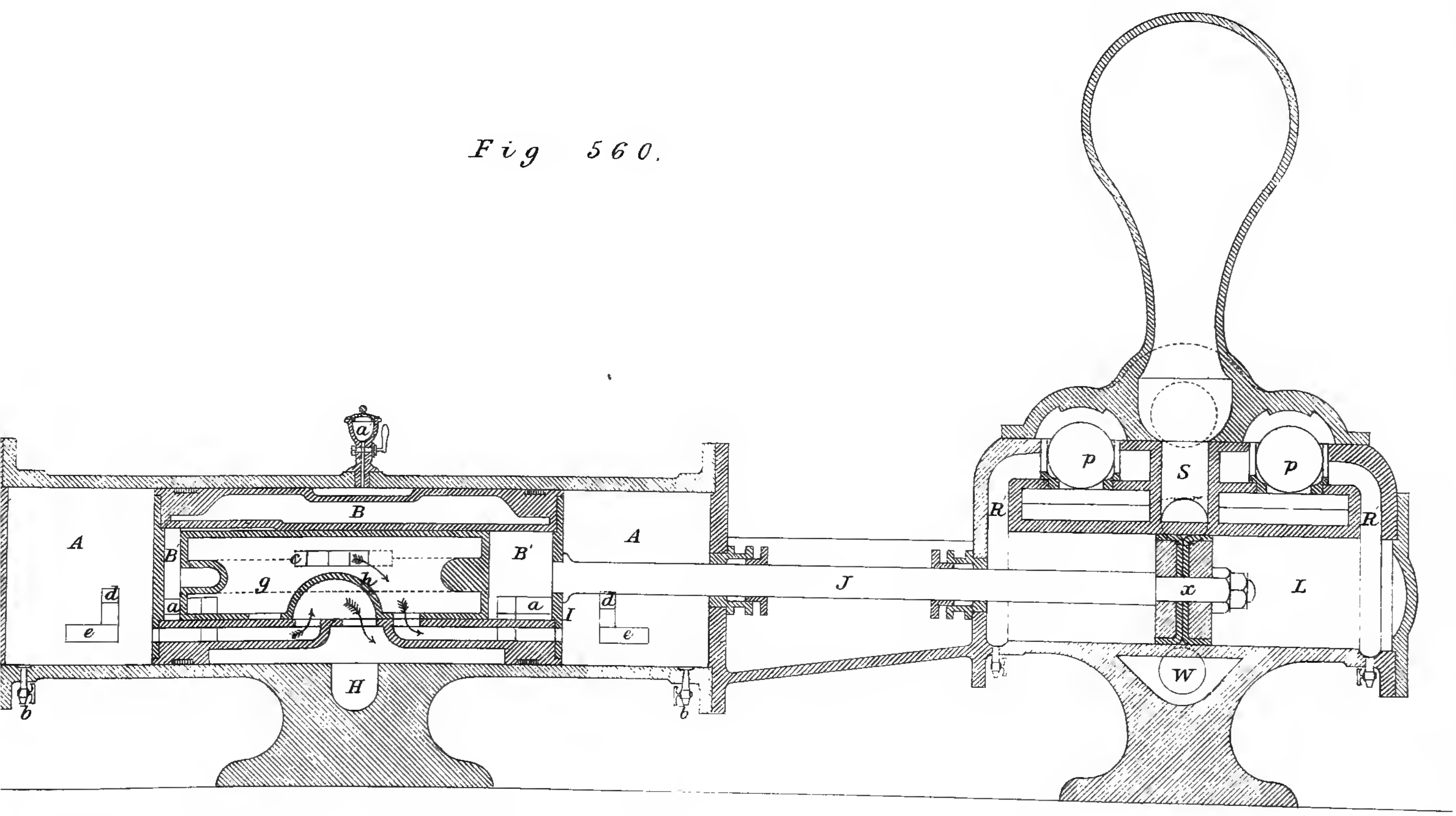


Fig 560.



DIRECT ACTING PUMPING

Fig 564.

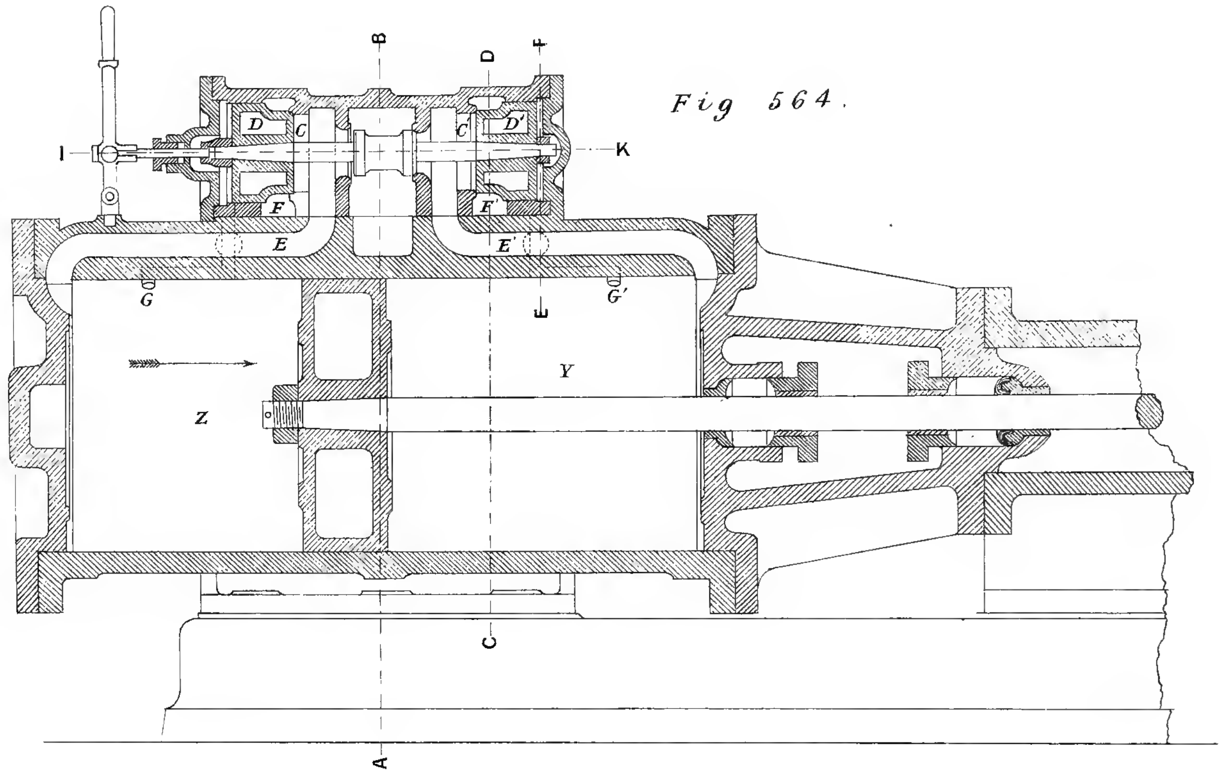
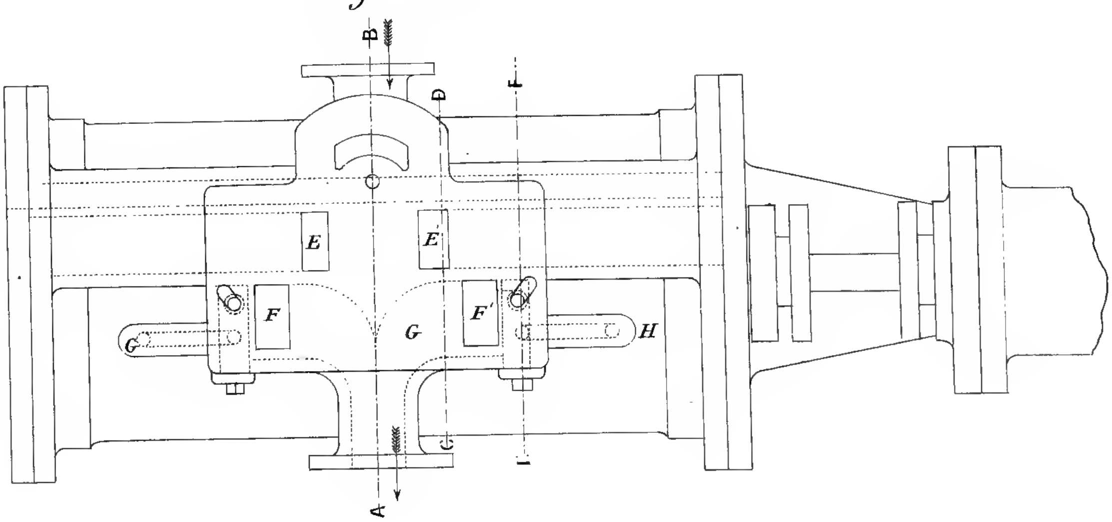
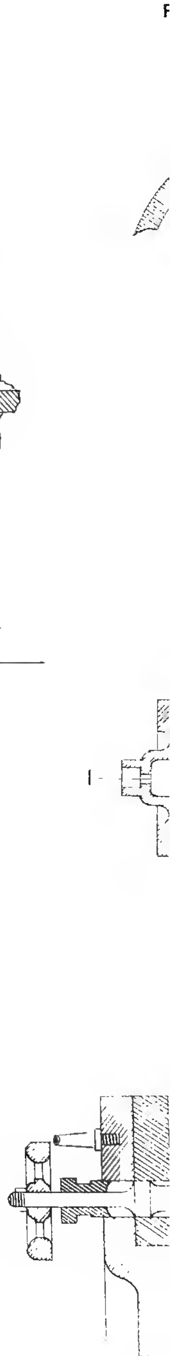


Fig 565.





FIGS 564 _ 570. AND 576.

INCHES 12 9 6 3 0 1 2 3 4 5 FEET

NGINES —— PARKER AND WESTON'S

566.

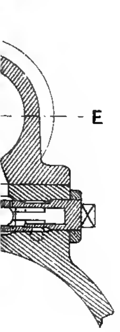


Fig 568

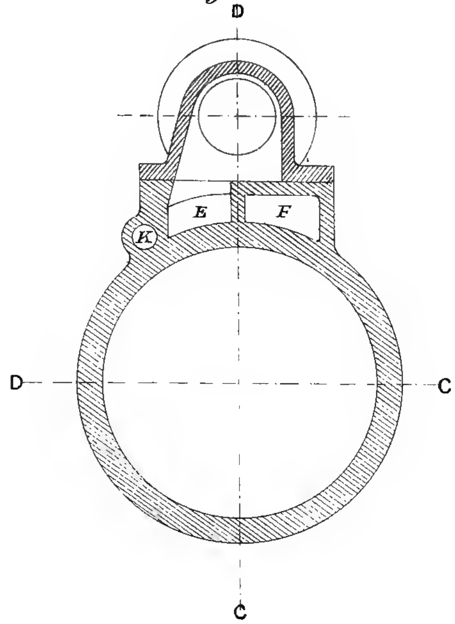
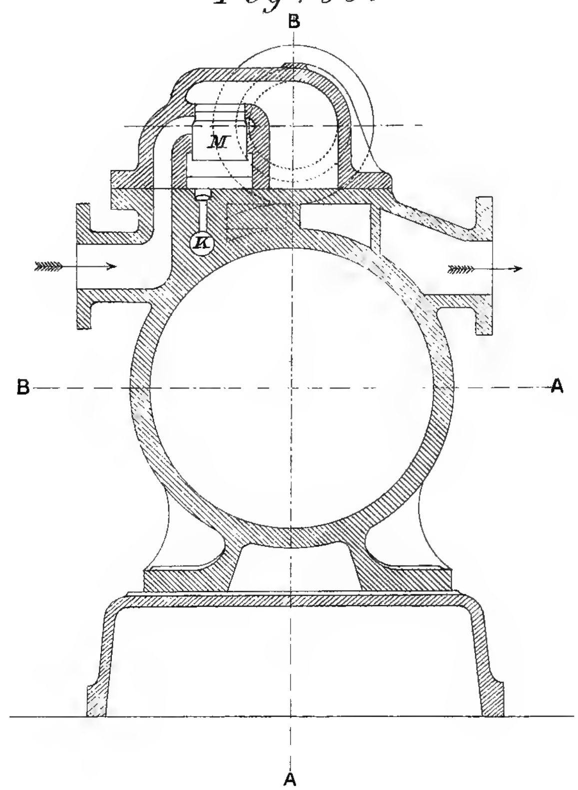


Fig. 567



g 569.

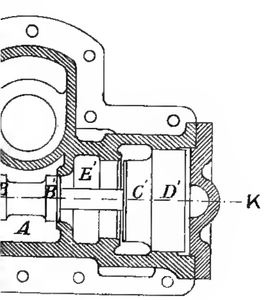


Fig. 570.

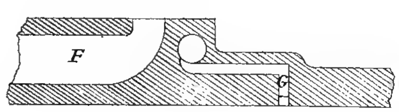


Fig 576.

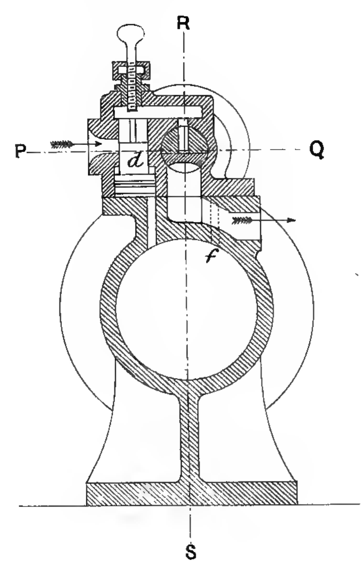


Fig. 571

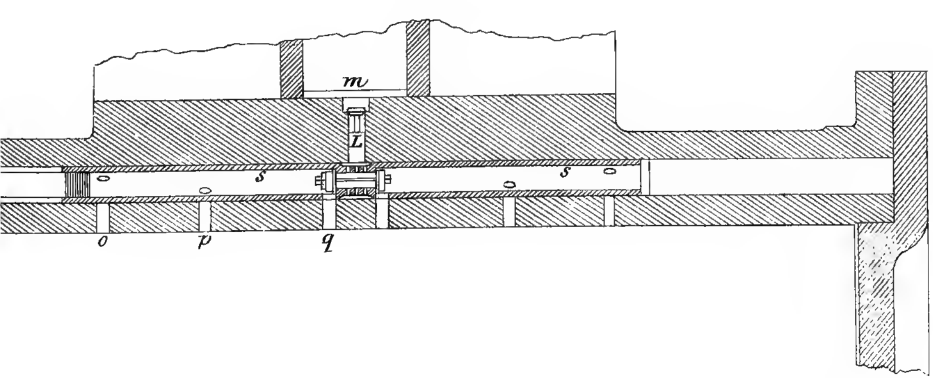


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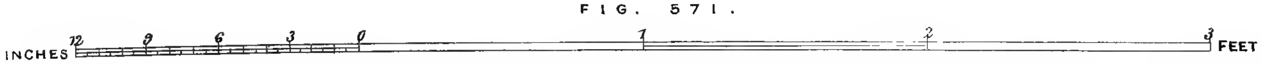
FIG. 571.



G.G.ANDRÉ.

DIRECT ACTING PUMPING ENGINE — PARKER & WESTON'S AND THE "NIAGARA".

Fig. 572.

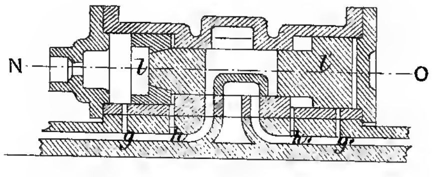


Fig. 574

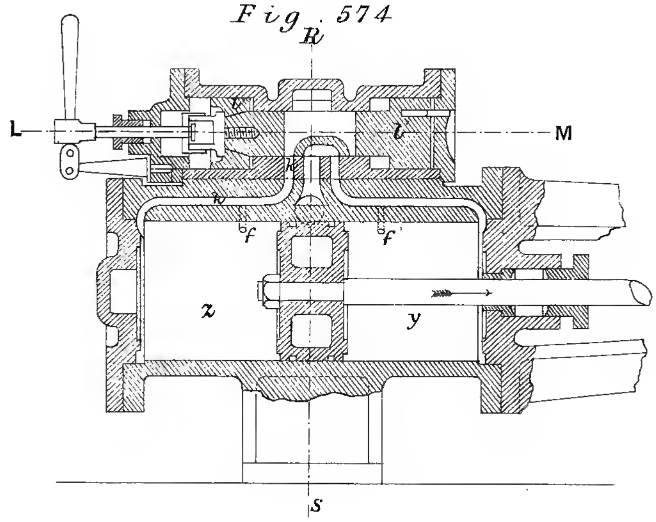


Fig. 573

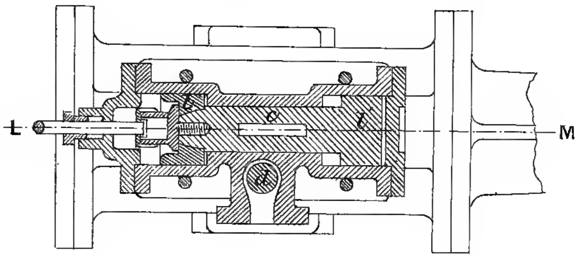


Fig. 575.

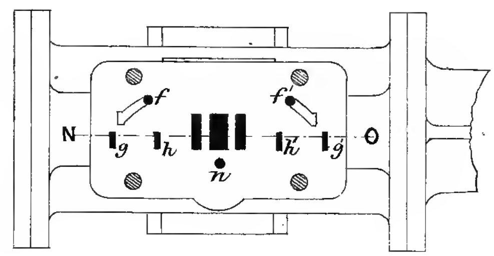
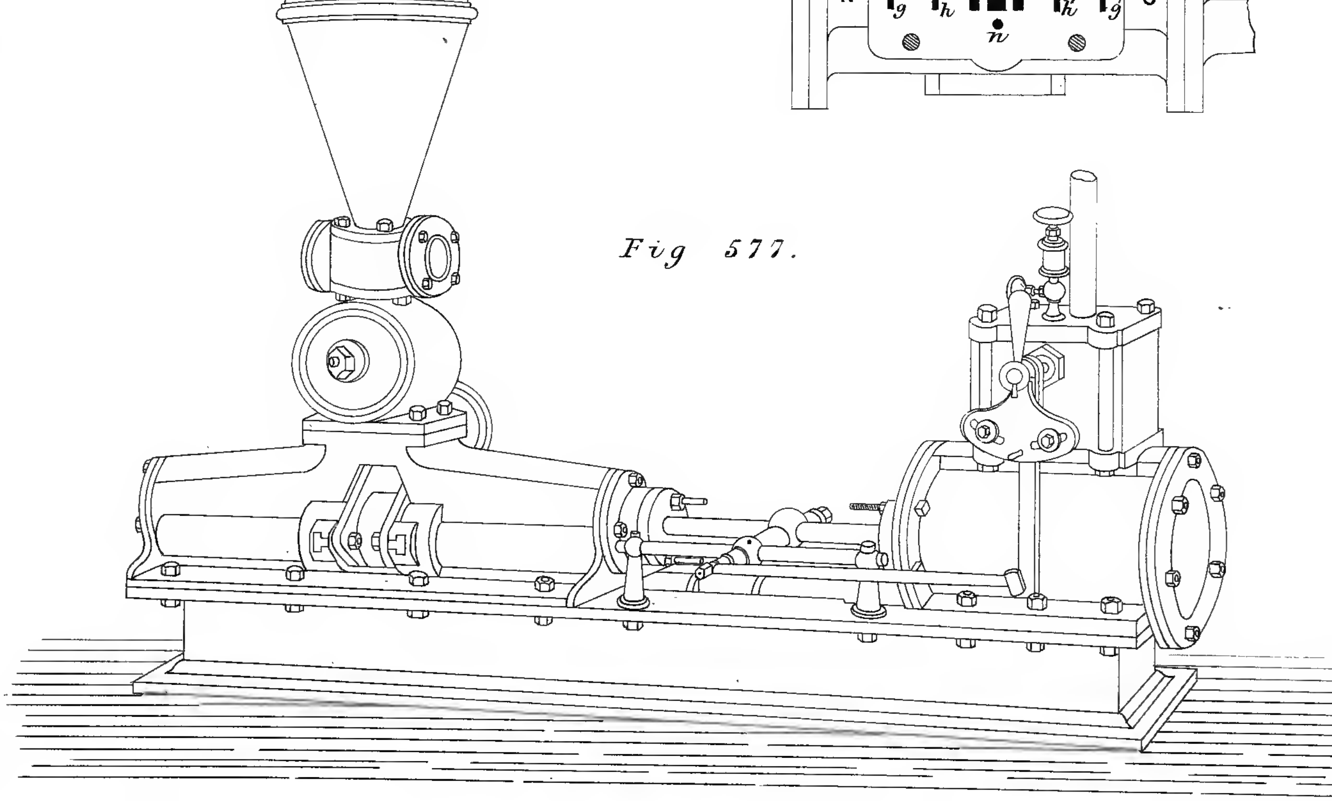


Fig 577.



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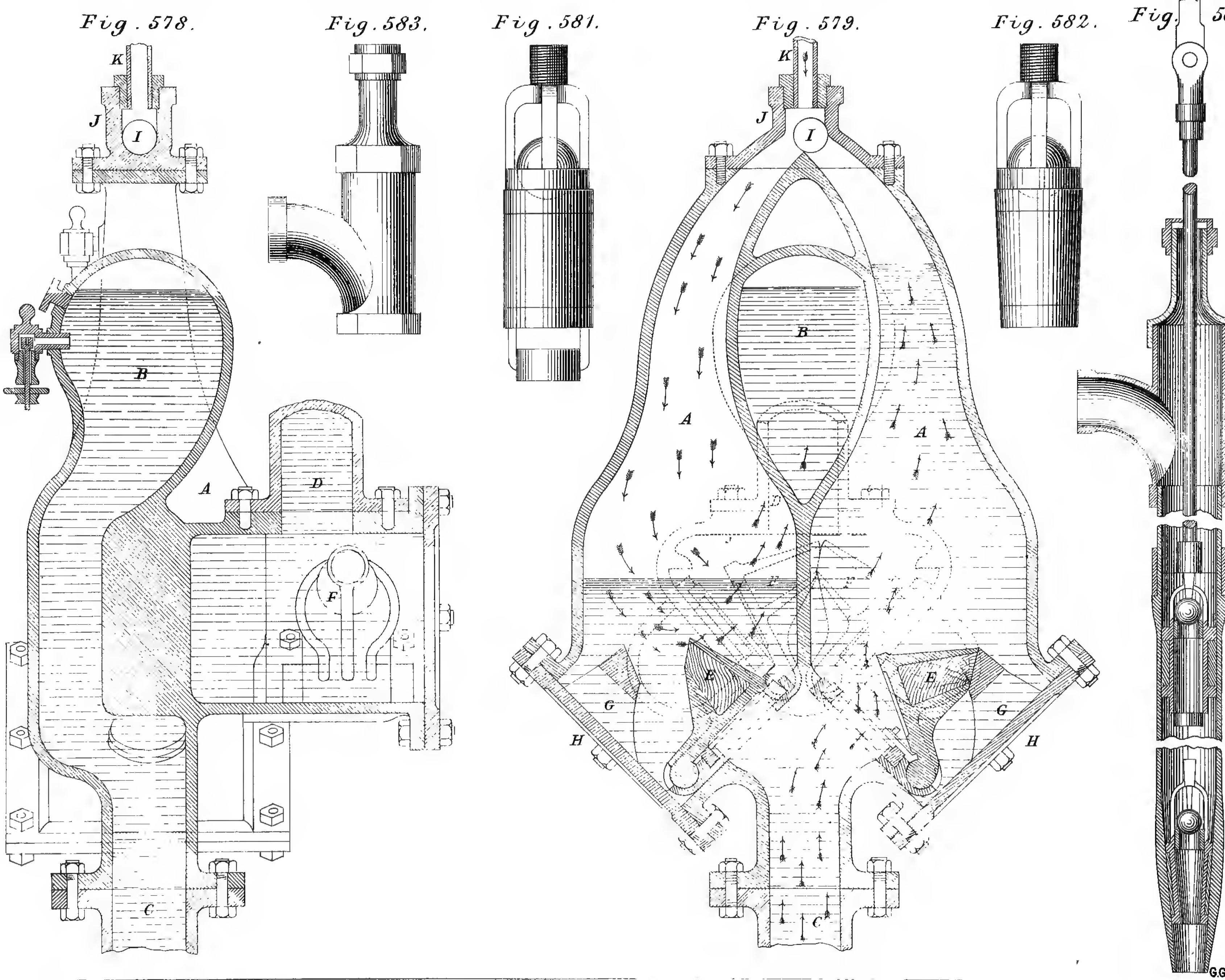
PUMPS — Pulsometer and American Oil-Well Pump.



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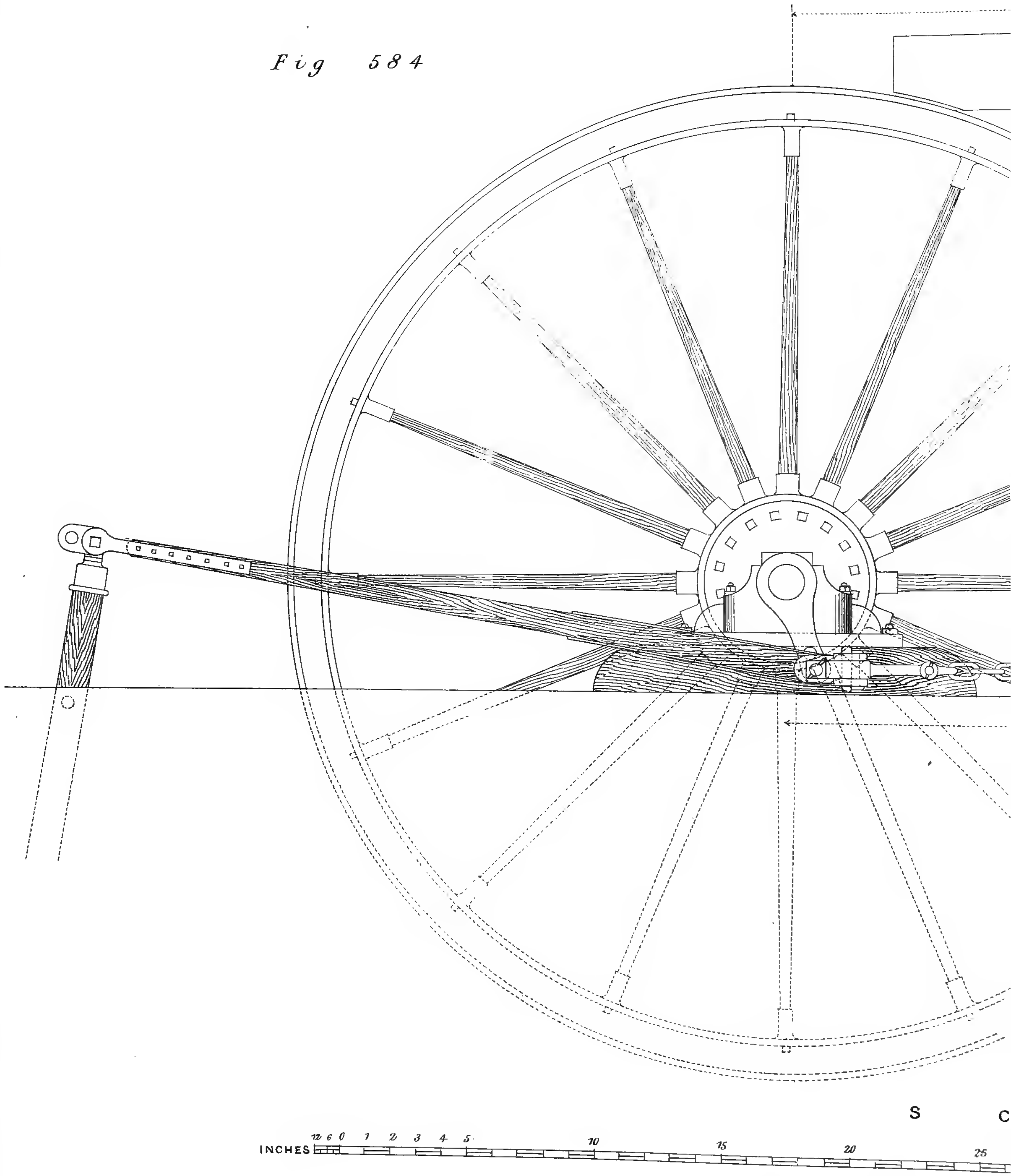
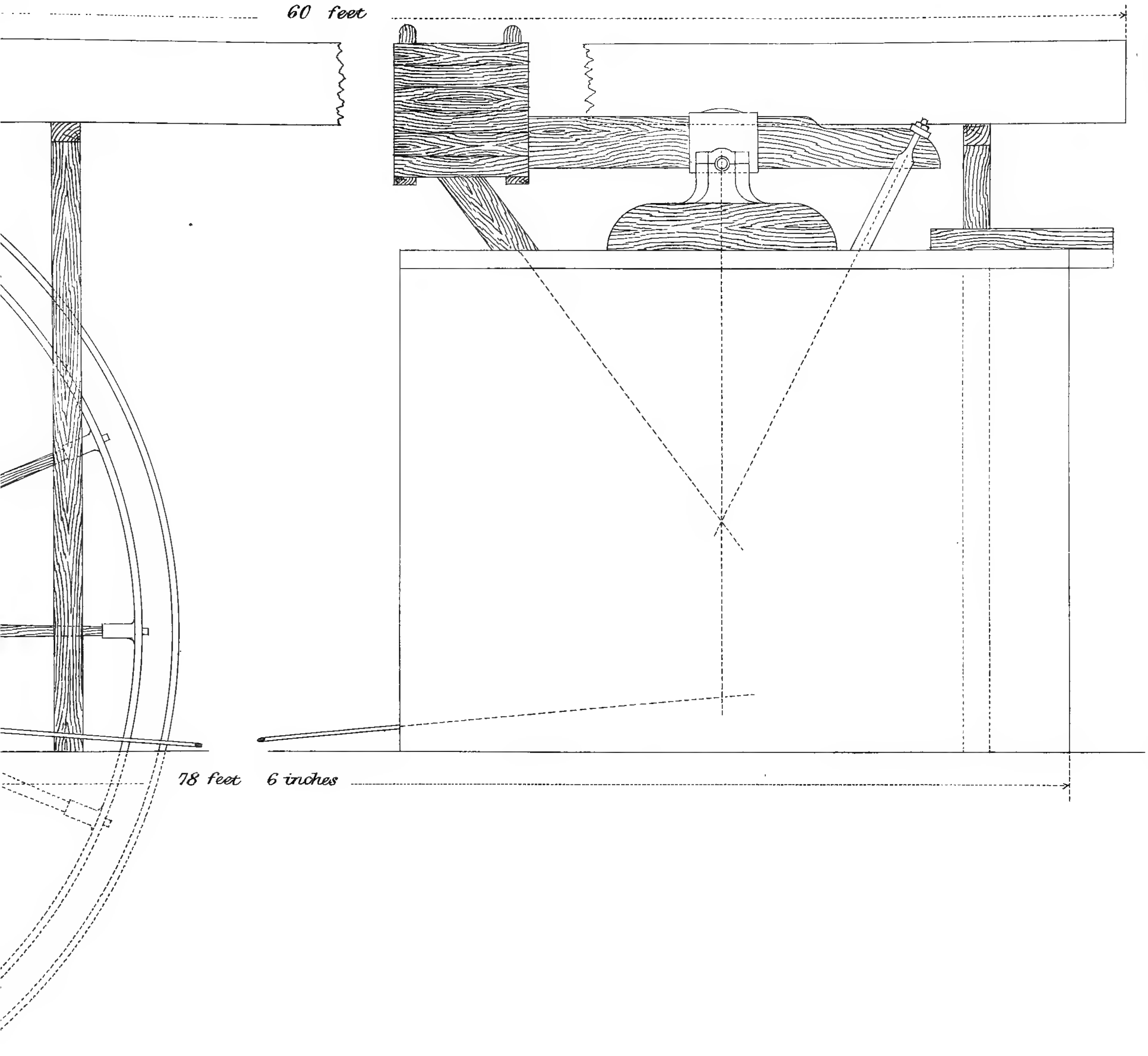
W A T E R   W H E E L — P U

Fig 584

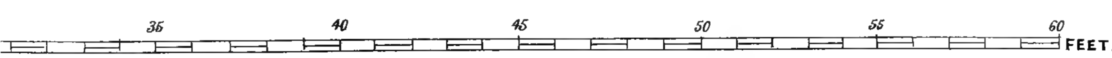


E & F N

G —— DEVON GREAT CONSOLS MINE.



L E.



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& New York.

WATER WHEEL — PUMPING — DEVON GREAT CONSOLS MINE.

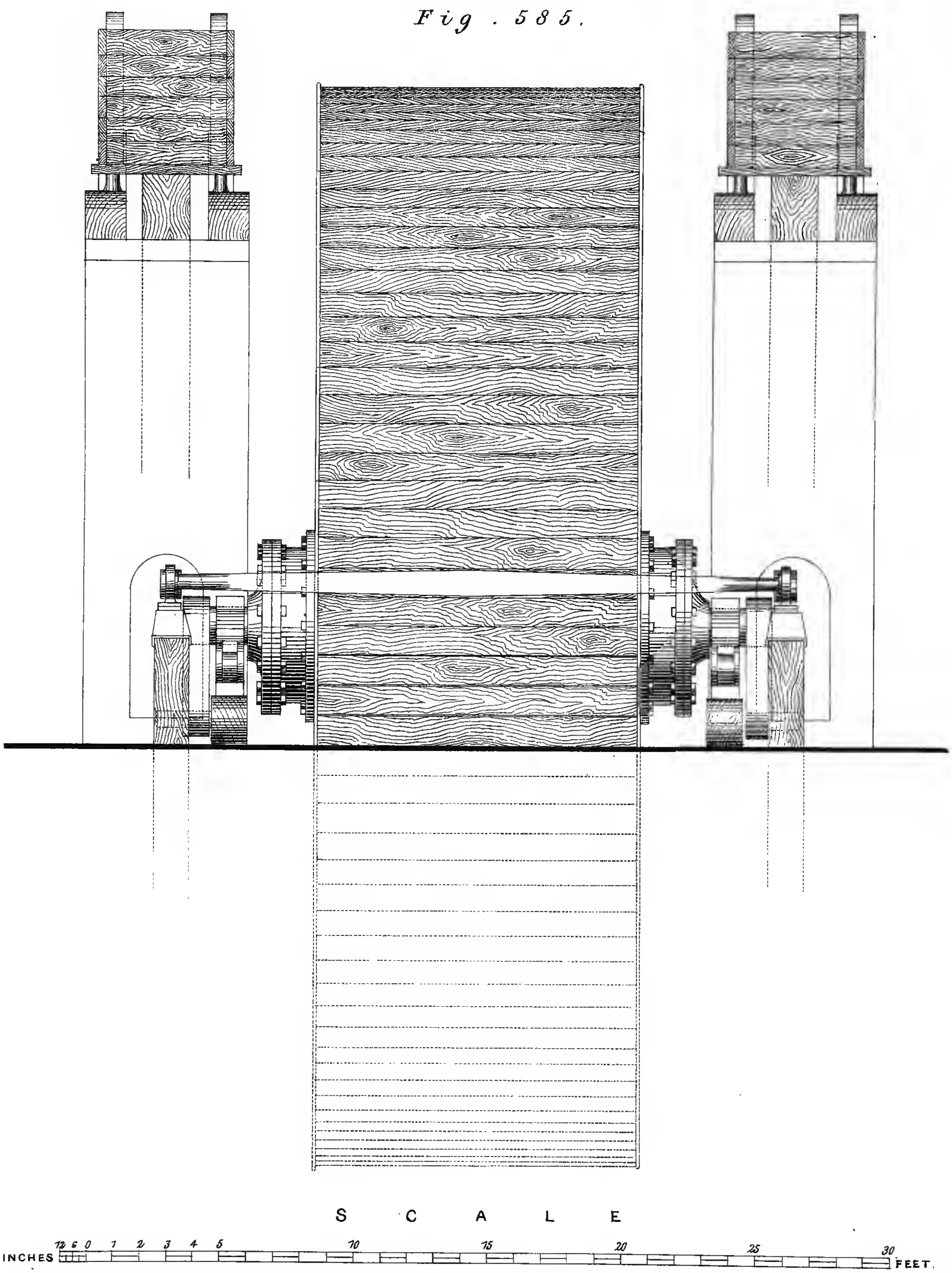

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Fig. 586

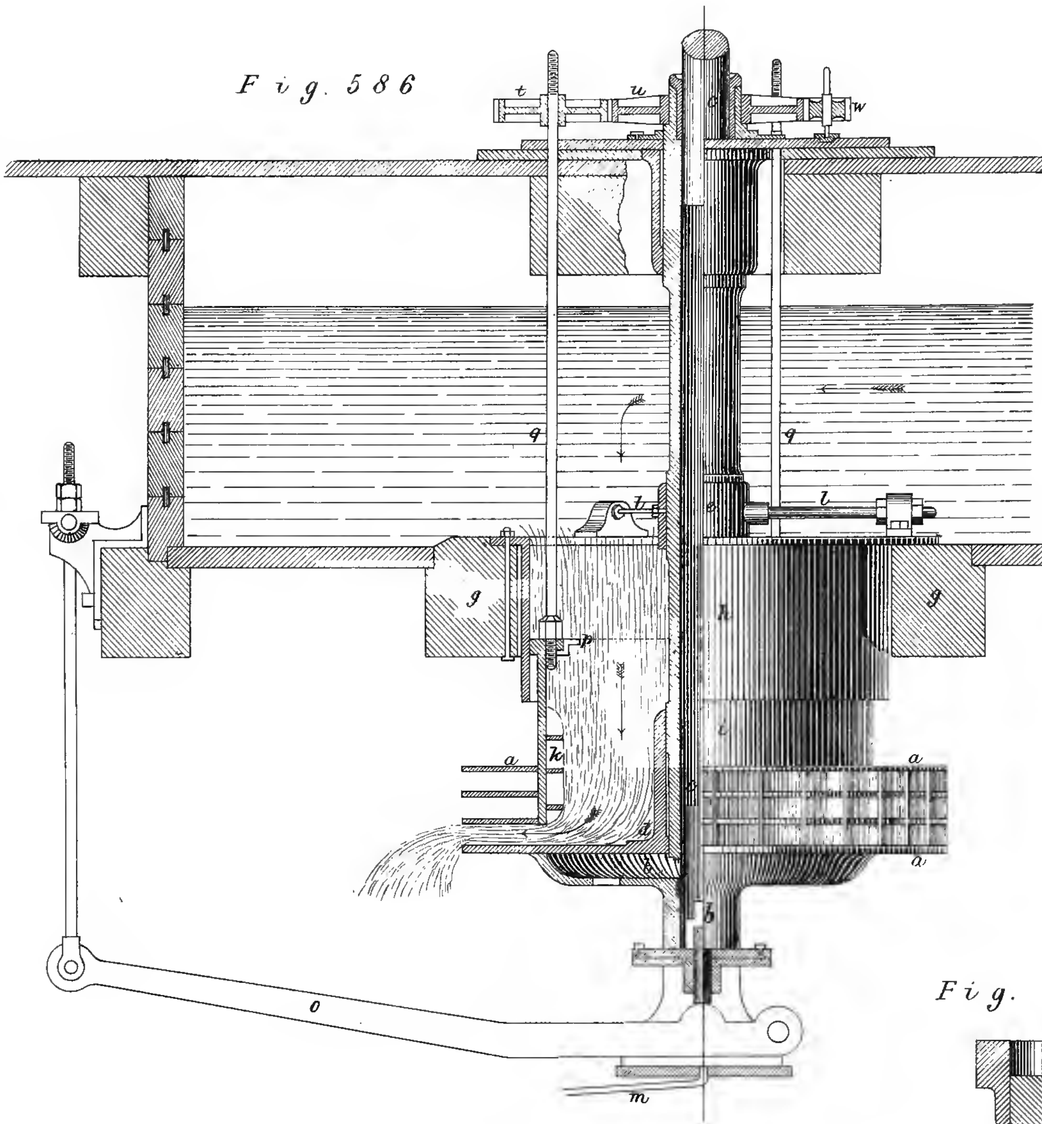


Fig.

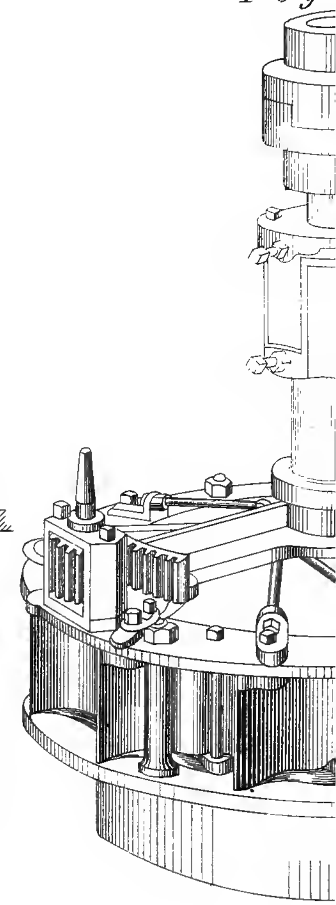


Fig. 591

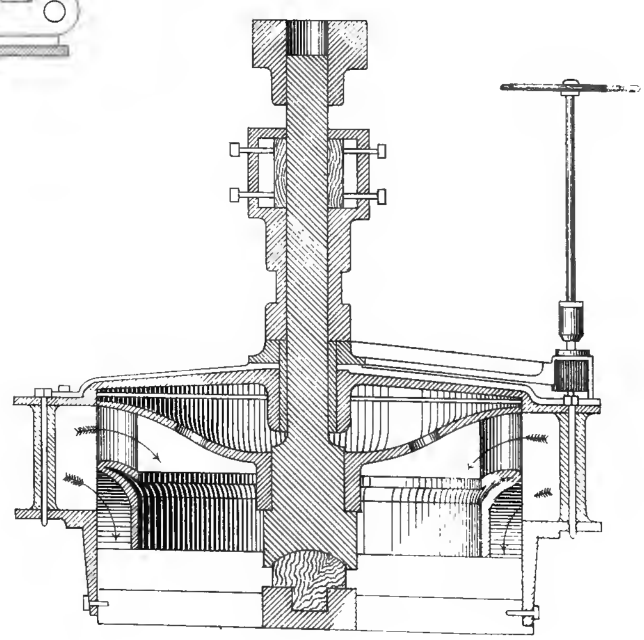
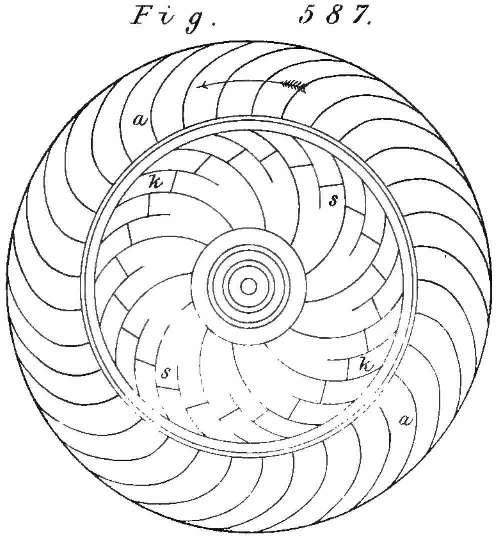


Fig. 587.



RNEYRON AND LEFELL

Fig. 590.

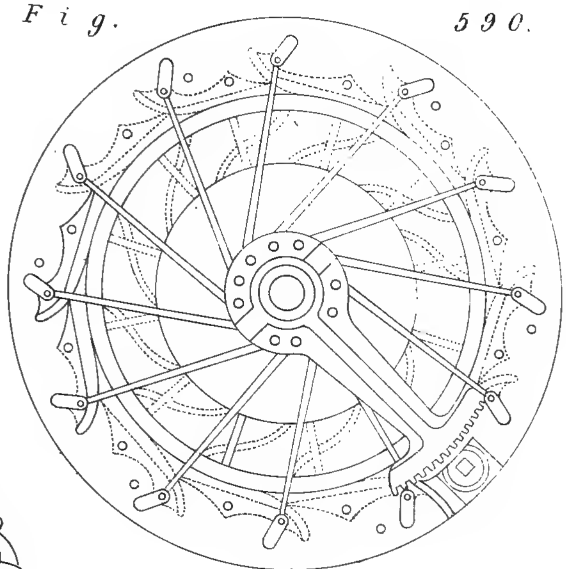
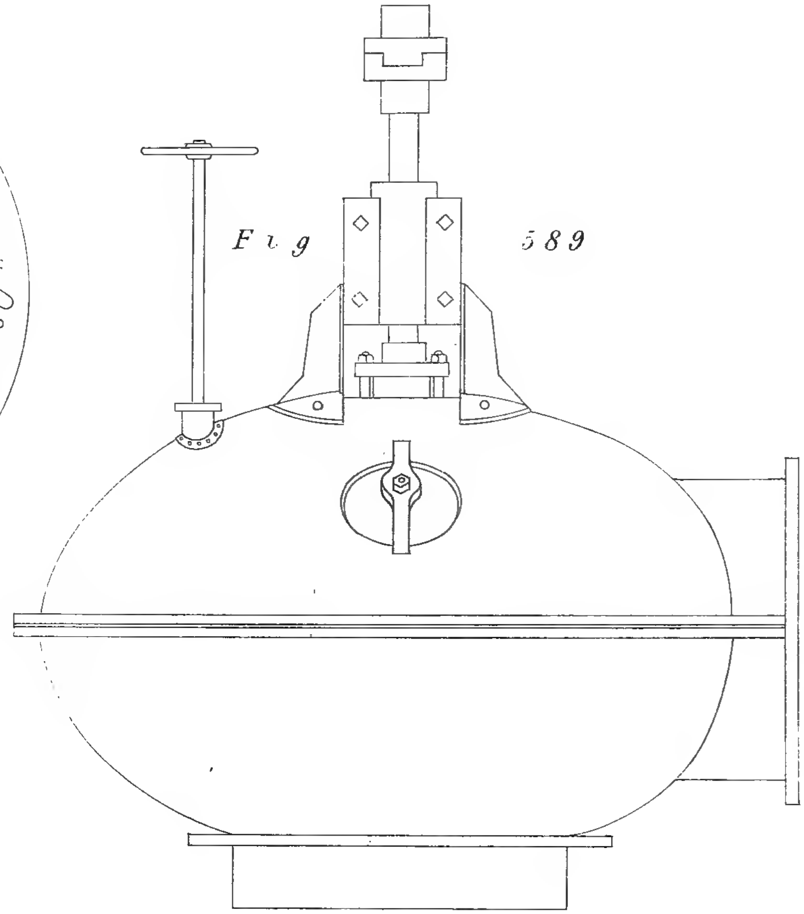


Fig 589



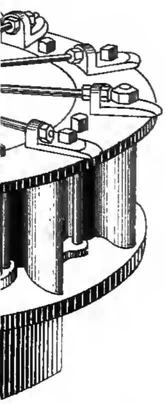


Fig 593

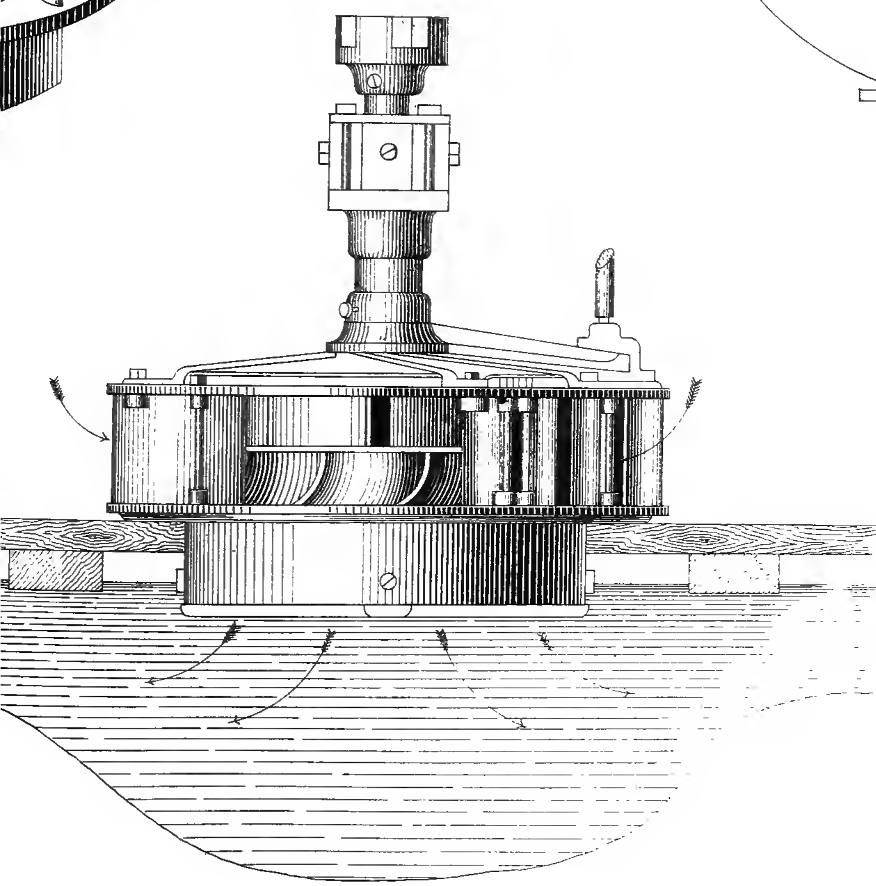
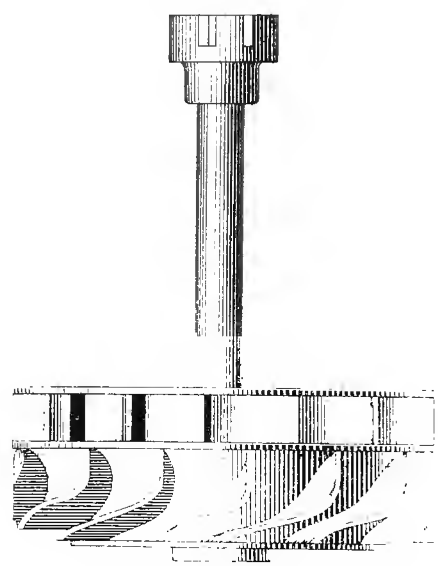
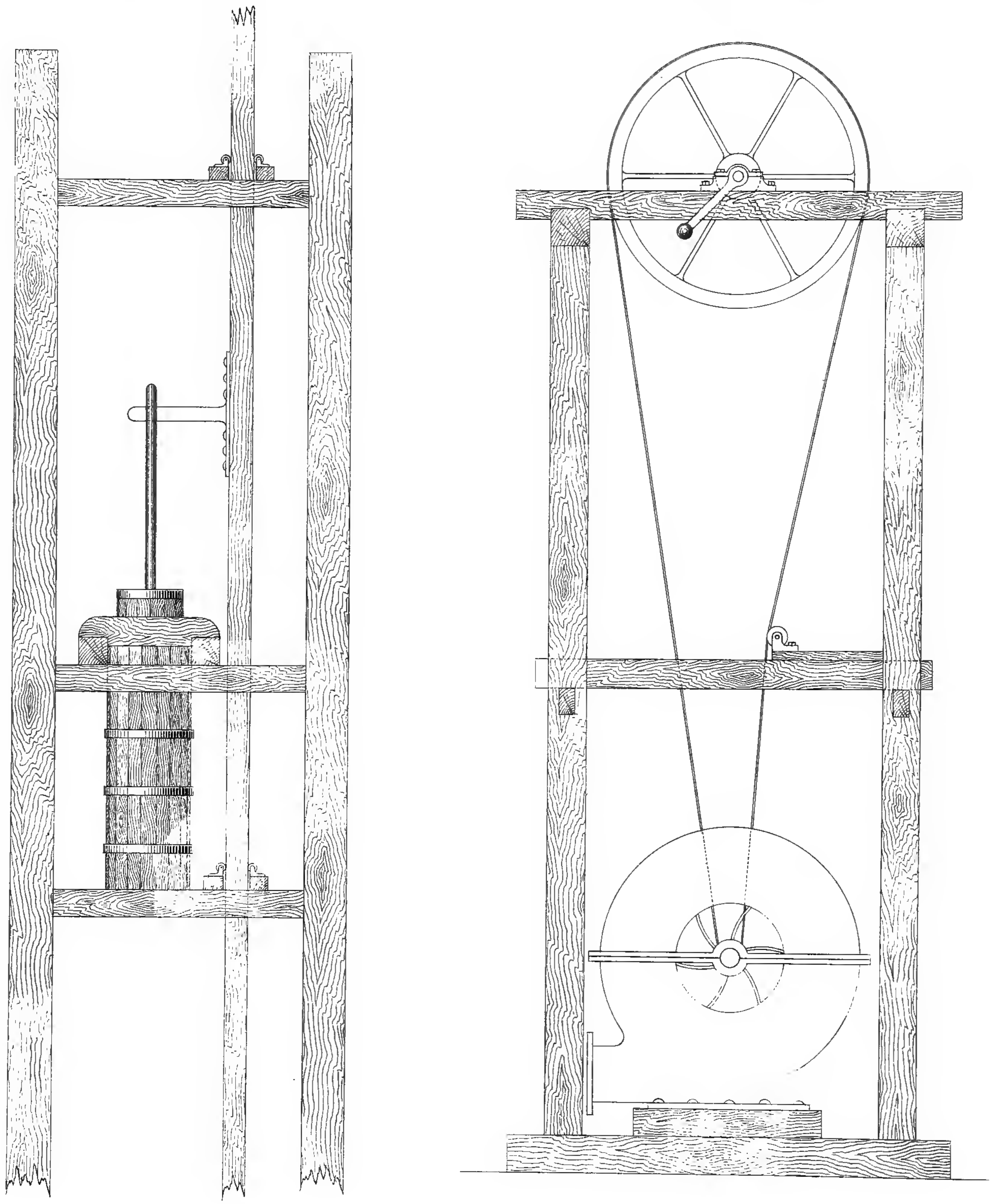


Fig 592



VENTILATING MACHINERY — BOX AND HAND FAN

Fig 594 *Fig 596*



SCALE

INCHES 12 9 6 3 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 FEET

G.G. ANDRÉ

E & F.N. Spon, London & New York.

VENTILATING MACHINERY — BELL — FABRY'S WHEEL — COOKE'S FAN.

Fig. 595.

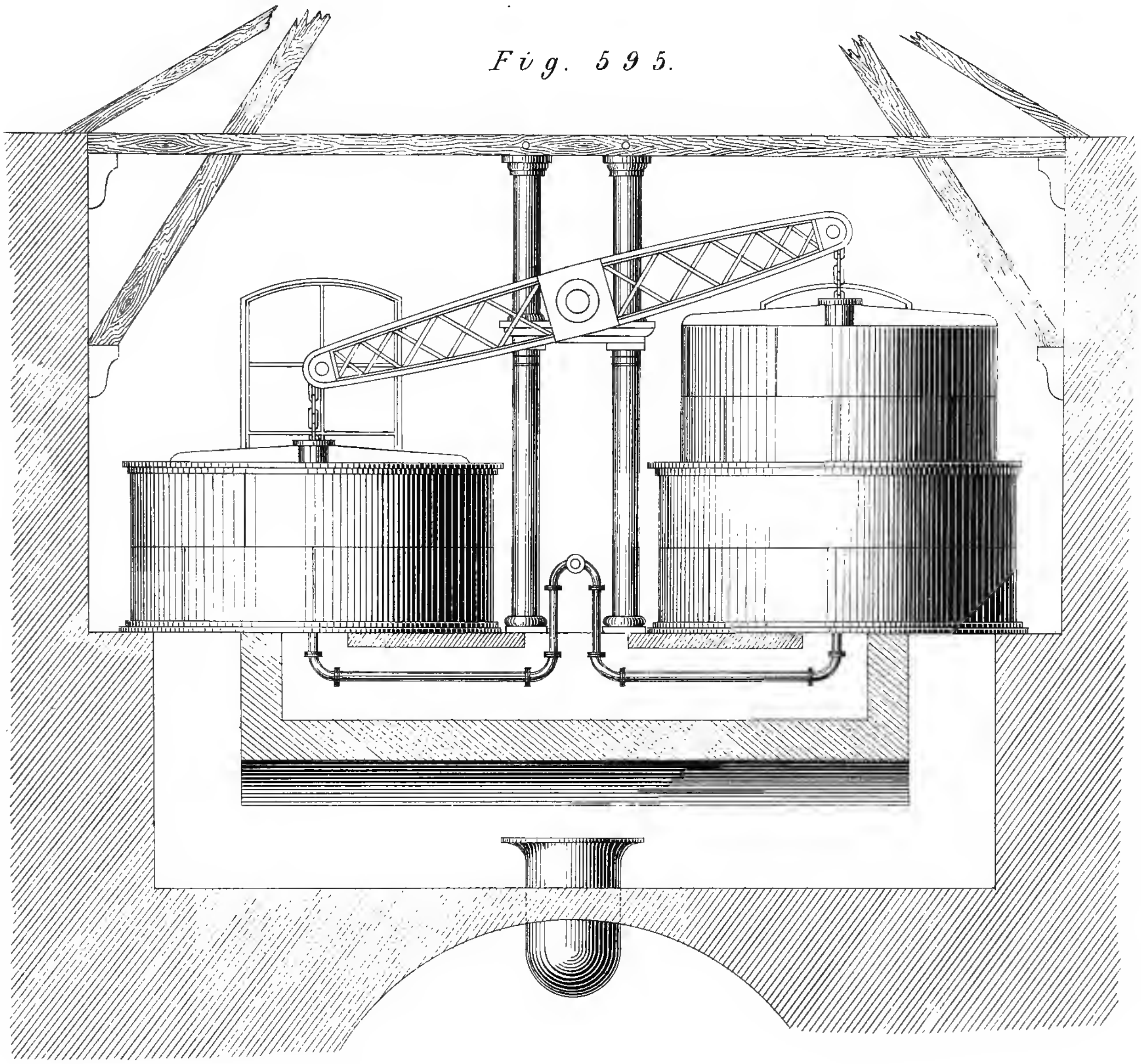


Fig. 598.

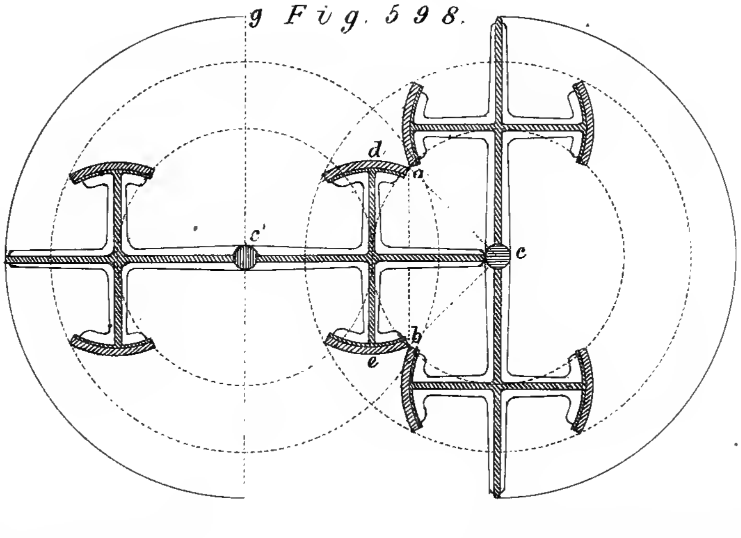
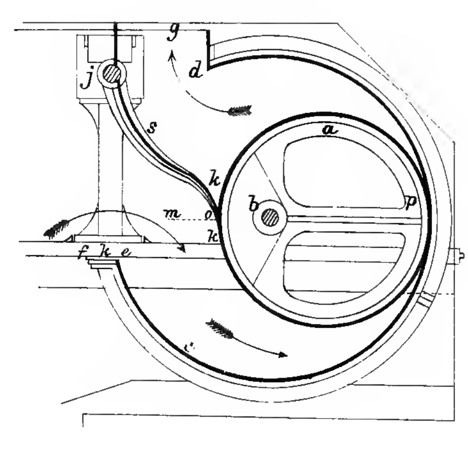


Fig. 601.



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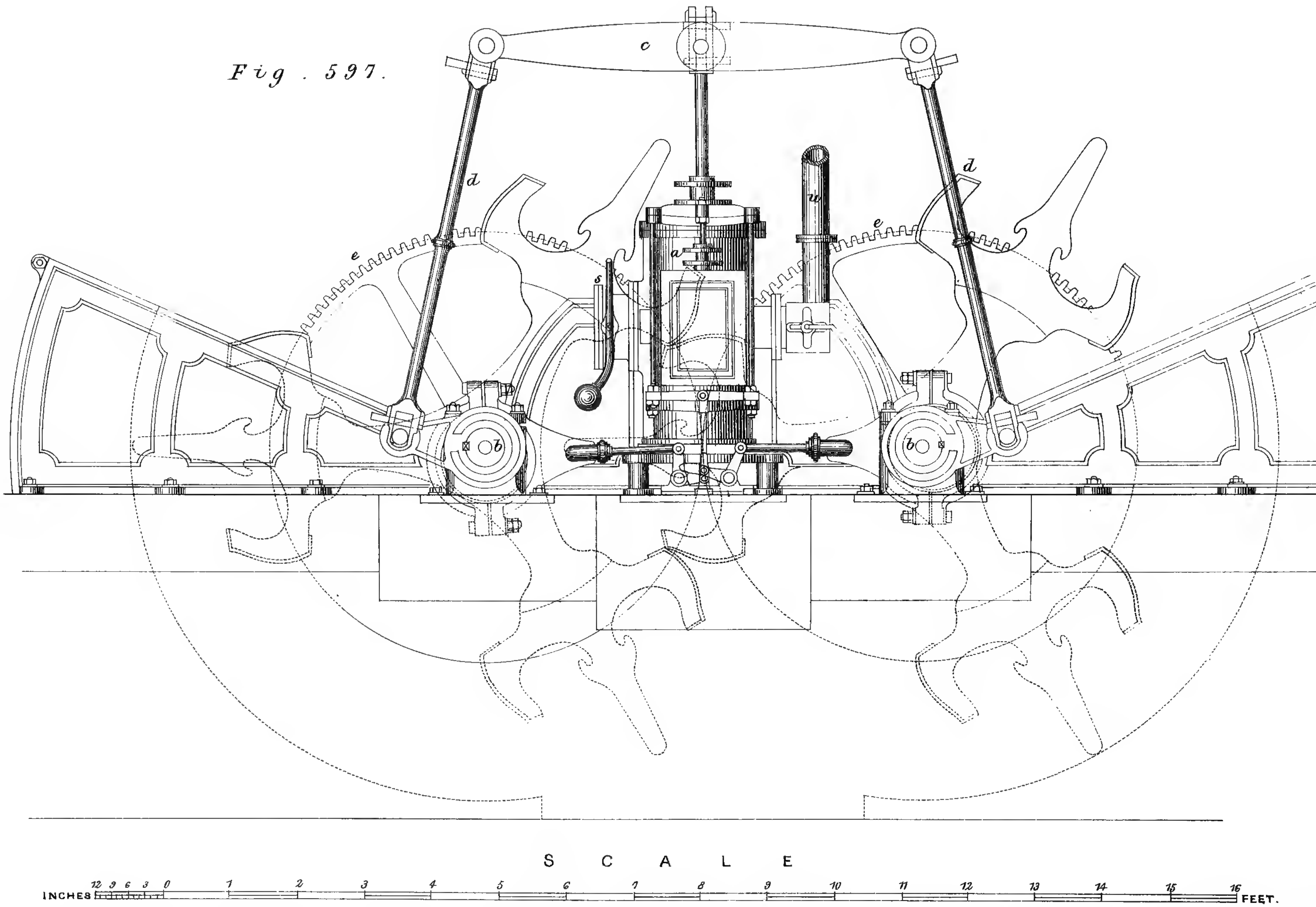
VENTILATING MACHINERY — FABRY'S WHEEL

Fig. 597.



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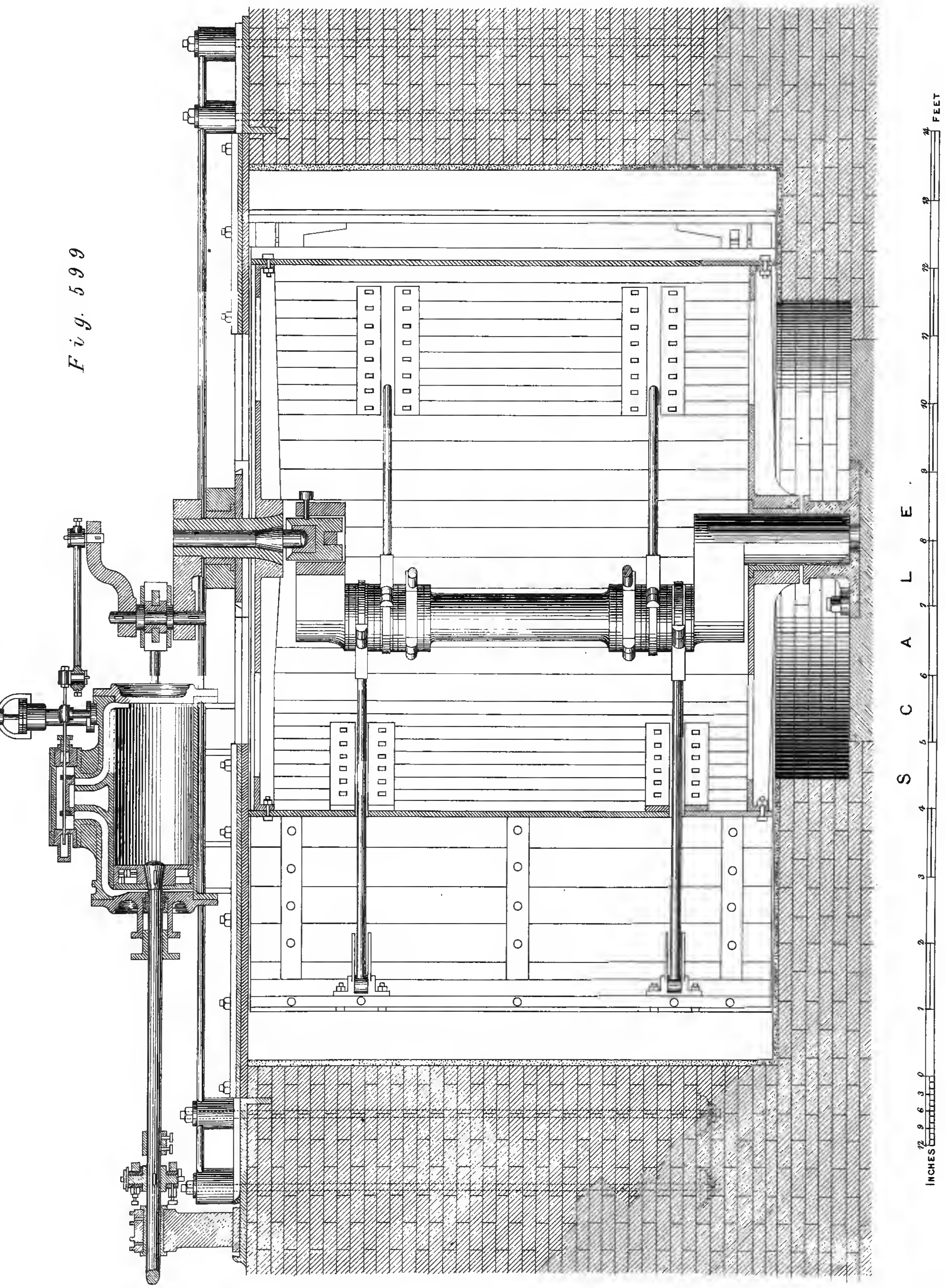
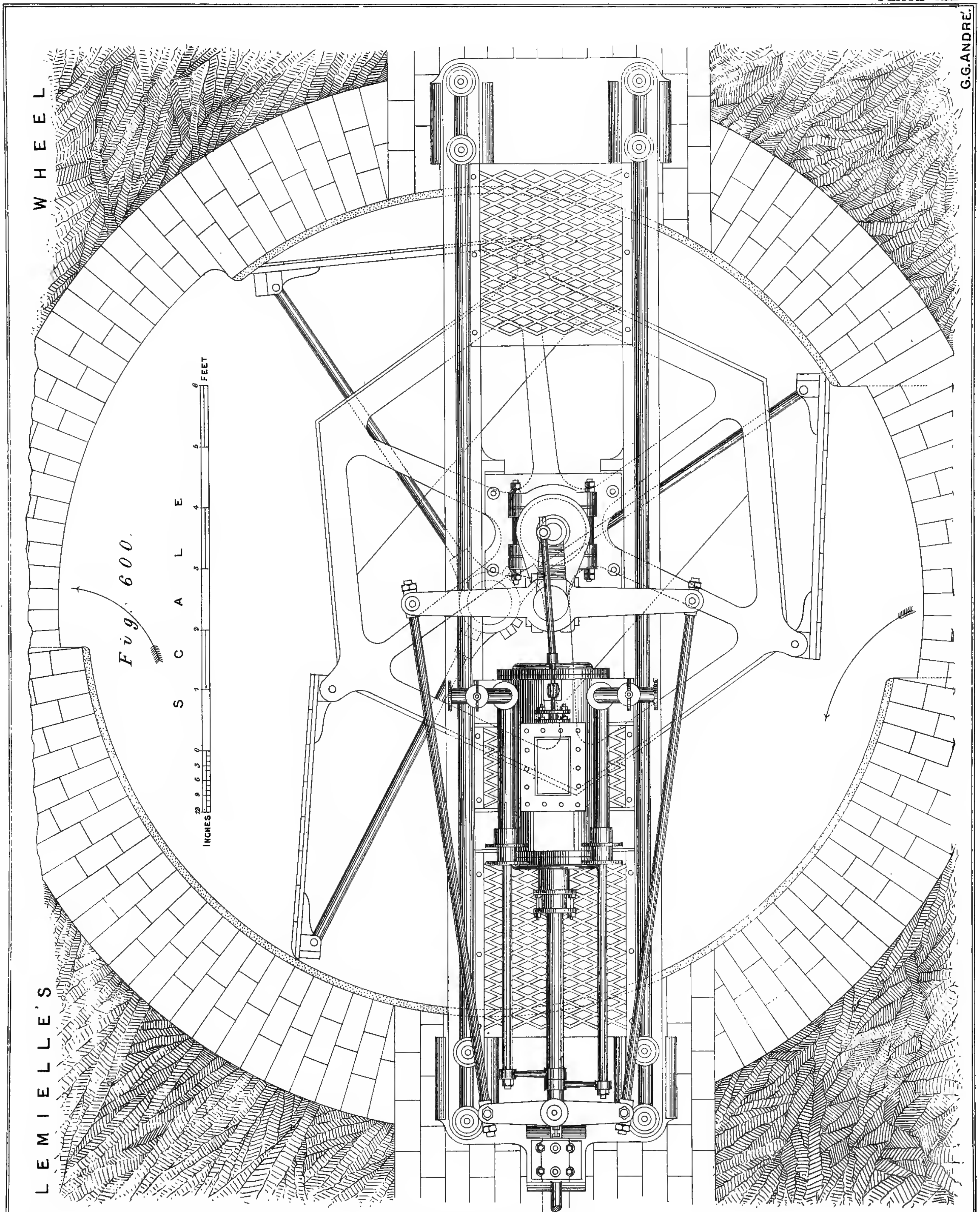
VENTILATING MACHINERY —— LEMIELLE'S WHEEL.

Fig. 599



G.G. ANDRÉ



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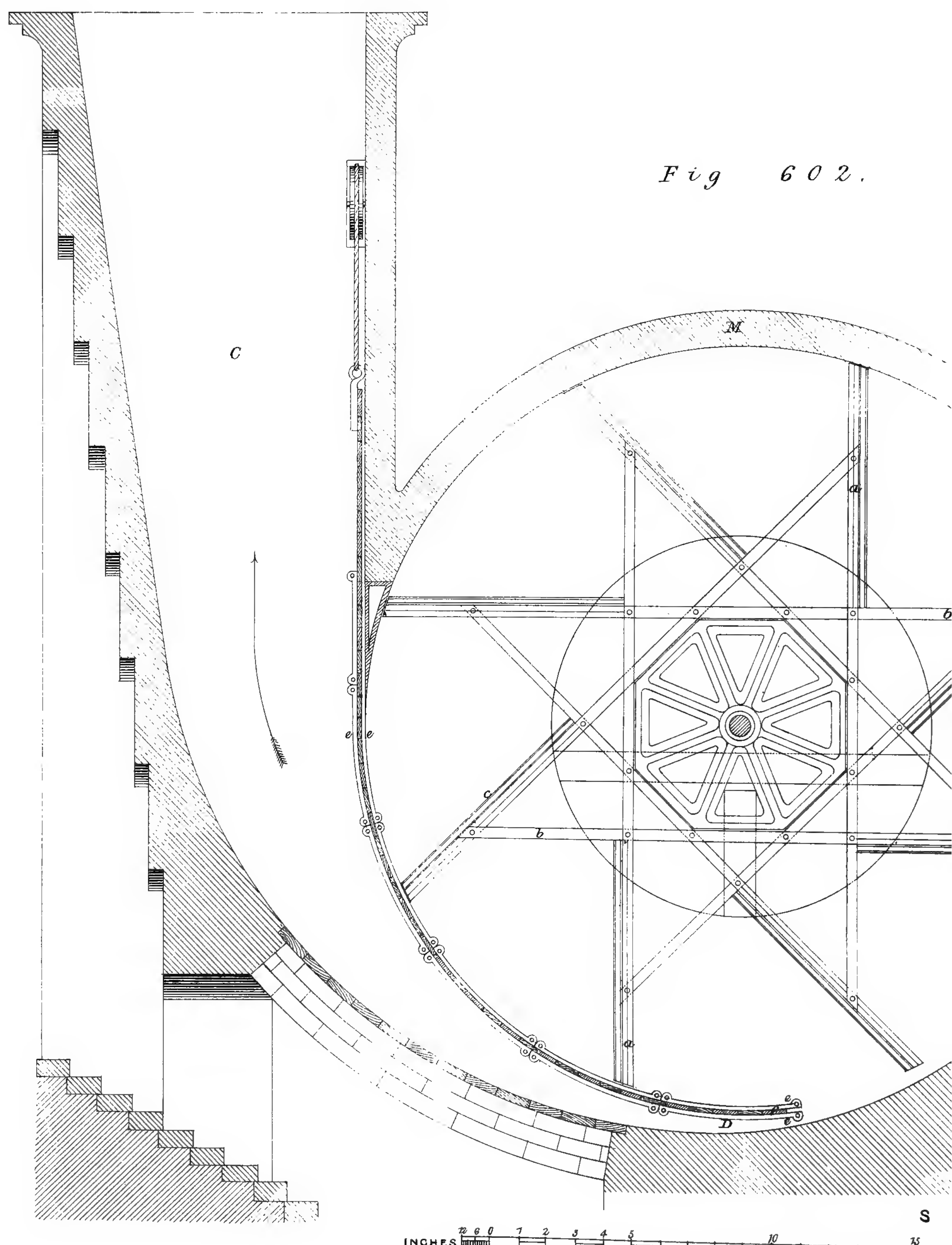
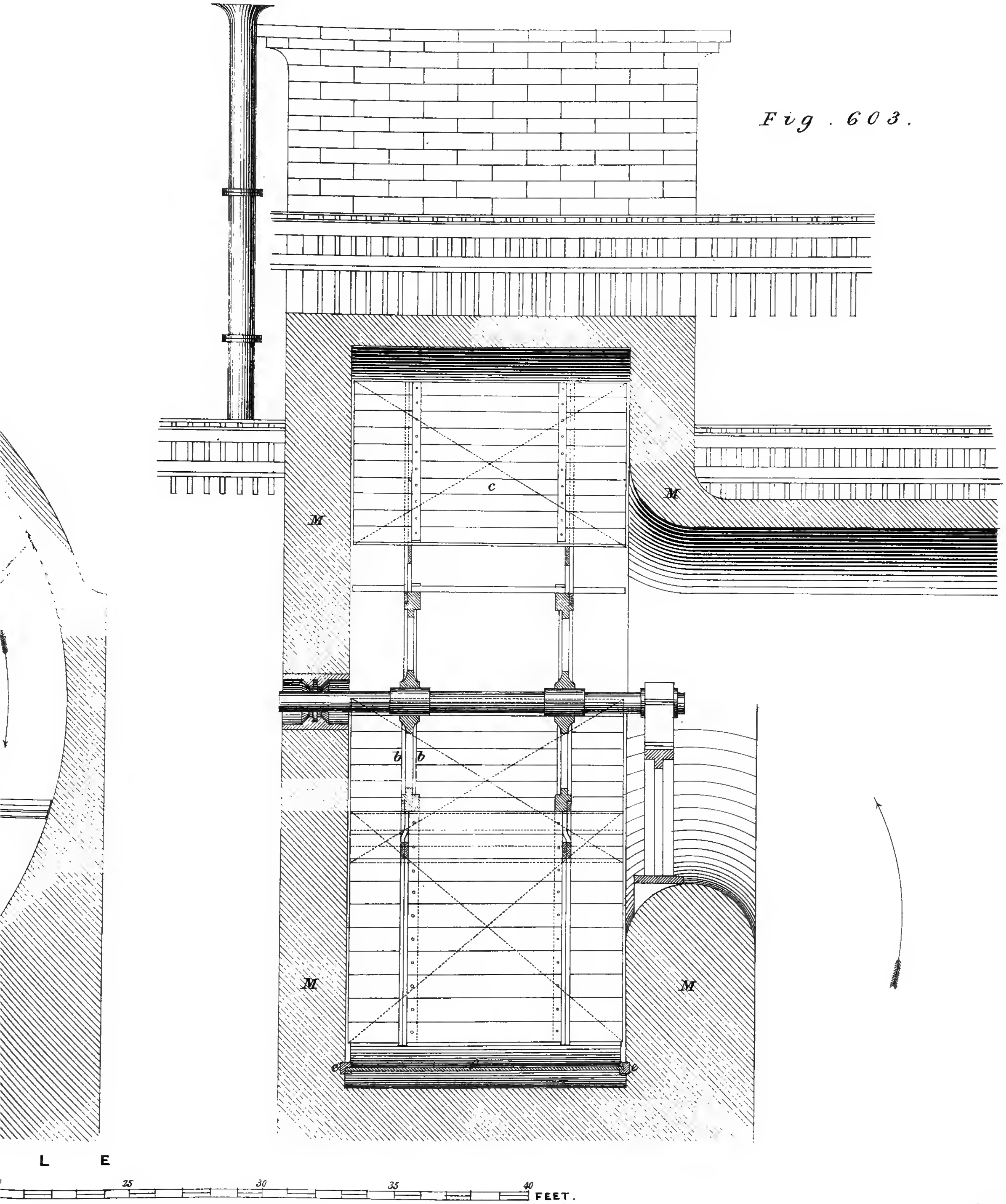
VENTILATING MACH



E&F

ERY — GUIBAL'S FAN



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VENTILATING MACHINERY — ROOT'S BLOWER, AIR PIPE, ANEMOMETER. —

Fig. 604

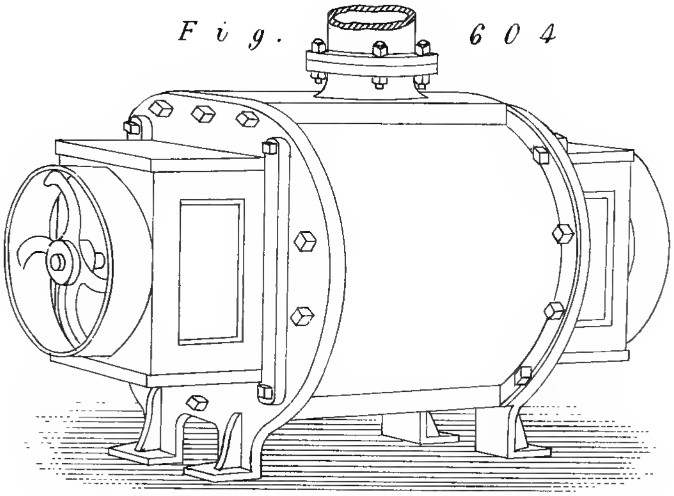


Fig. 605.

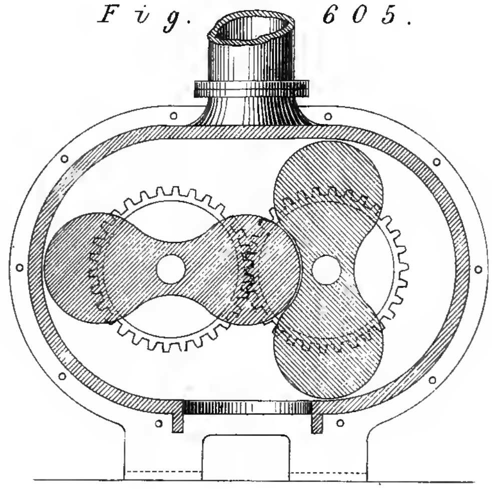
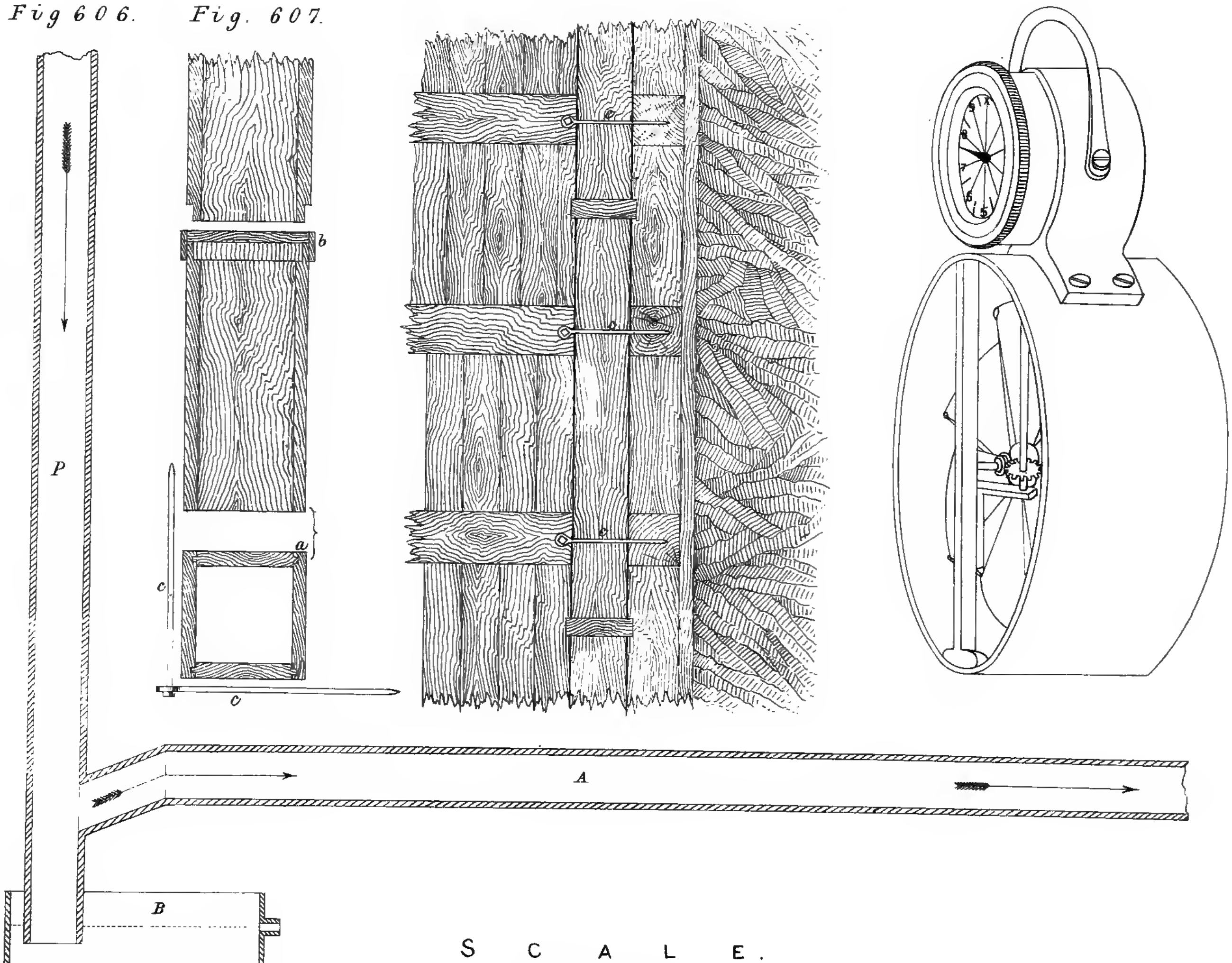


Fig 606. *Fig. 607.* *Fig 608* *Fig 609.*



SCALE.

FIGS. 606 AND 608.

INCHES 12 9 6 3 0 — 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 FEET

G. G. ANDRÉ

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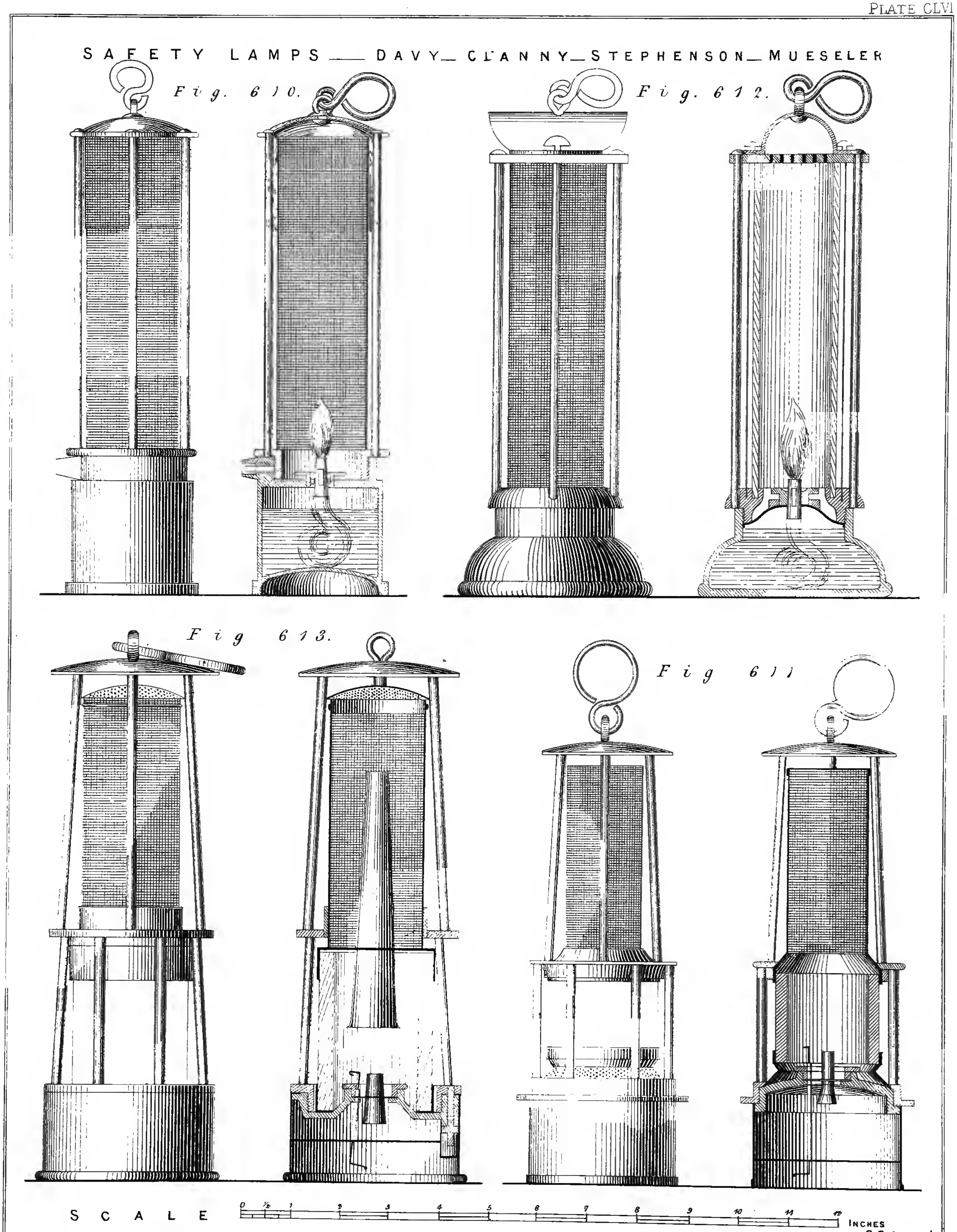

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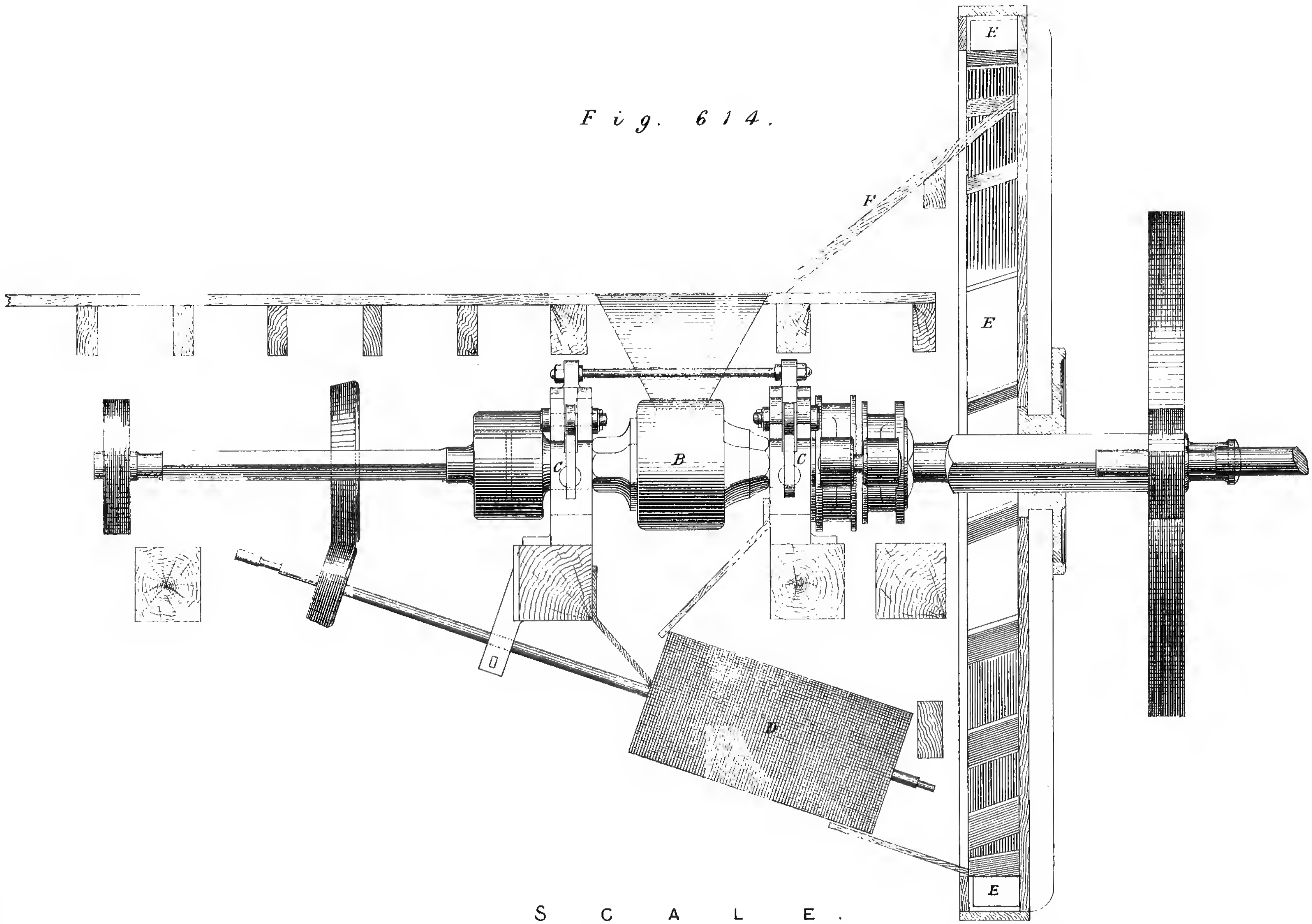
ORE DRESSING MACHINERY — CRUSHING ROLLS.

Fig. 614.



SCALE.

G.G. ANDRÉ

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ORE DRESSING MACHINERY — CRUSHING ROLLS

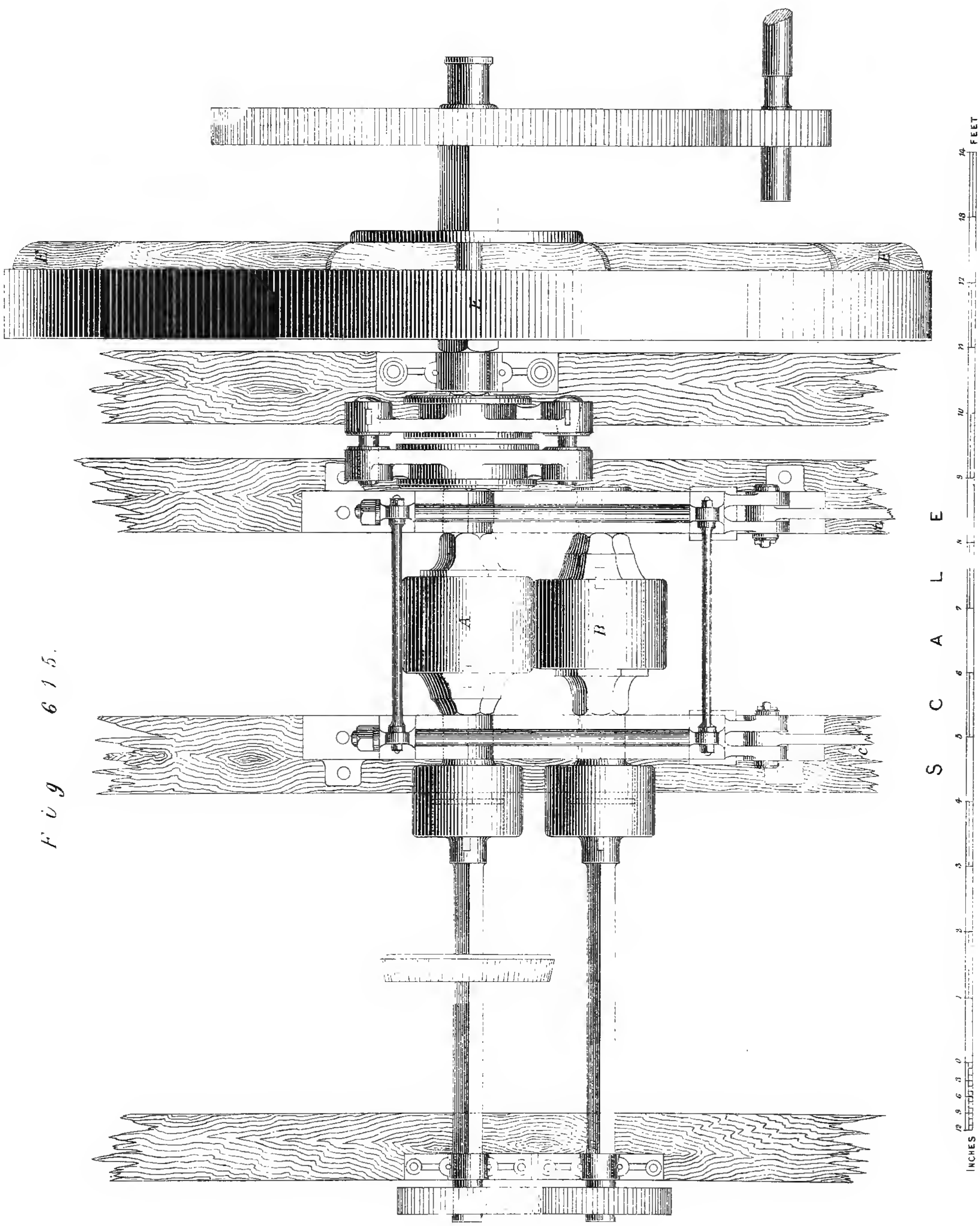


Fig. 615.

G. G. André

E. & F. N. Spon, London & New York.

ORE DRESSING MACHINERY — ROLLS — BLAKE'S STONE BREAKERS ECT.

Fig 616

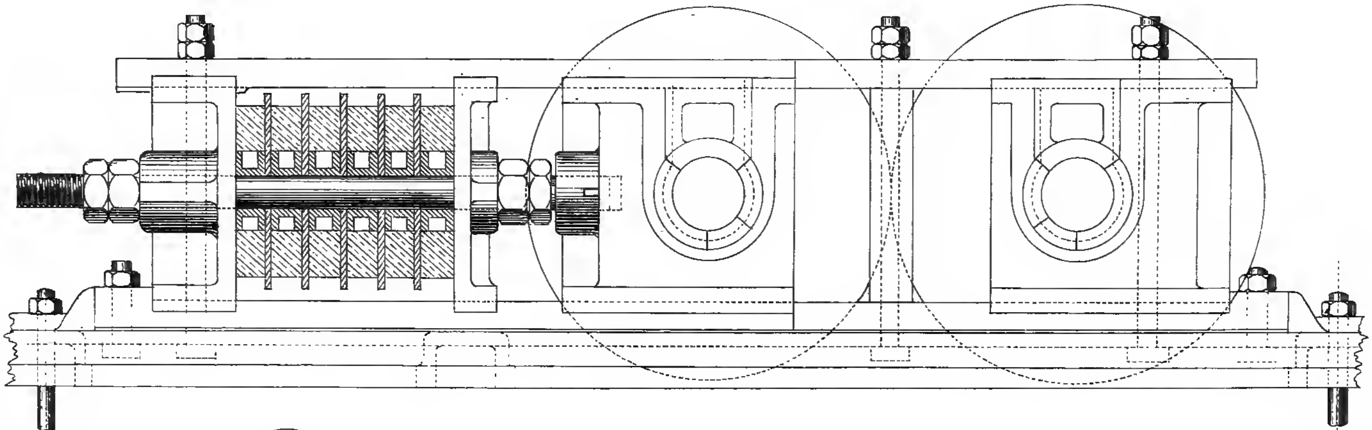


Fig. 617

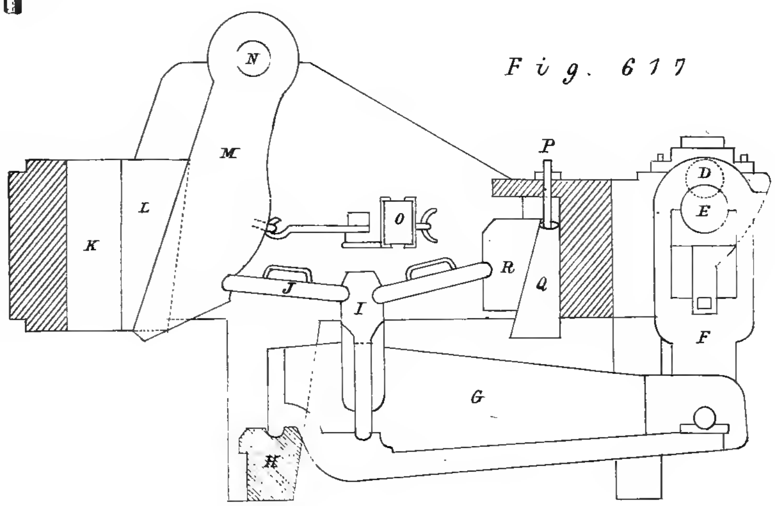


Fig. 621.

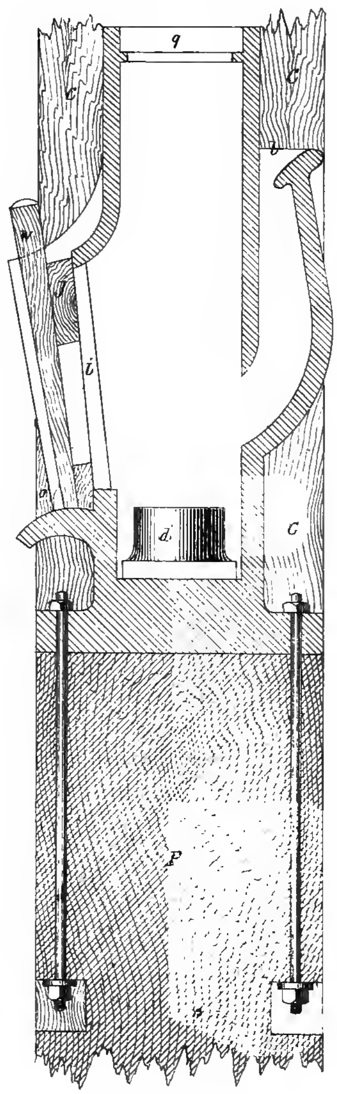
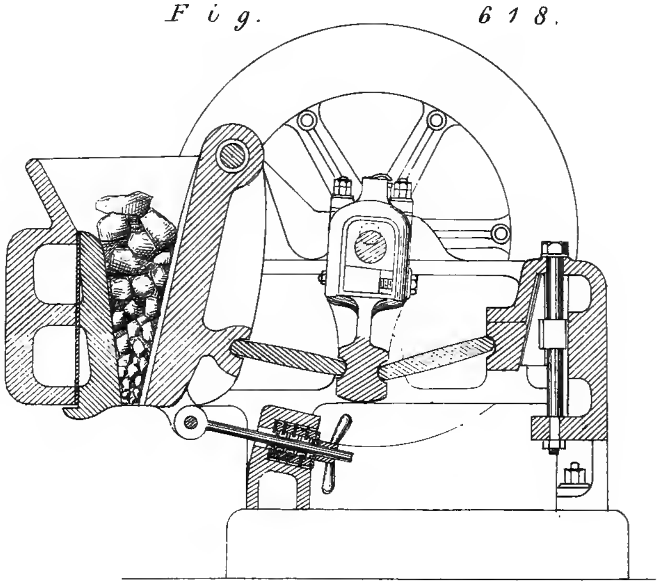


Fig. 618.



S C A L E.

FIG — 616.

INCHES 12 9 6 3 0 1 2 3 4 5 6 FEET

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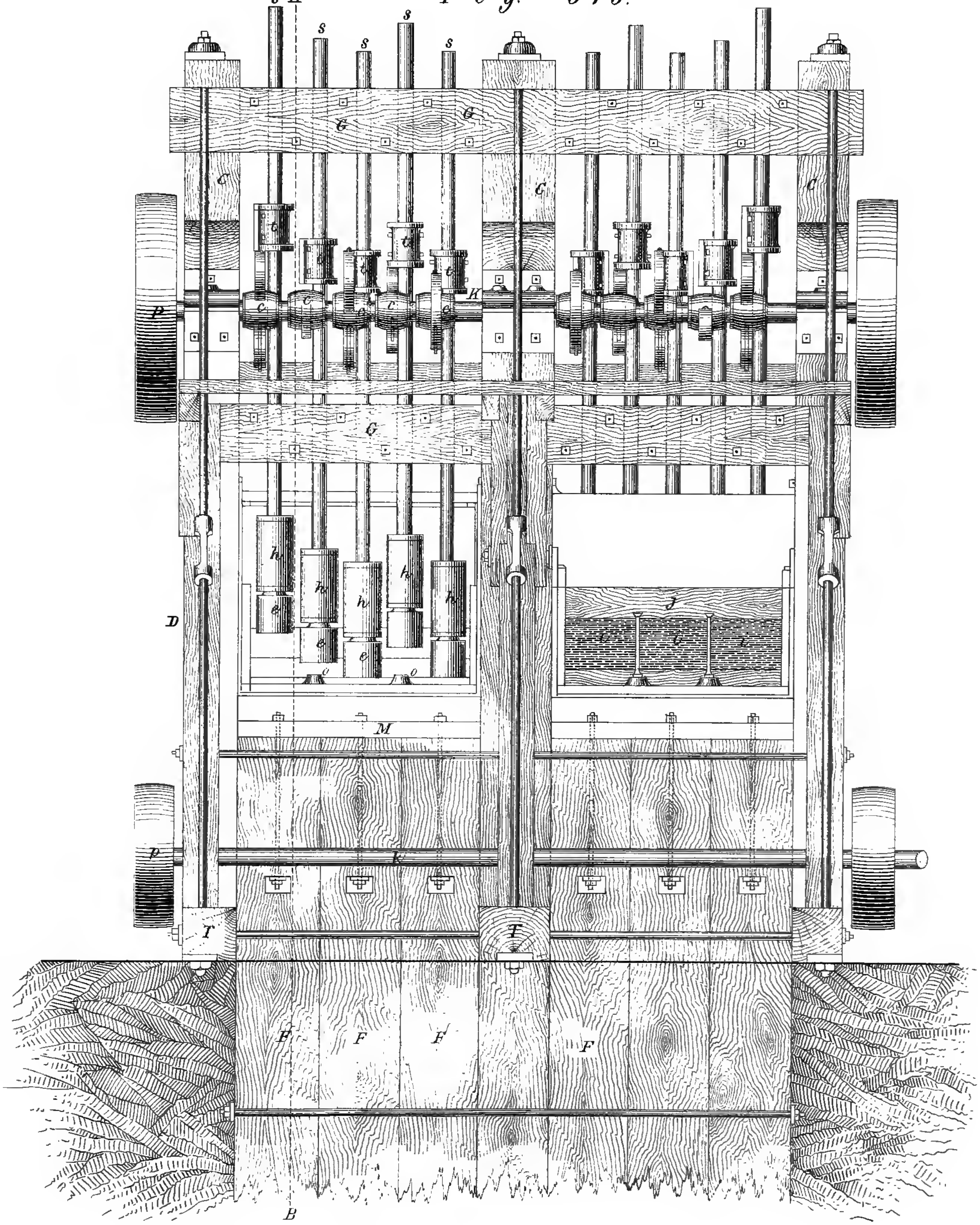
E & F.N Spon, London & New York.

ORE DRESSING MACHINERY — STAMPS.

Fig. 619.



SCALE.

Inches 12 9 6 3 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 Feet

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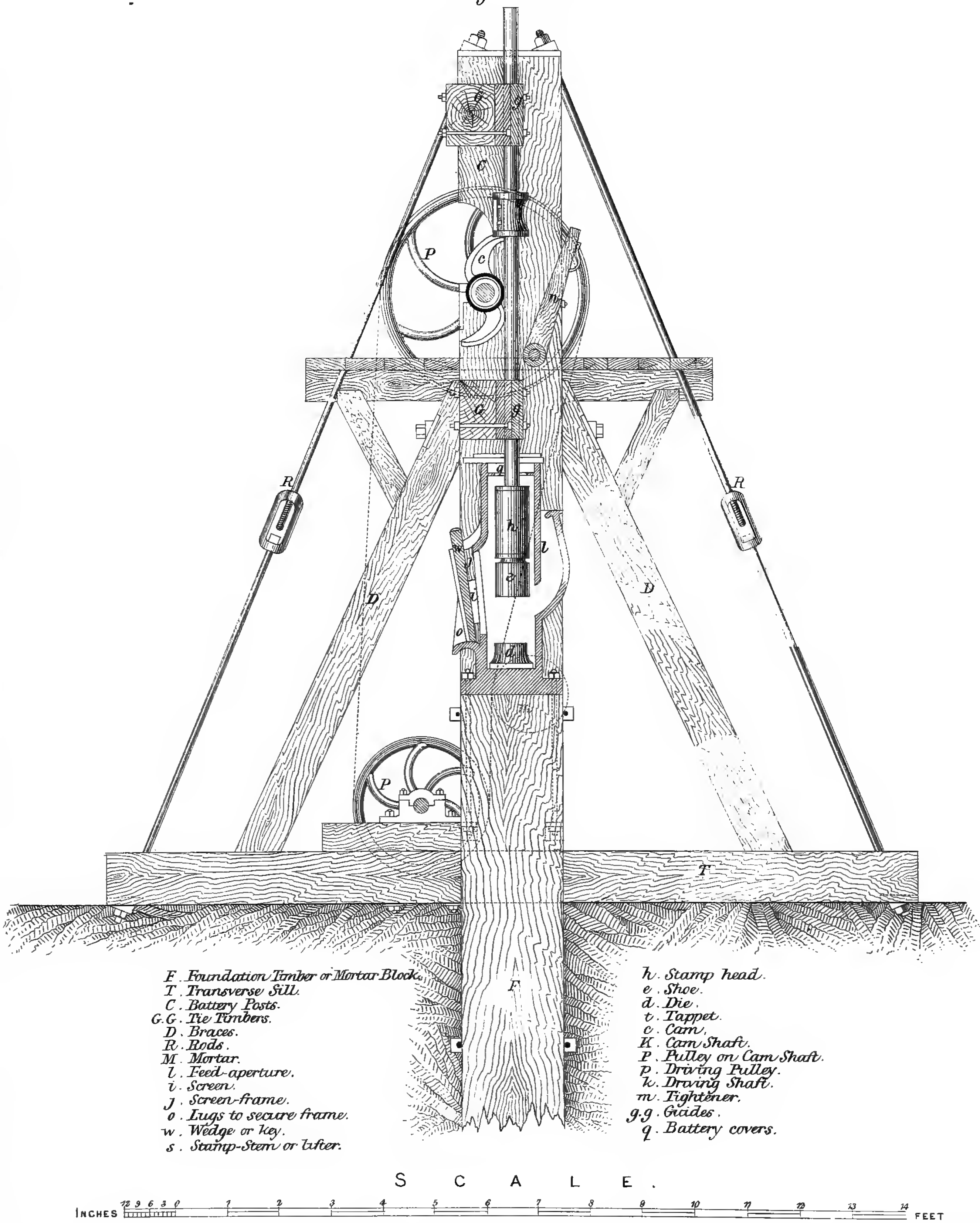
ORE DRESSING MACHINERY —— STAMPS.

Fig. 620



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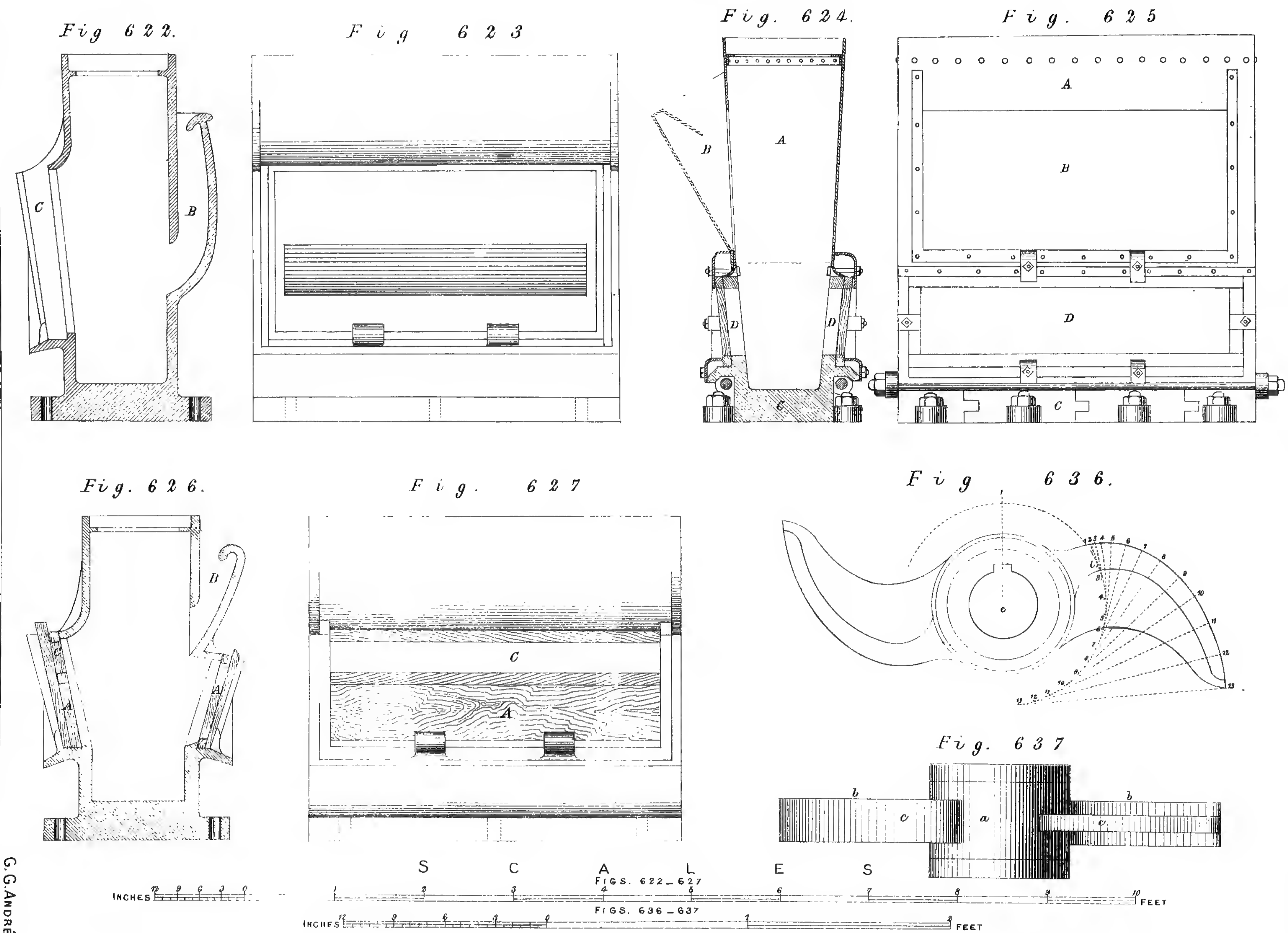
ORE DRESSING MACHINERY —— MORTARS — CAM FOR STAMPS



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ORE DRESSING MACHINERY —— STAMPS — DIES, LIFTERS, STAMP-HEADS, ETC.

Fig. 632

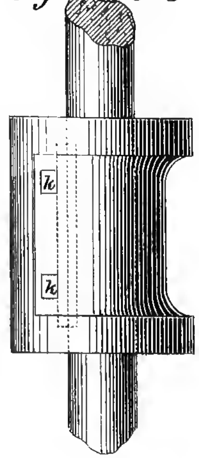


Fig. 633

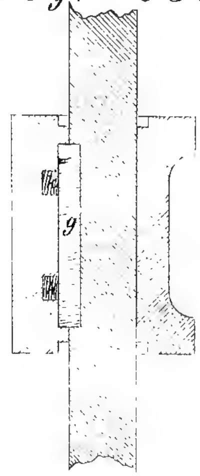


Fig. 631

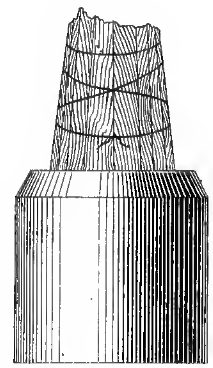


Fig. 634.

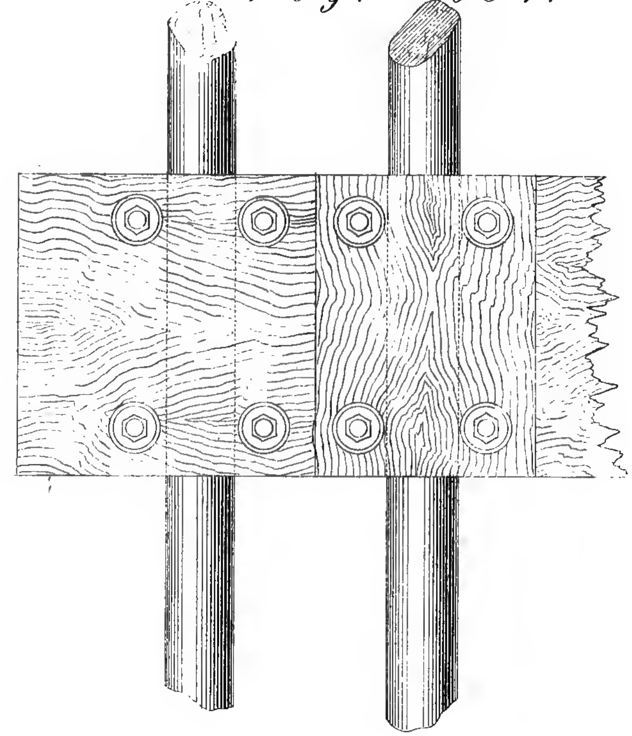


Fig 629.

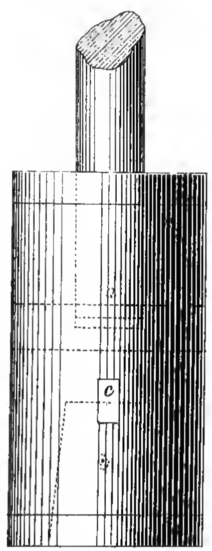


Fig. 630

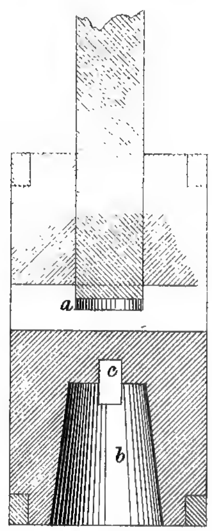


Fig. 628.

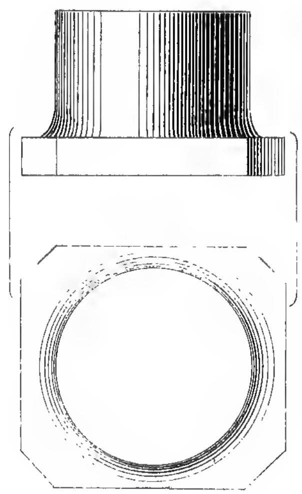
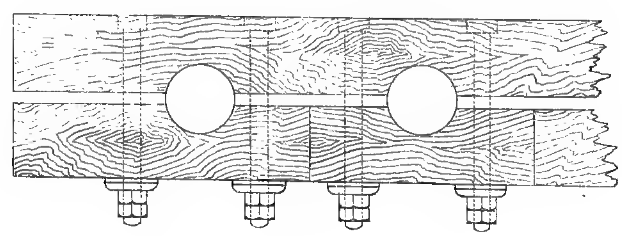


Fig. 635.



SCALE

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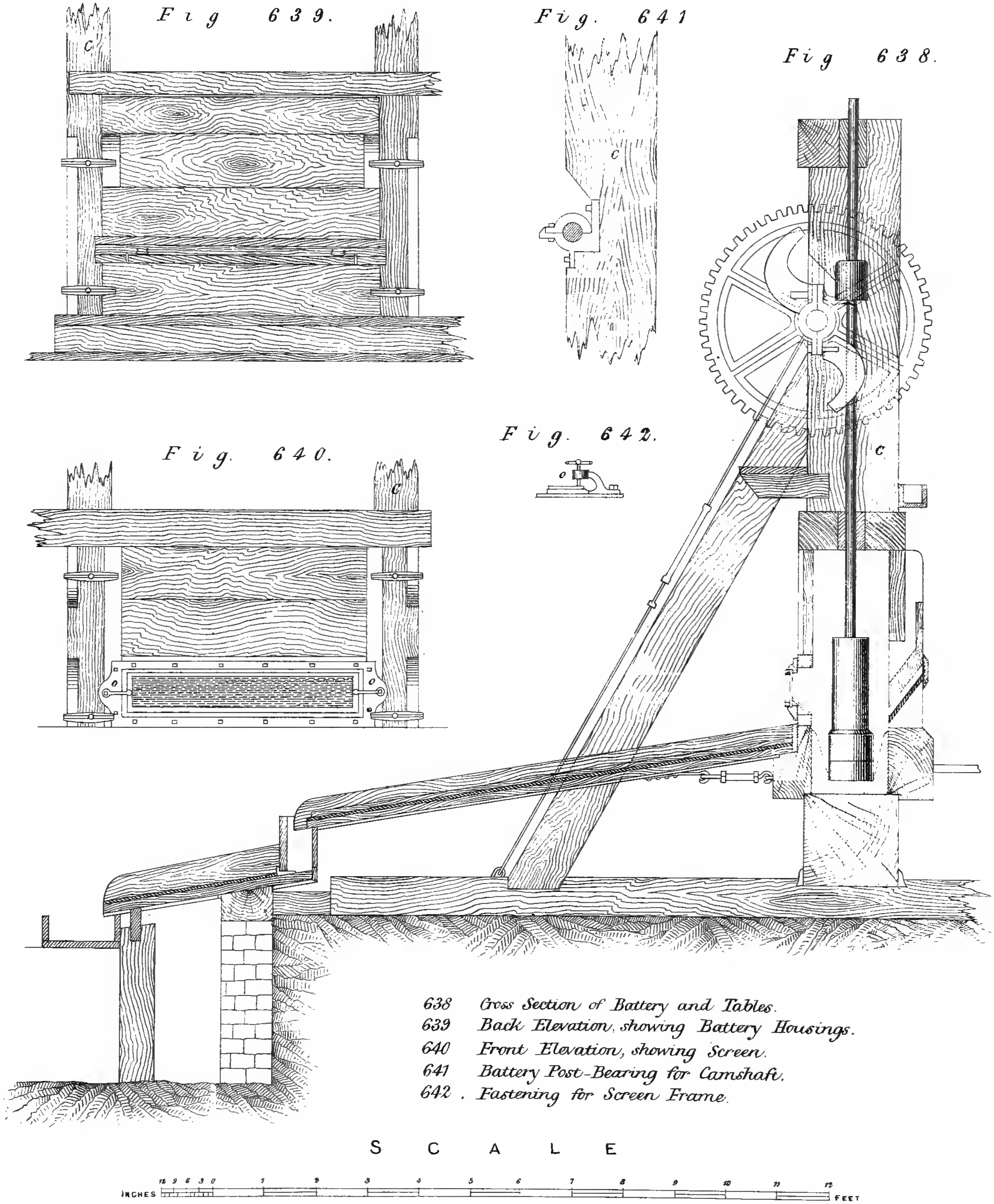
Ore Dressing Machinery — Colorado Stamps.



638 Cross Section of Battery and Tables.
639 Back Elevation, showing Battery Housings.
640 Front Elevation, showing Screen.
641 Battery Post-Bearing for Camshaft.
642. Fastening for Screen Frame.

G.G. André

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ORE DRESSING MACHINERY — RITTINGER TABLE.

Fig. 643

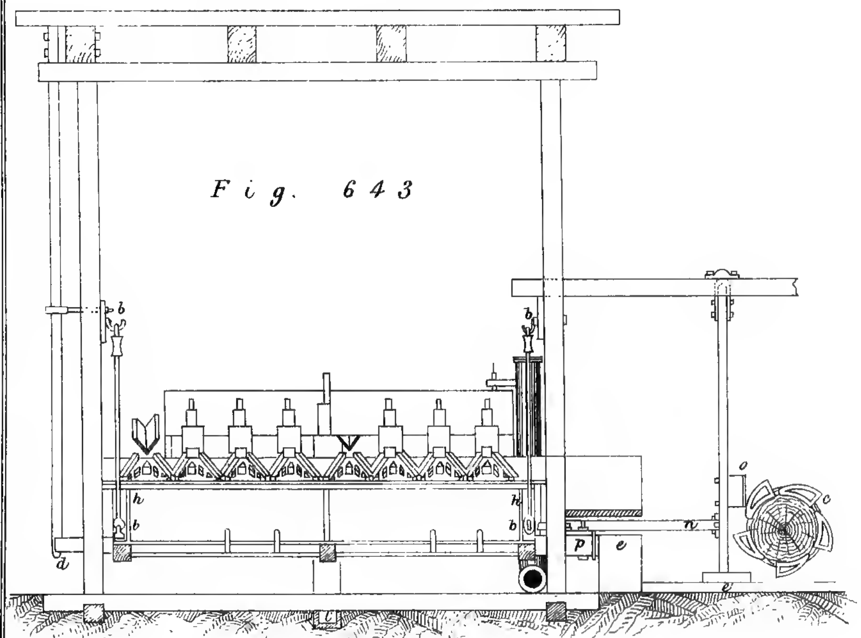


Fig 648.

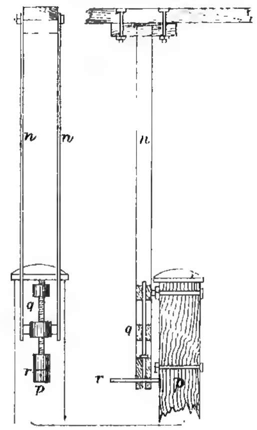


Fig 645.

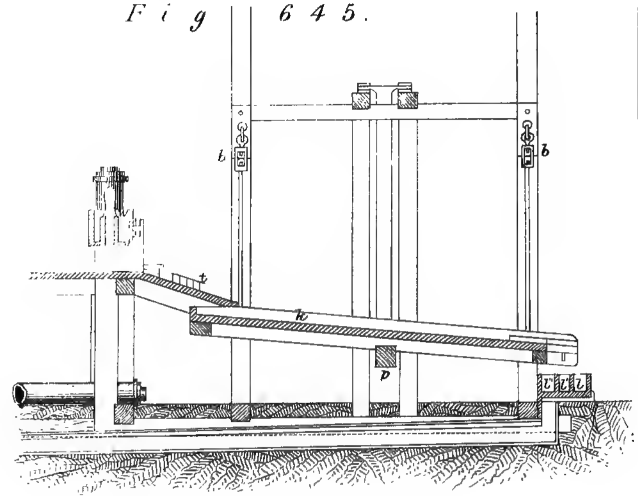


Fig 647

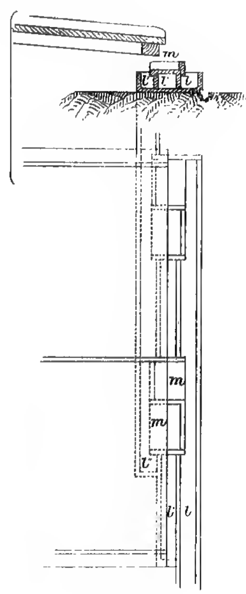


Fig 446

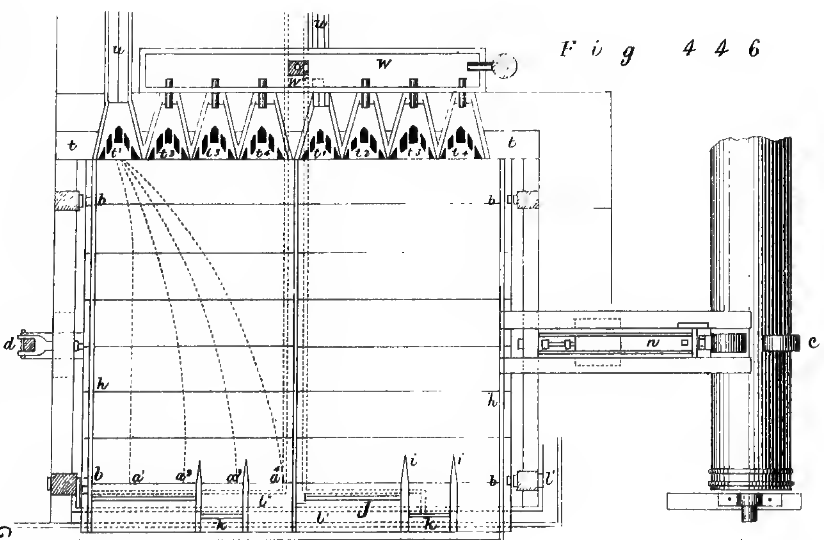
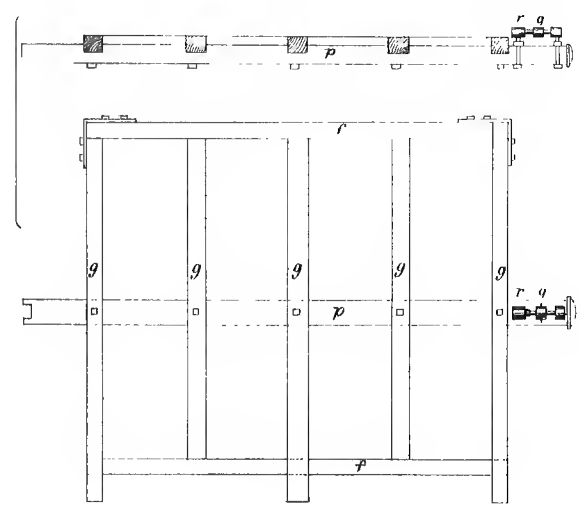
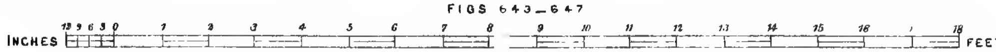


Fig. 646



SCALE

FIGS 643_647



G.G ANDRÉ

E&F.N.Spon, London & New York.

ORE DRESSING MACHINERY — GRINDING & AMALGAMATING PANS.

Fig 669

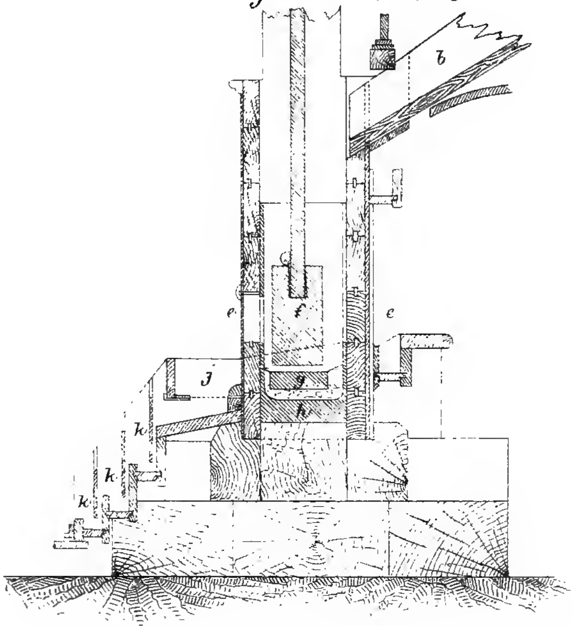


Fig. 650.

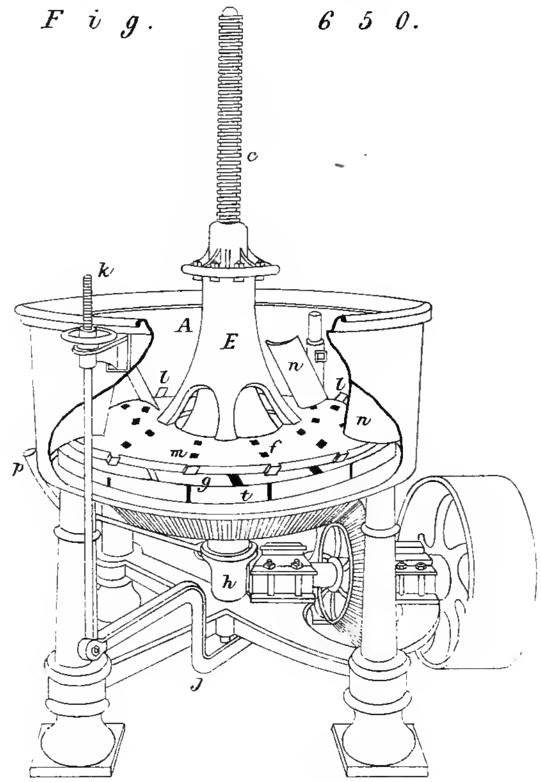


Fig. 652

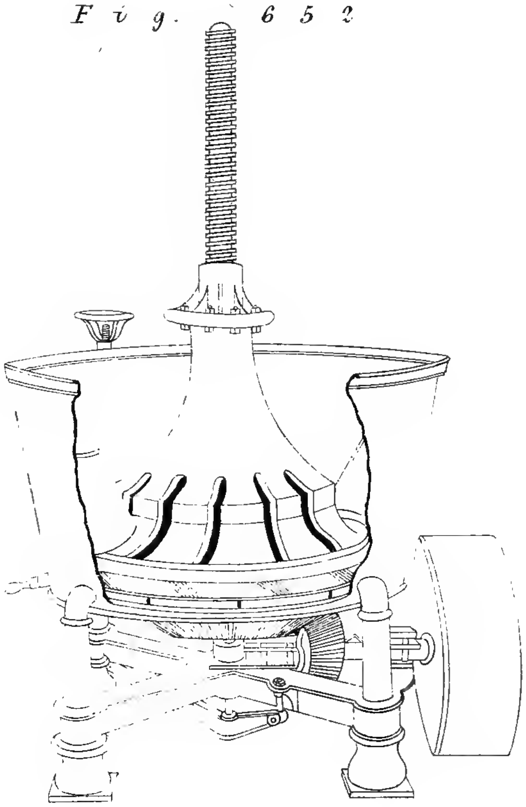
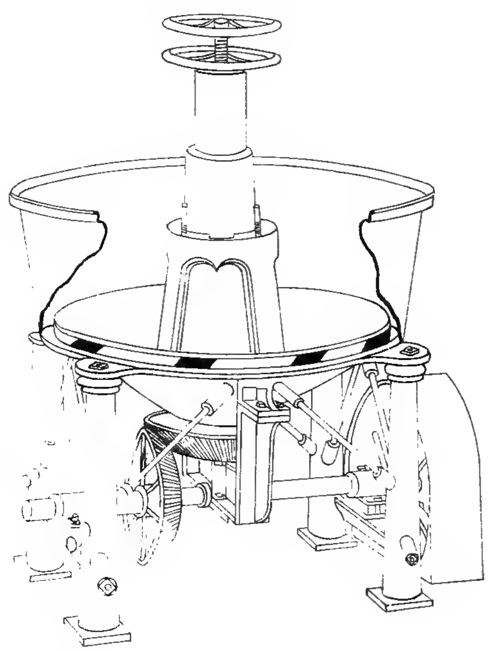


Fig. 651



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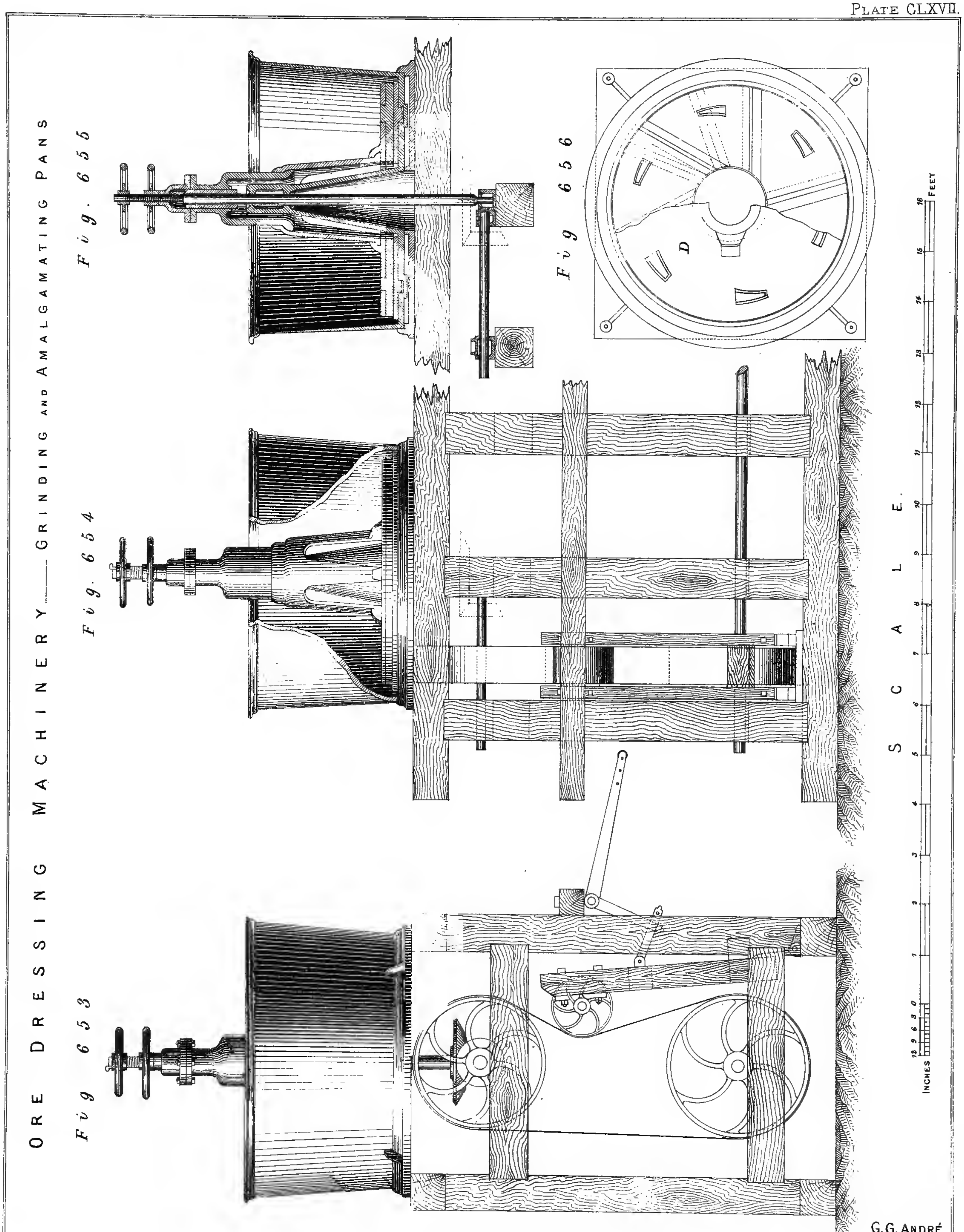

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ORE DRESSING MACHINERY — AMALGAMA

Fig 657.

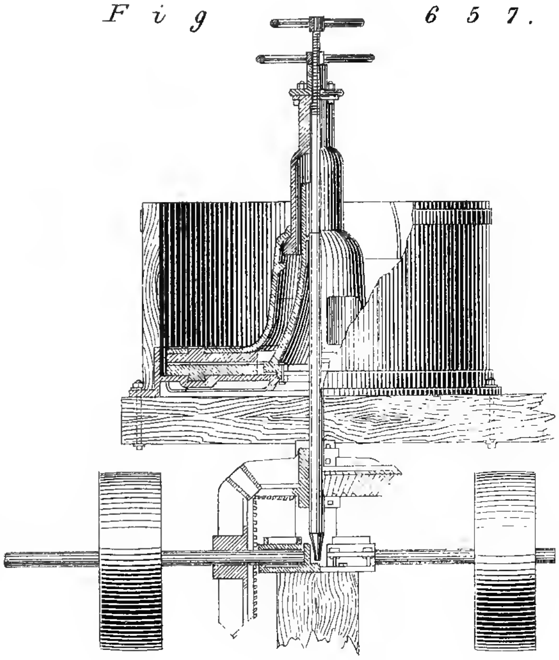


Fig 658.

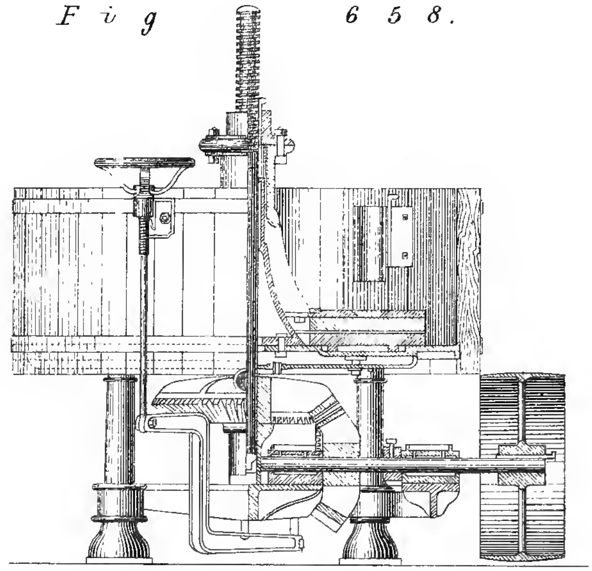


Fig 661.

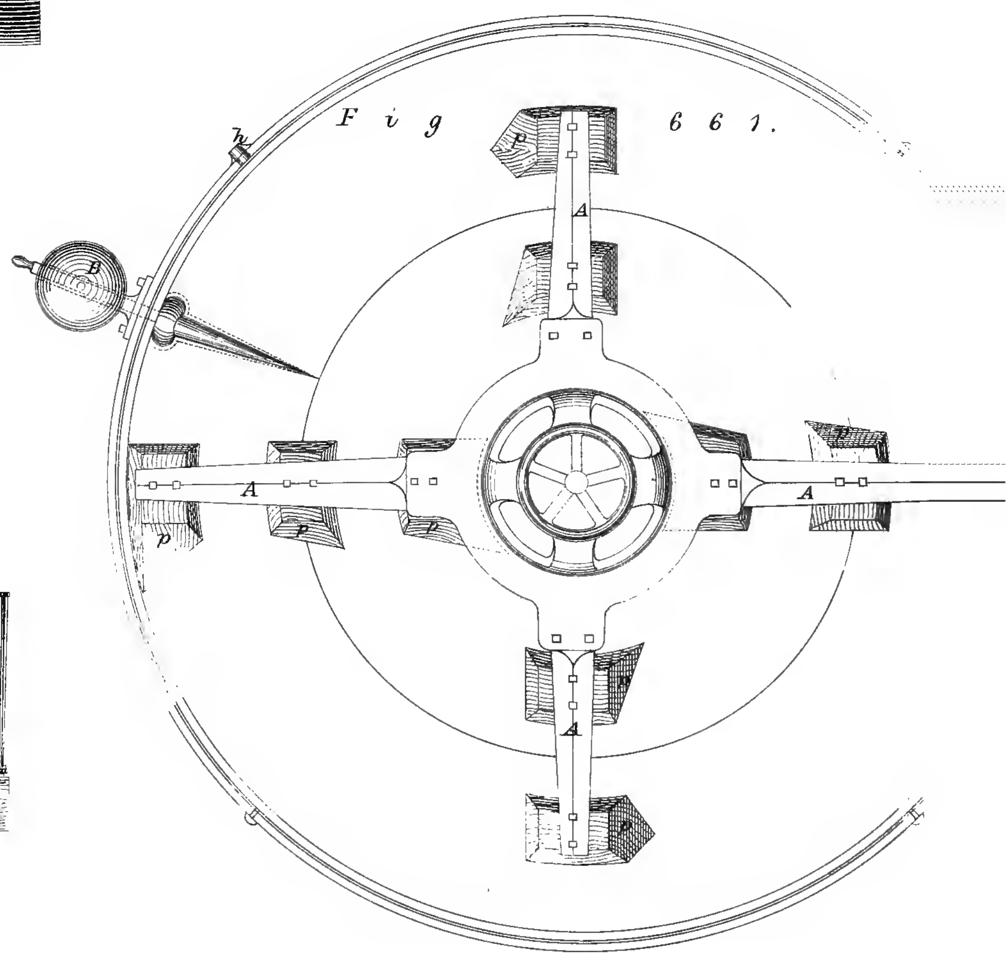
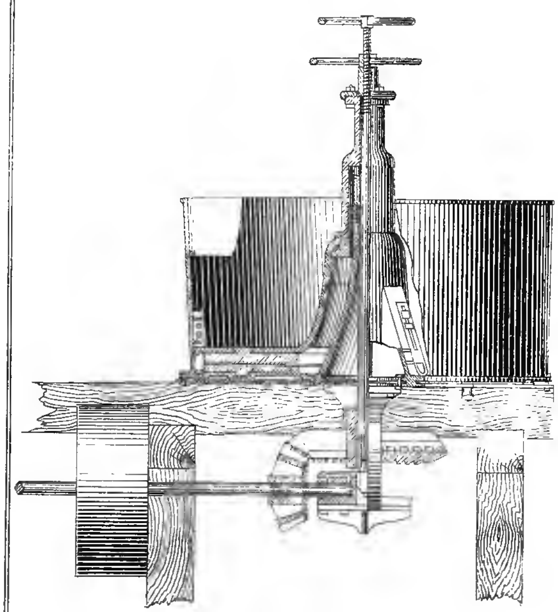


Fig 659



S

INCHES 12 9 6 3 0 1 2 3

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PANS — SEPARATORS — ORE WASHING MACHINE.

Fig. 660.

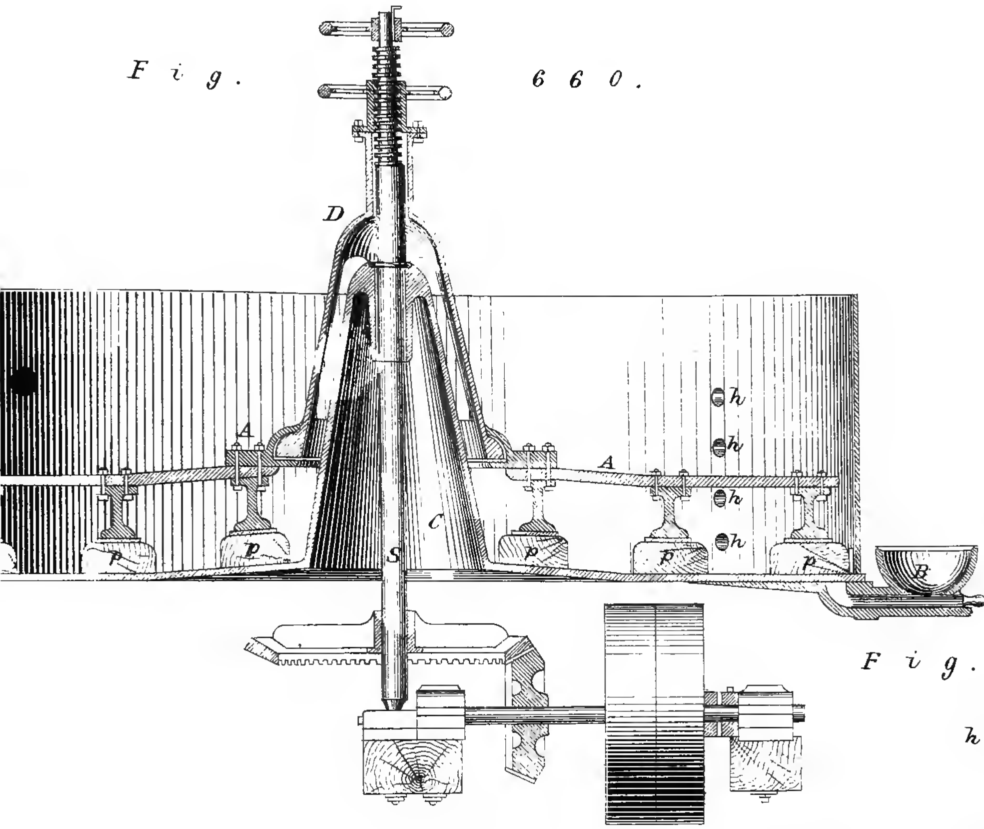


Fig. 663.

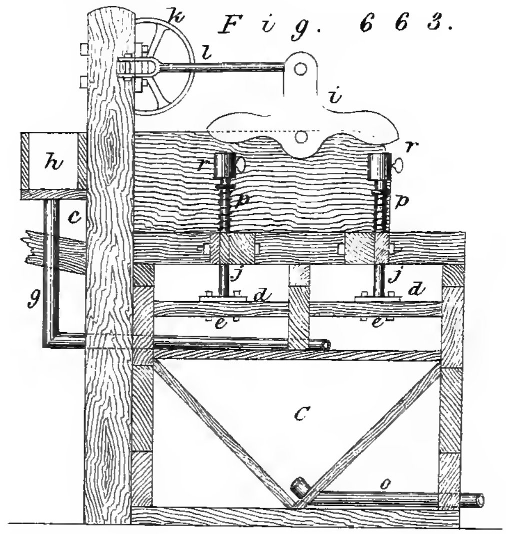


Fig. 664.

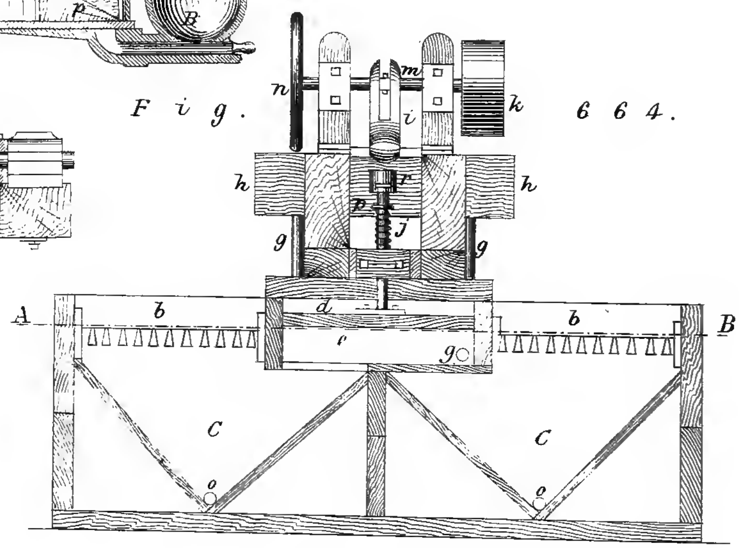


Fig. 665.

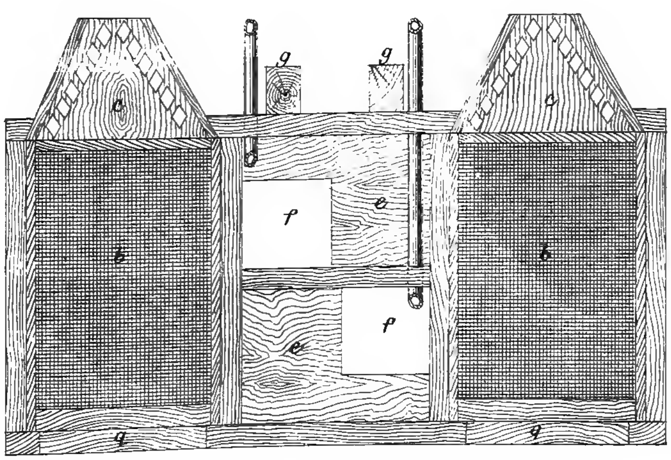
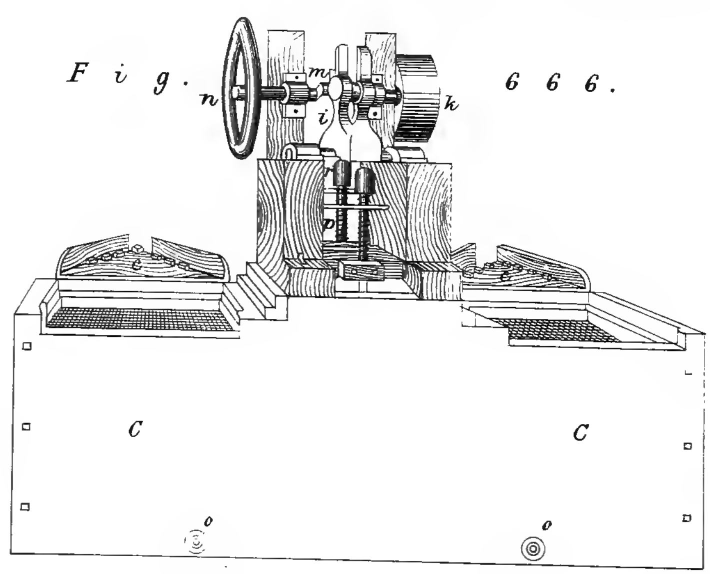


Fig. 666.



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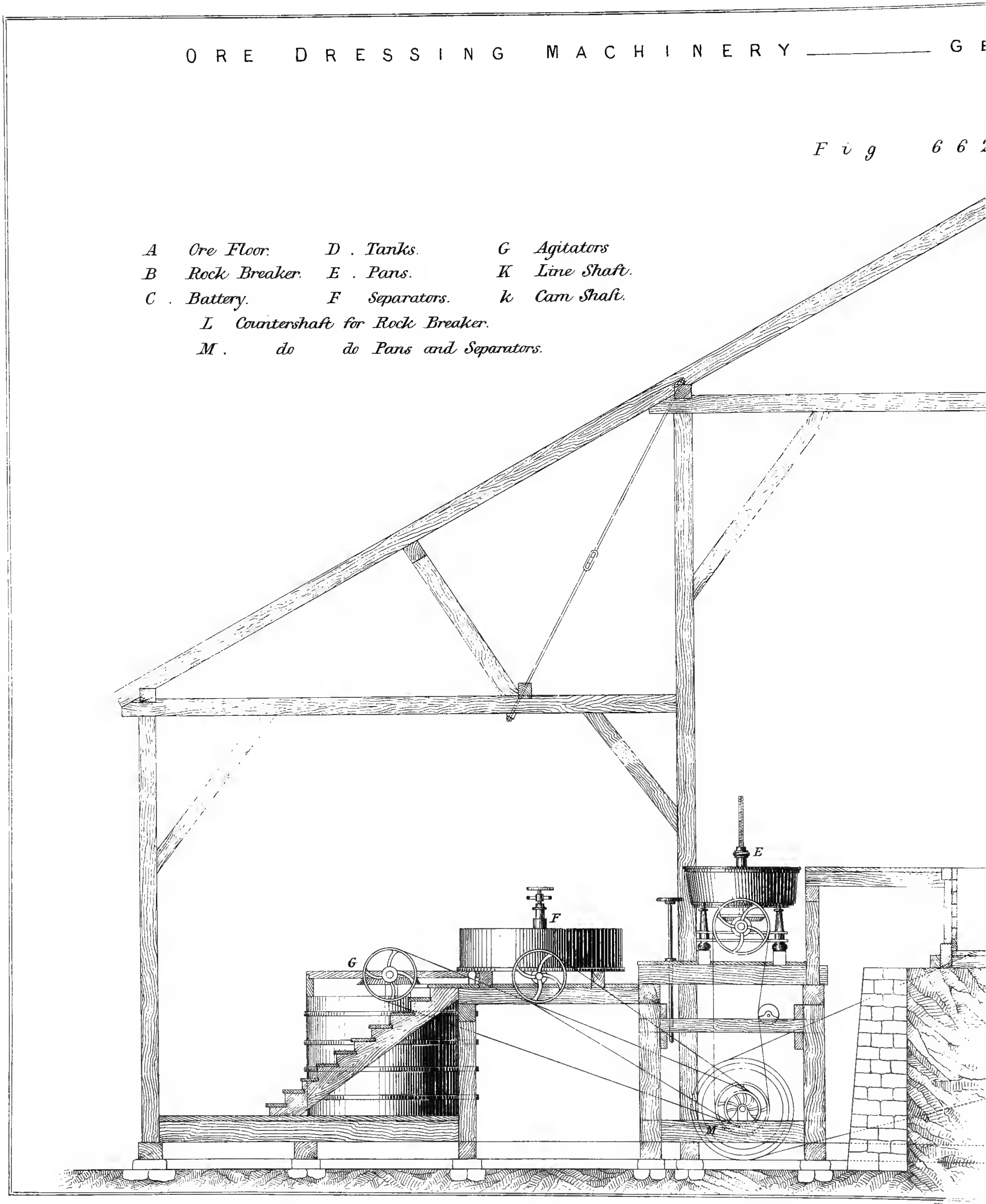
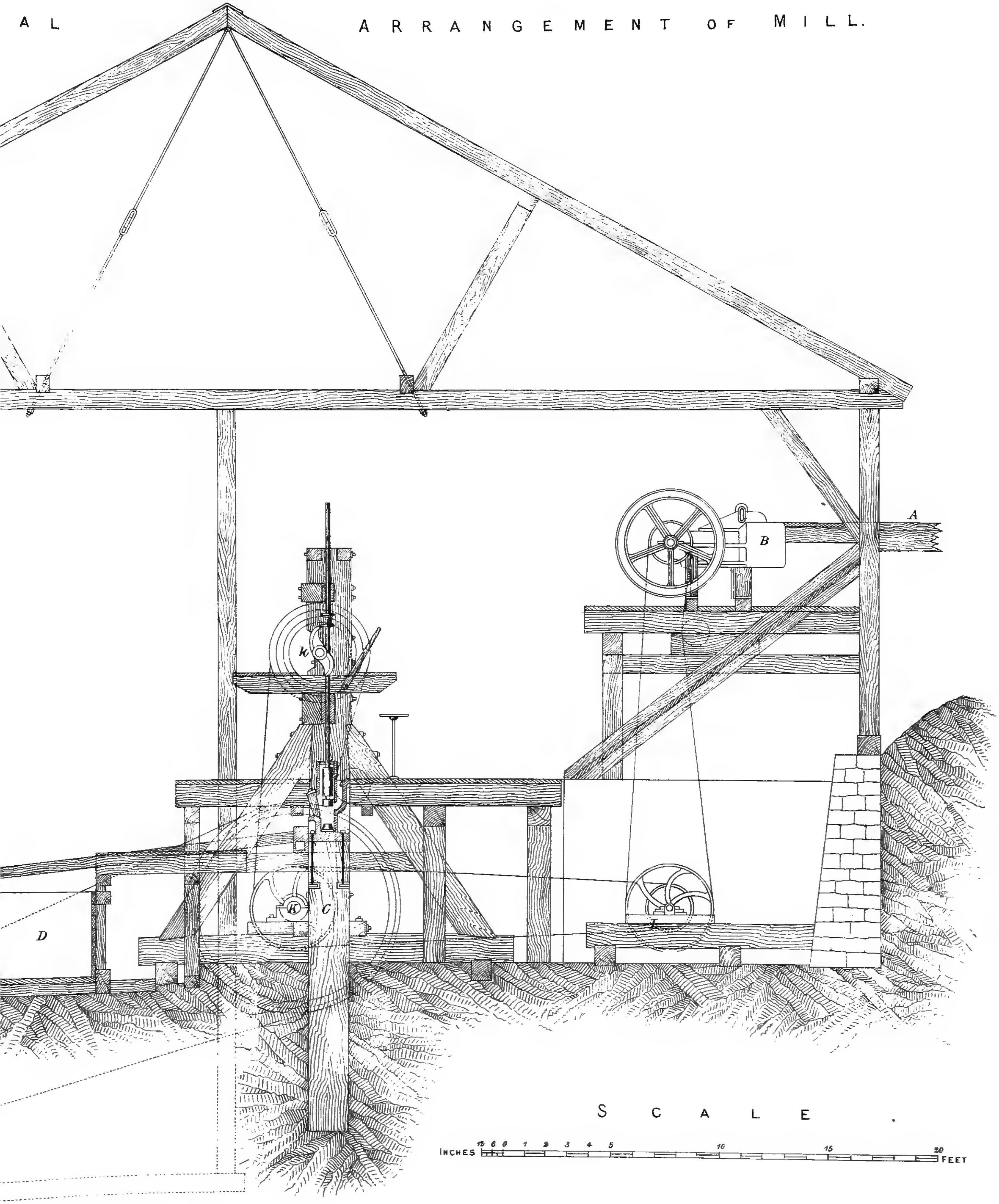

ORE DRESSING MACHINERY
Fig 66
A Ore Floor.
B Rock Breaker.
C . Battery.
D . Tanks.
E . Pans.
F Separators.
G Agitators
K Line Shaft.
k Cam Shaft.
L Countershaft for Rock Breaker.
M . do do Pans and Separators.
E
F
G
M

A L   ARRANGEMENT OF MILL.



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New York

ORE DRESSING MACHINERY

Fig. 670

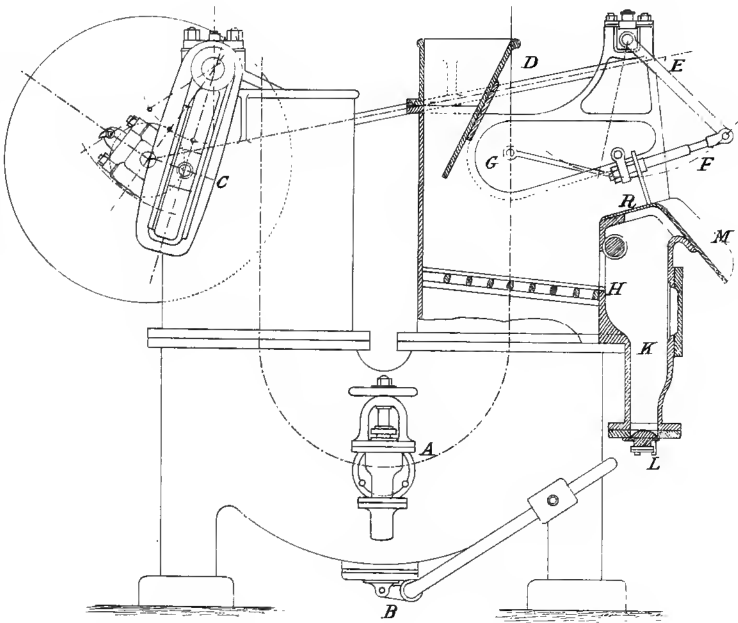


Fig. 671.

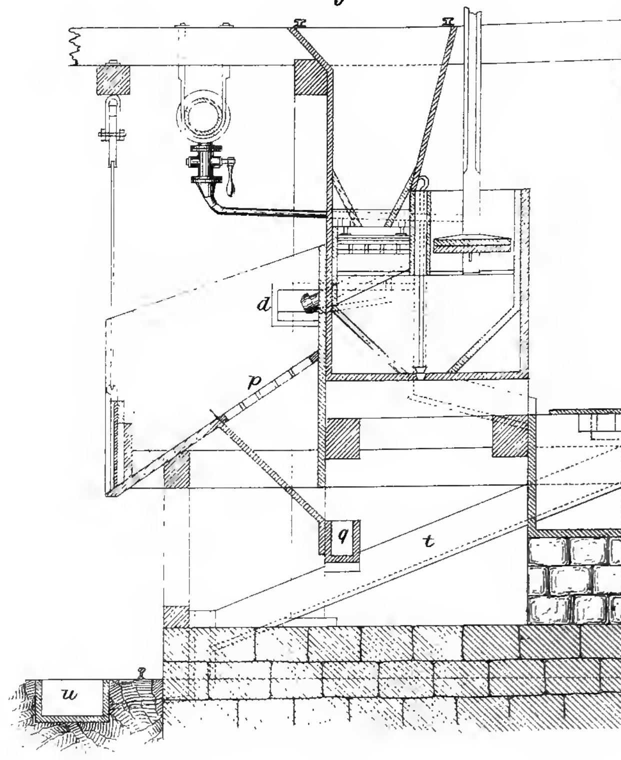


Fig. 672.

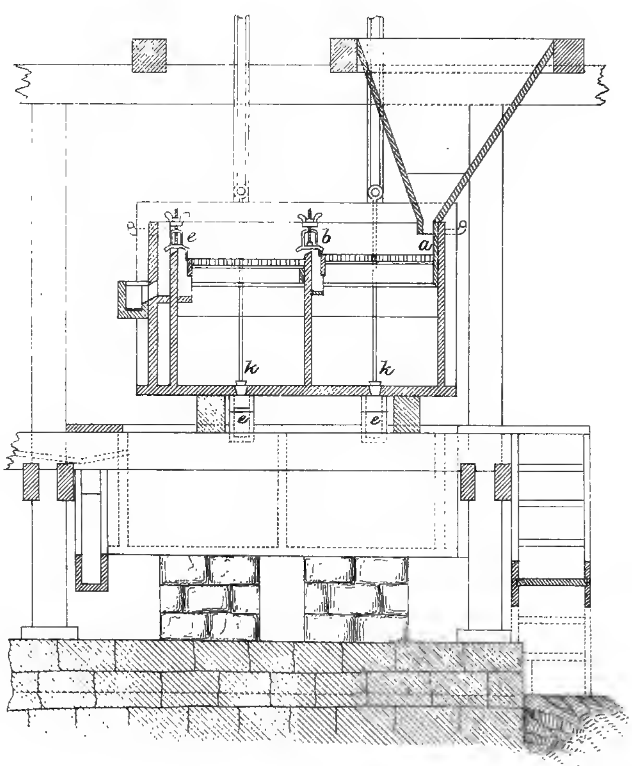
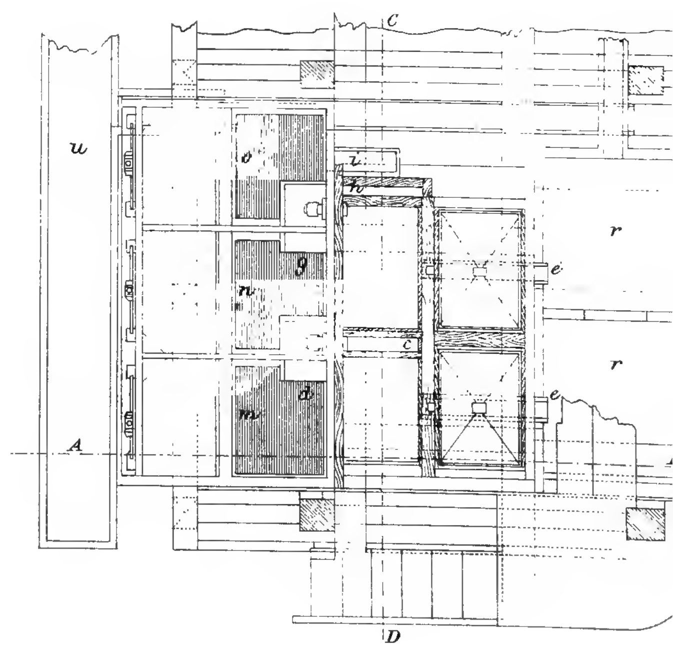


Fig. 673



HAND AND SELF-ACTING JIGGING MACHINES

Fig. 667

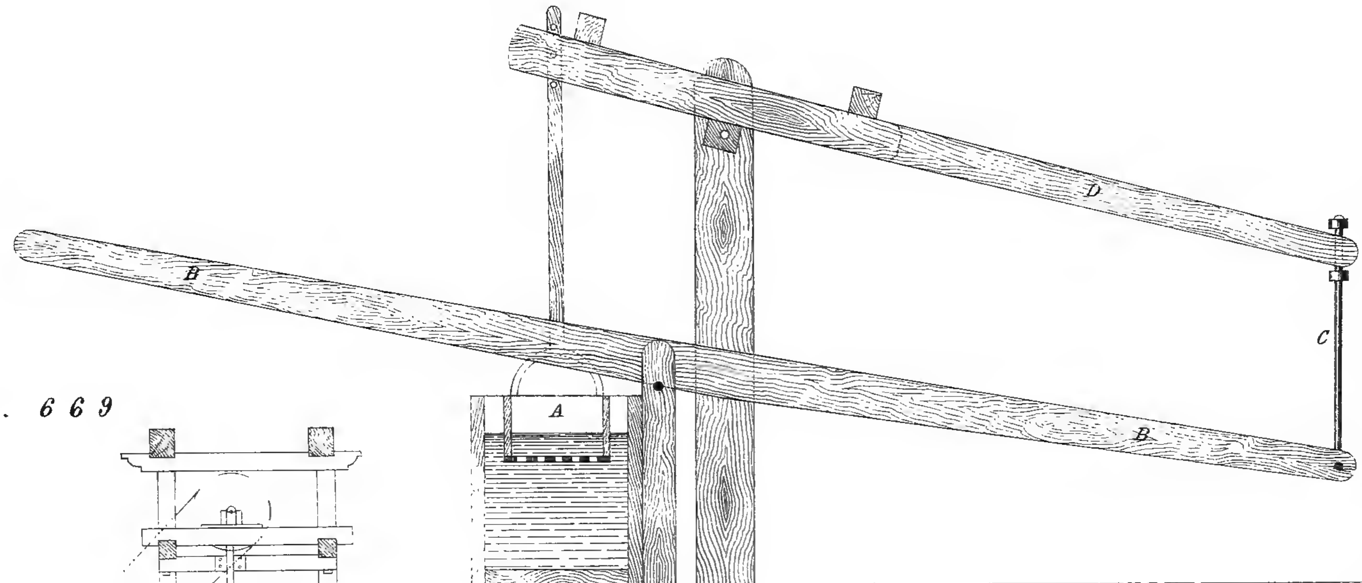


Fig. 669

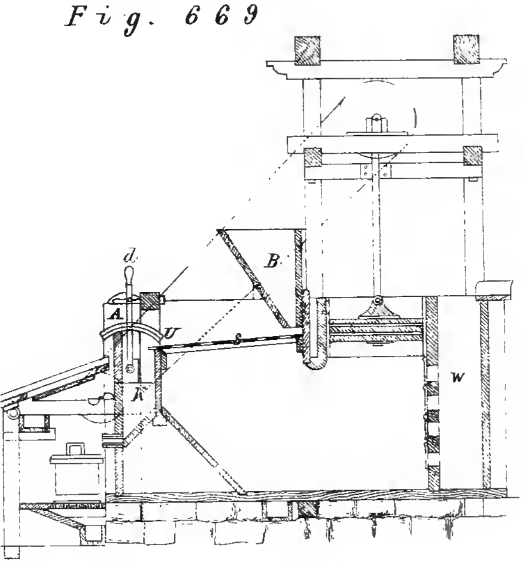
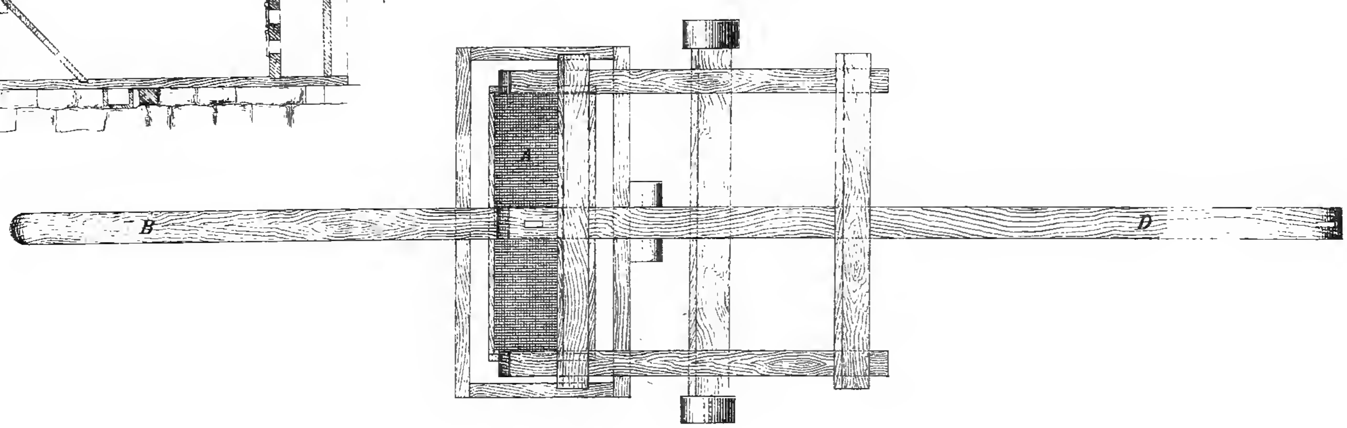


Fig. 668



SCALES

FIGS. 671 – 673.

FIGS. 667 – 668.

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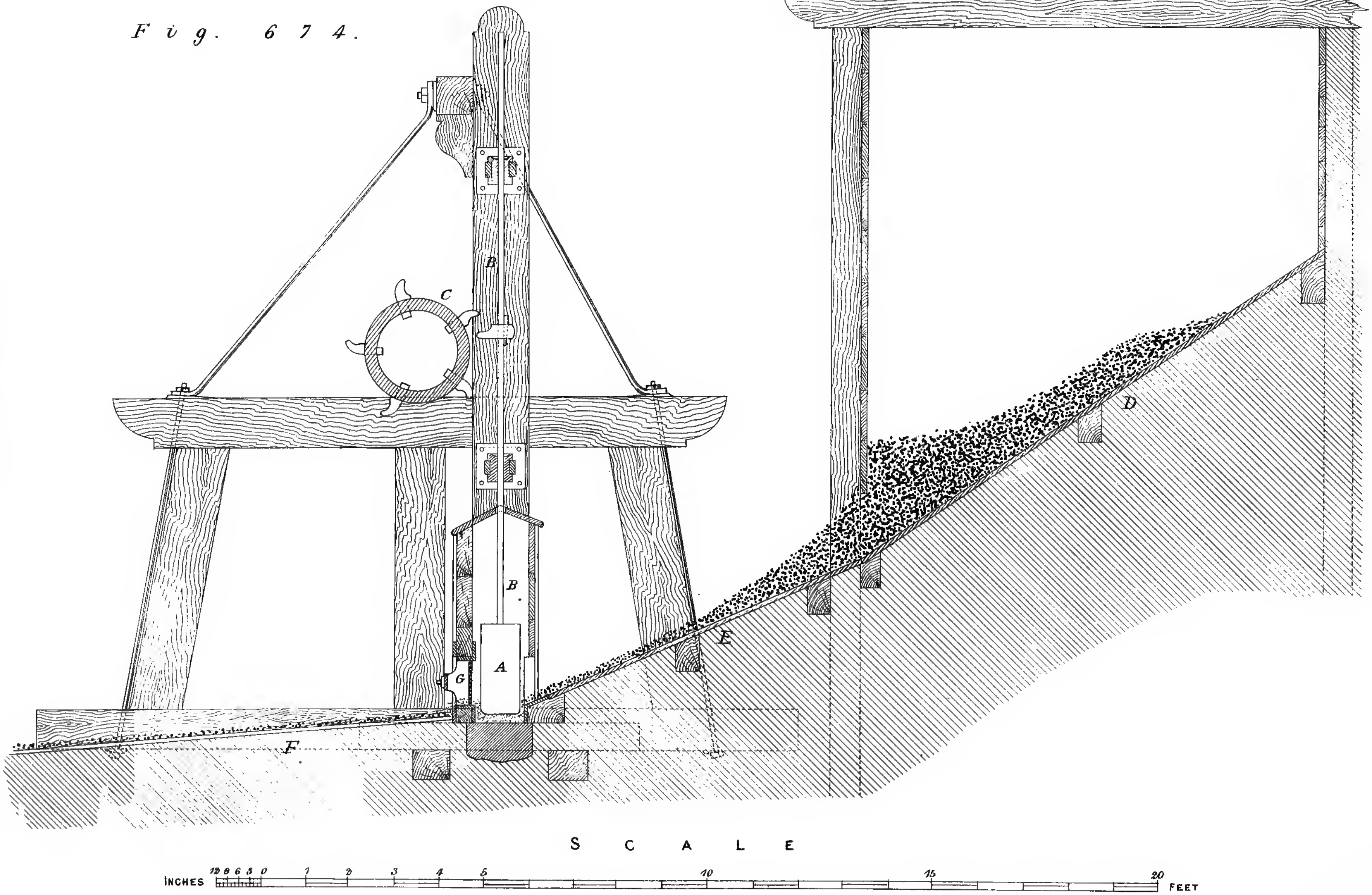
ORE DRESSING MACHINERY —— TIN STAMPS

Fig. 674.



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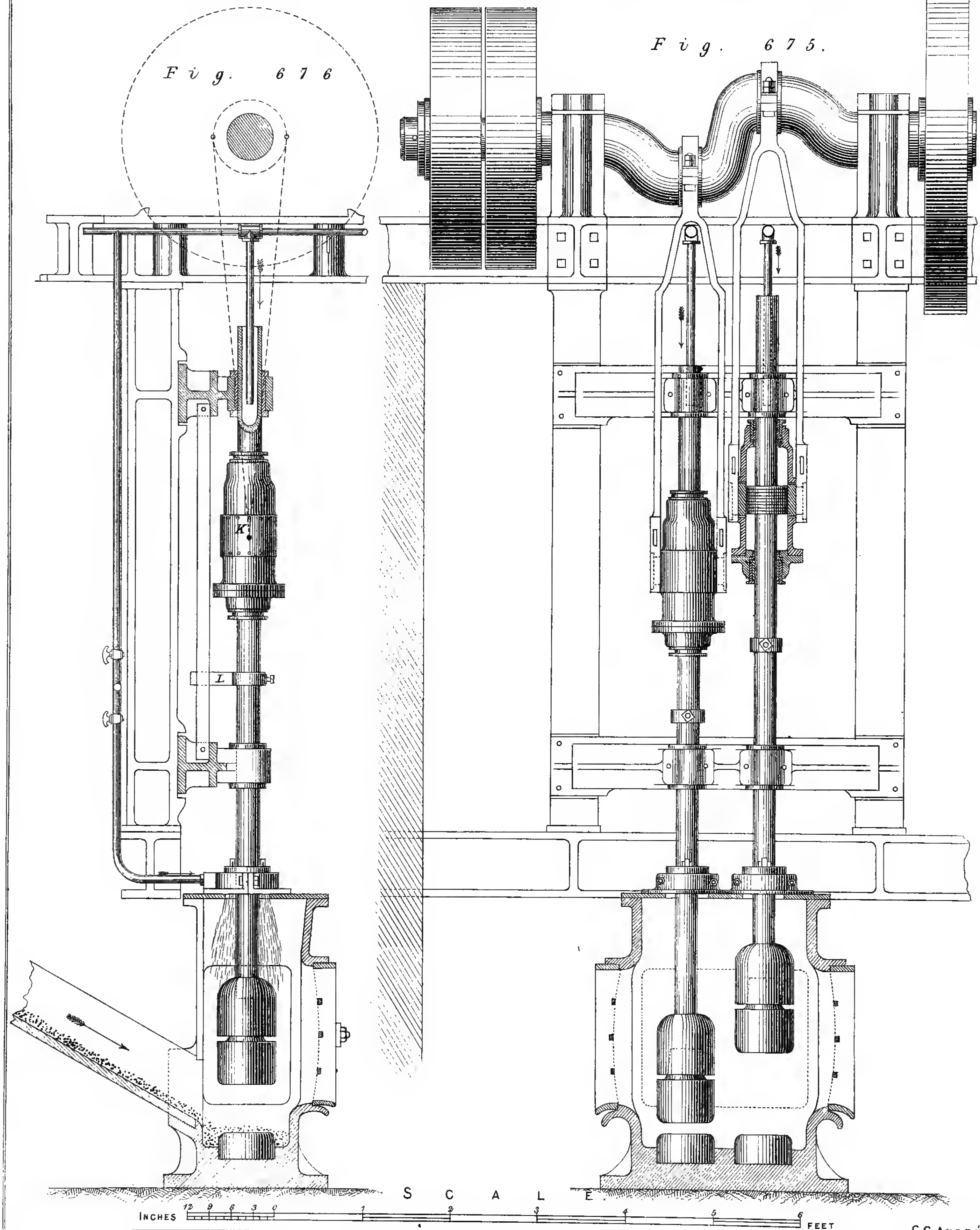
ORE DRESSING MACHINERY — HUSBAND'S PNEUMATIC STAMPS.



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ORE DRESSING MACHINERY

Fig. 677.

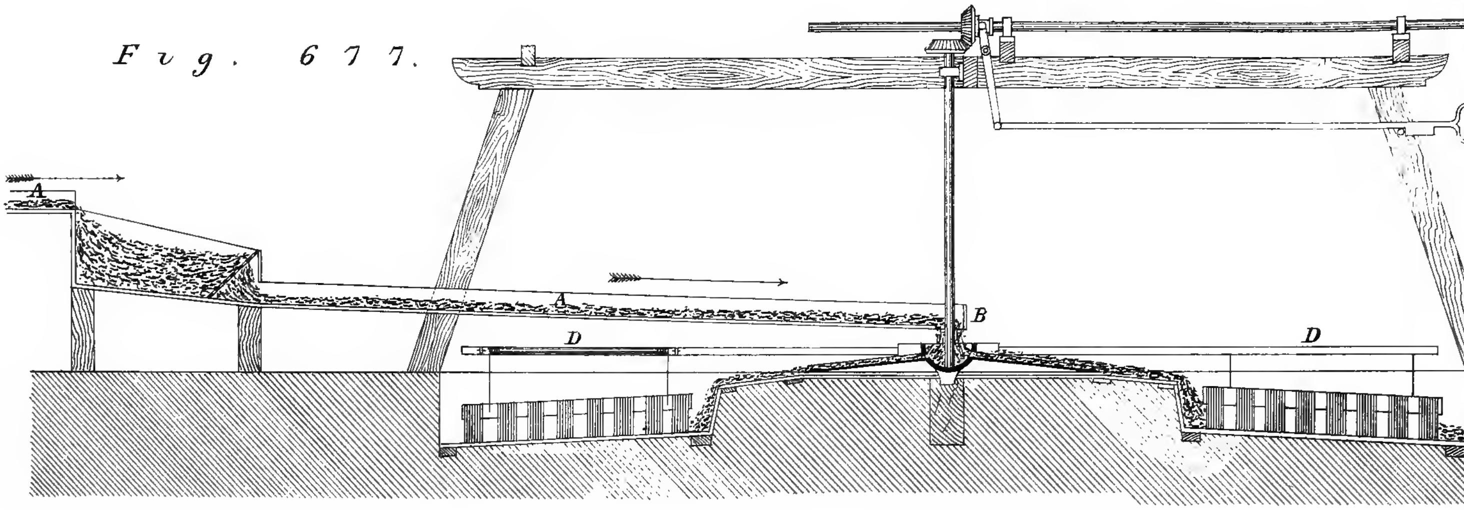
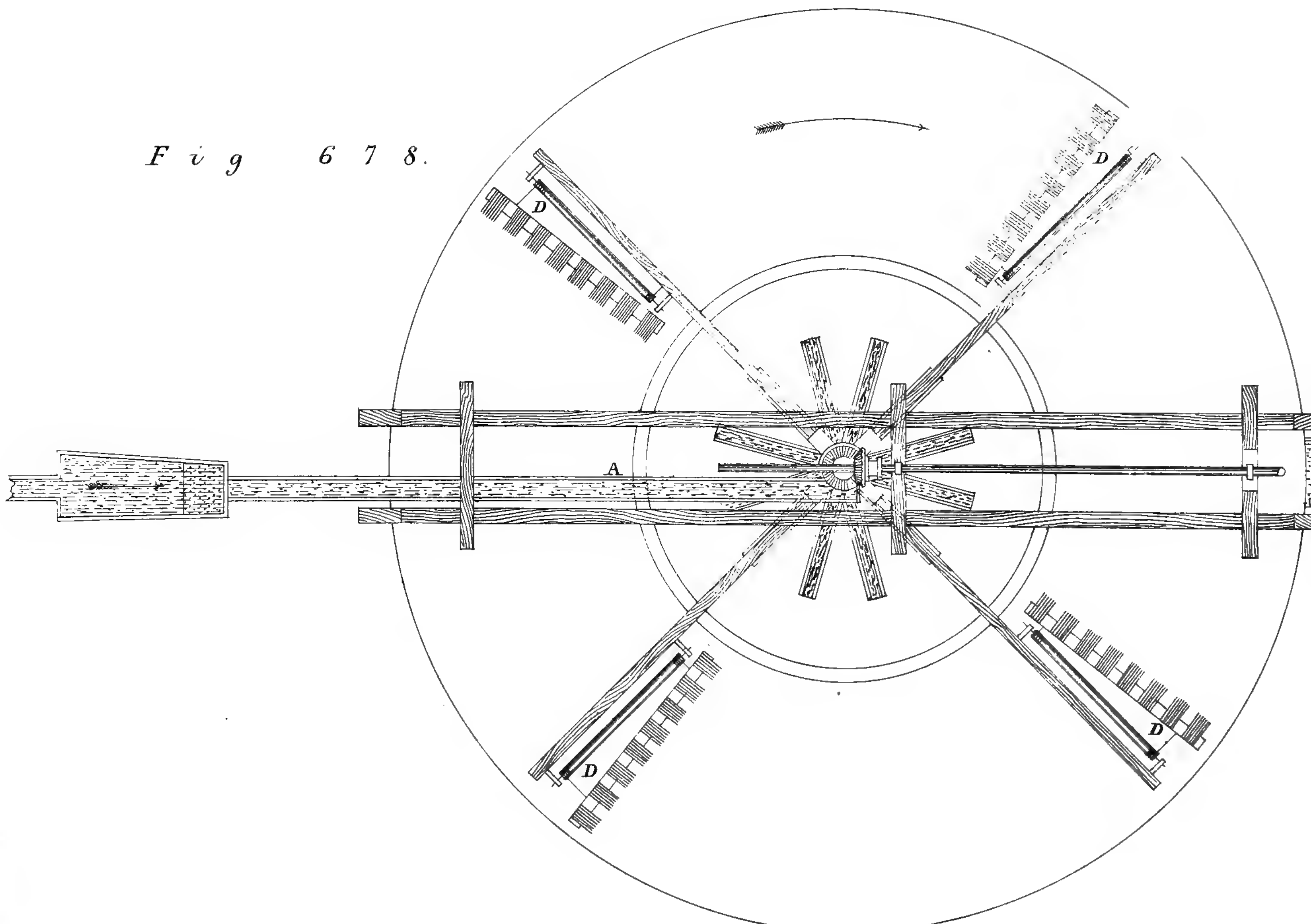


Fig 678.



S

INCHES 12 9 6 3 0 1 2 3 4 5 10 15

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ONVEX AND CONCAVE BUDDLES.

Fig. 679

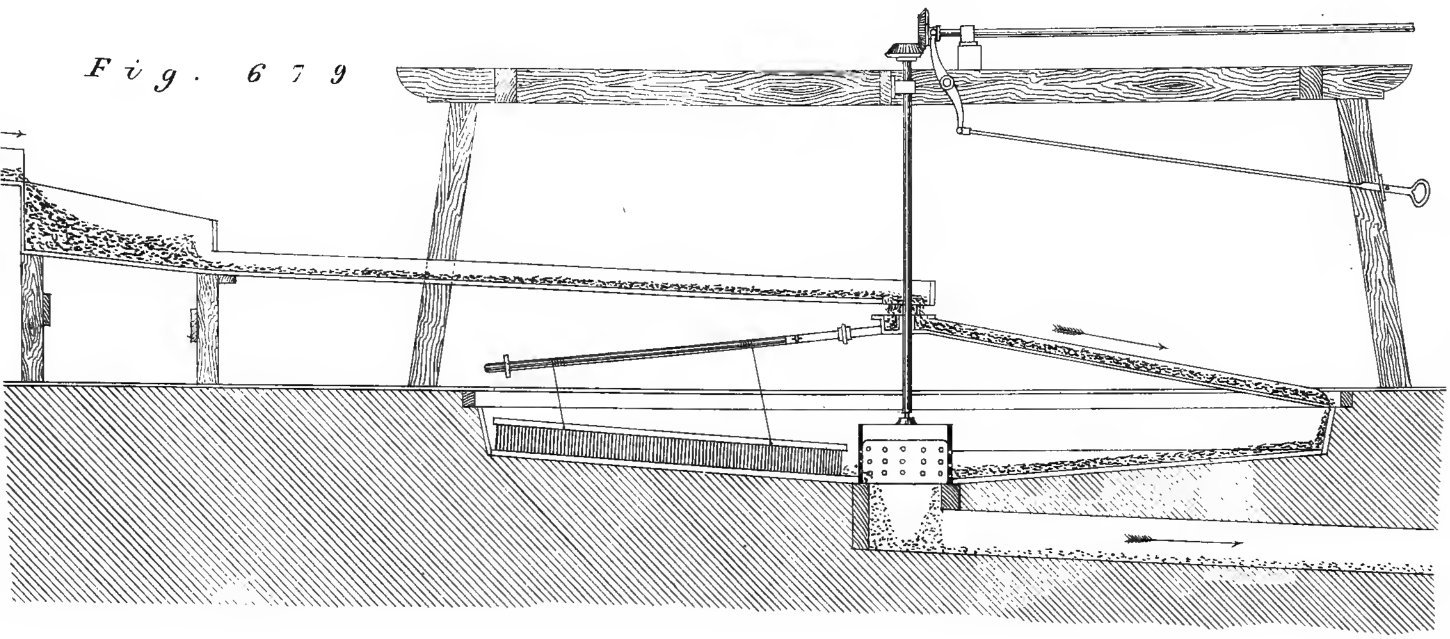
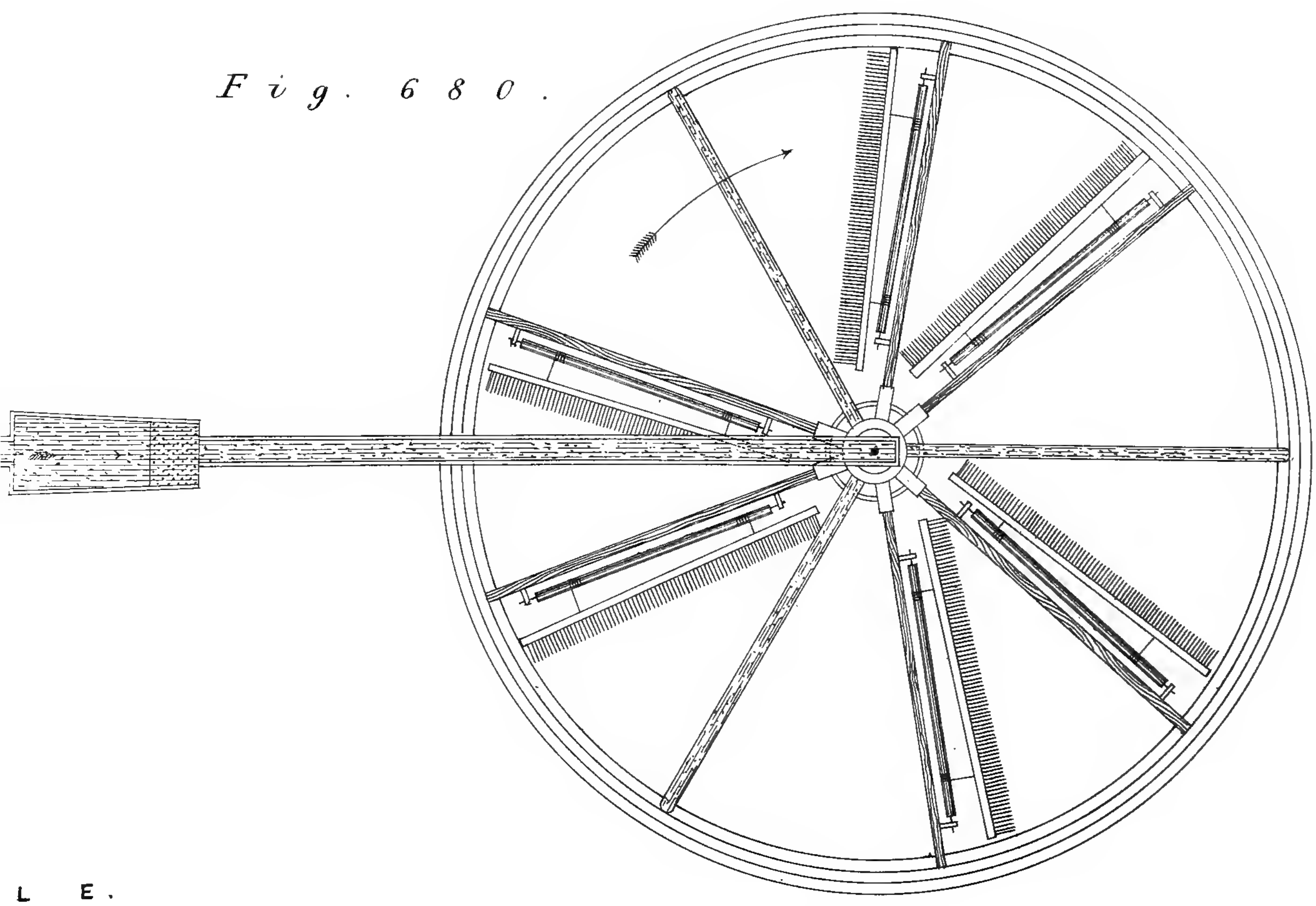


Fig. 680.



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25 30 35 40 FEET

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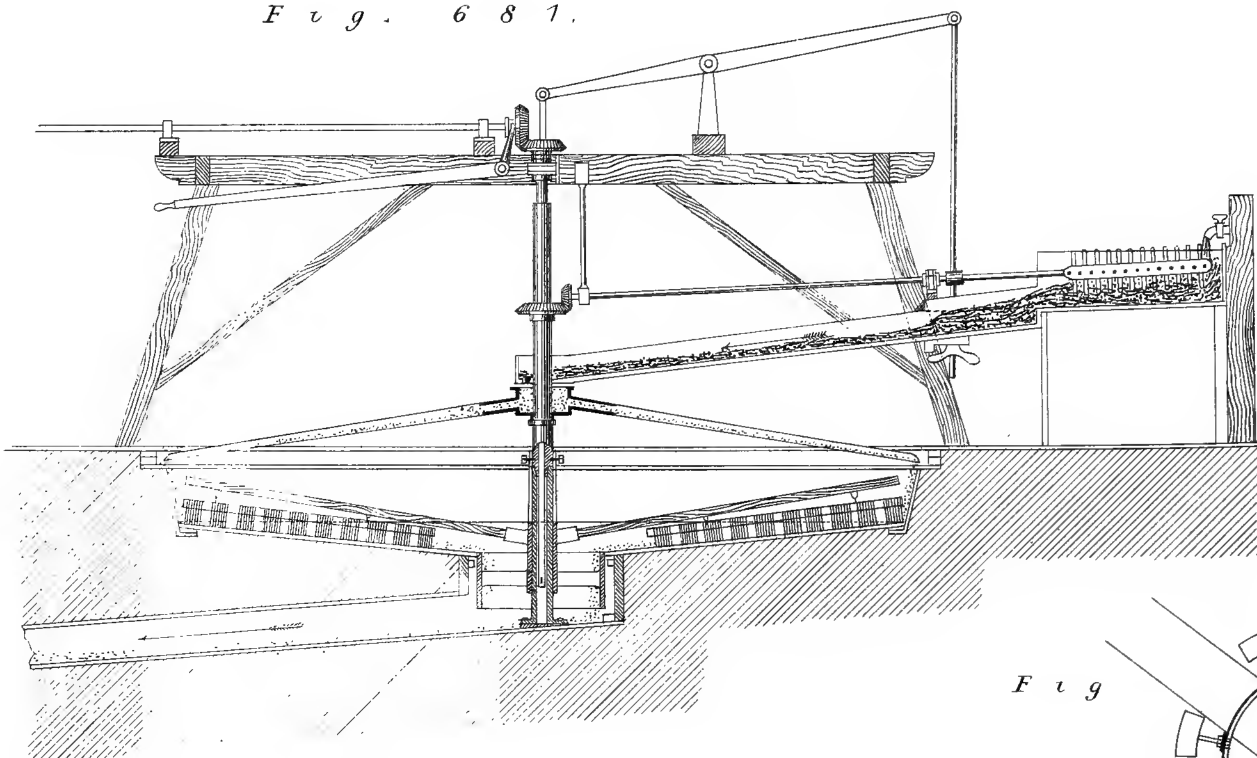
Fig. 681.



Fig

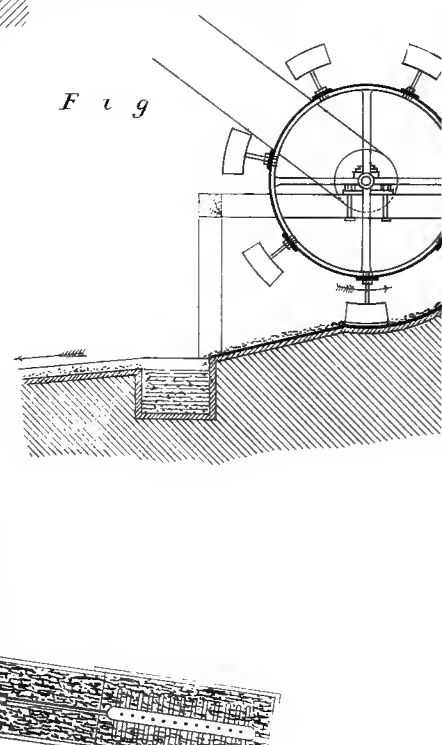
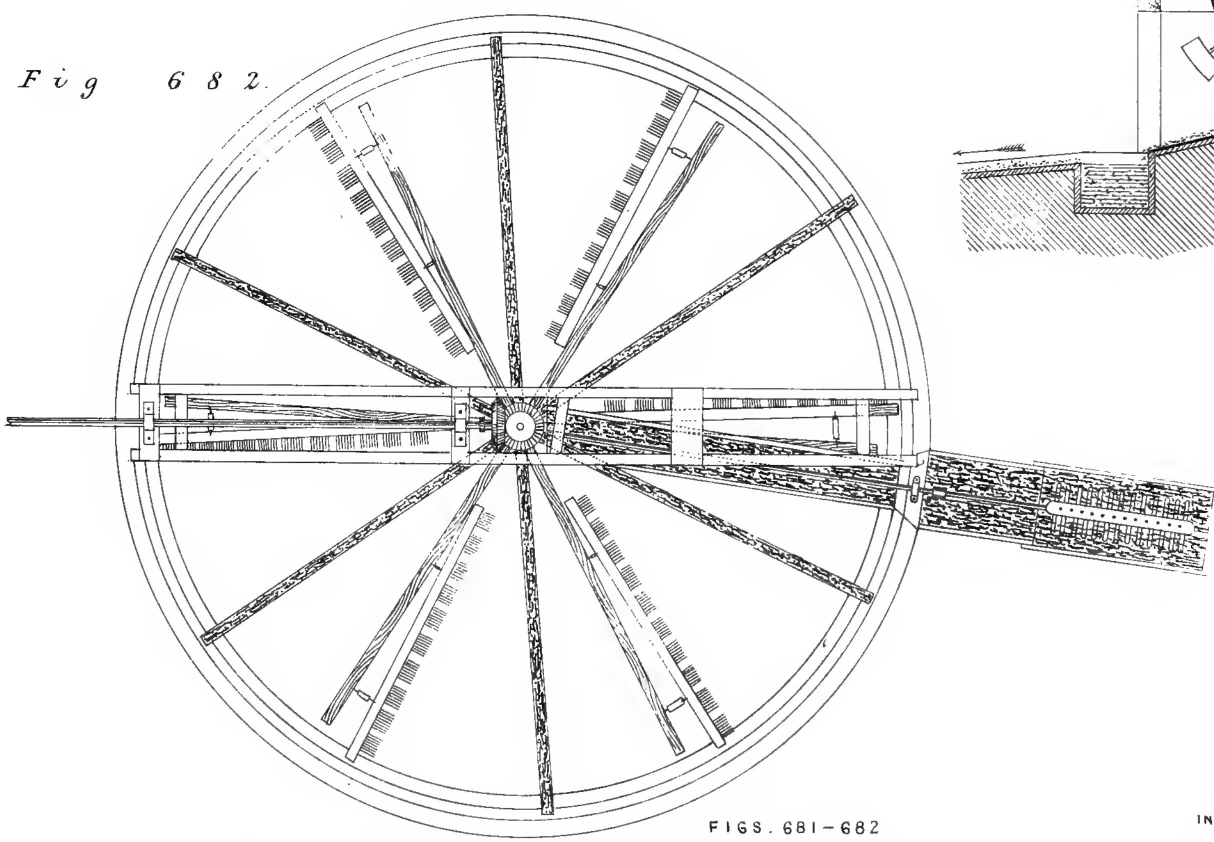


Fig 682.



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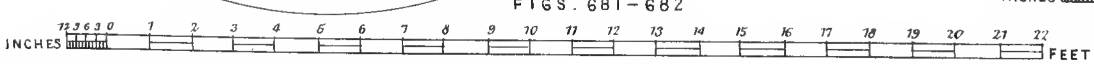
FIGS. 681–682



RLASE'S BUDDLE — PROPELLER KNIFE BUDDLE

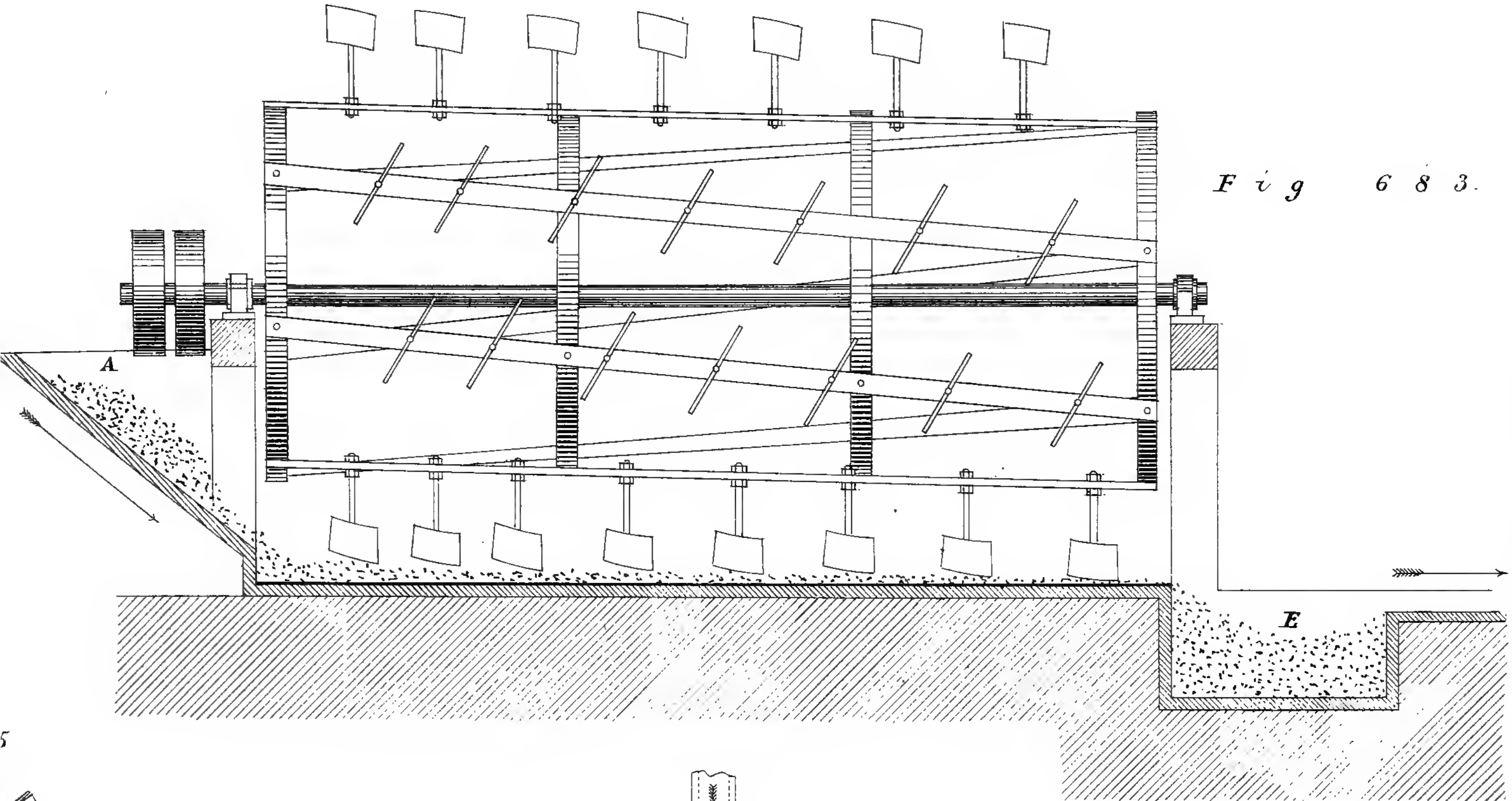


Fig 683.

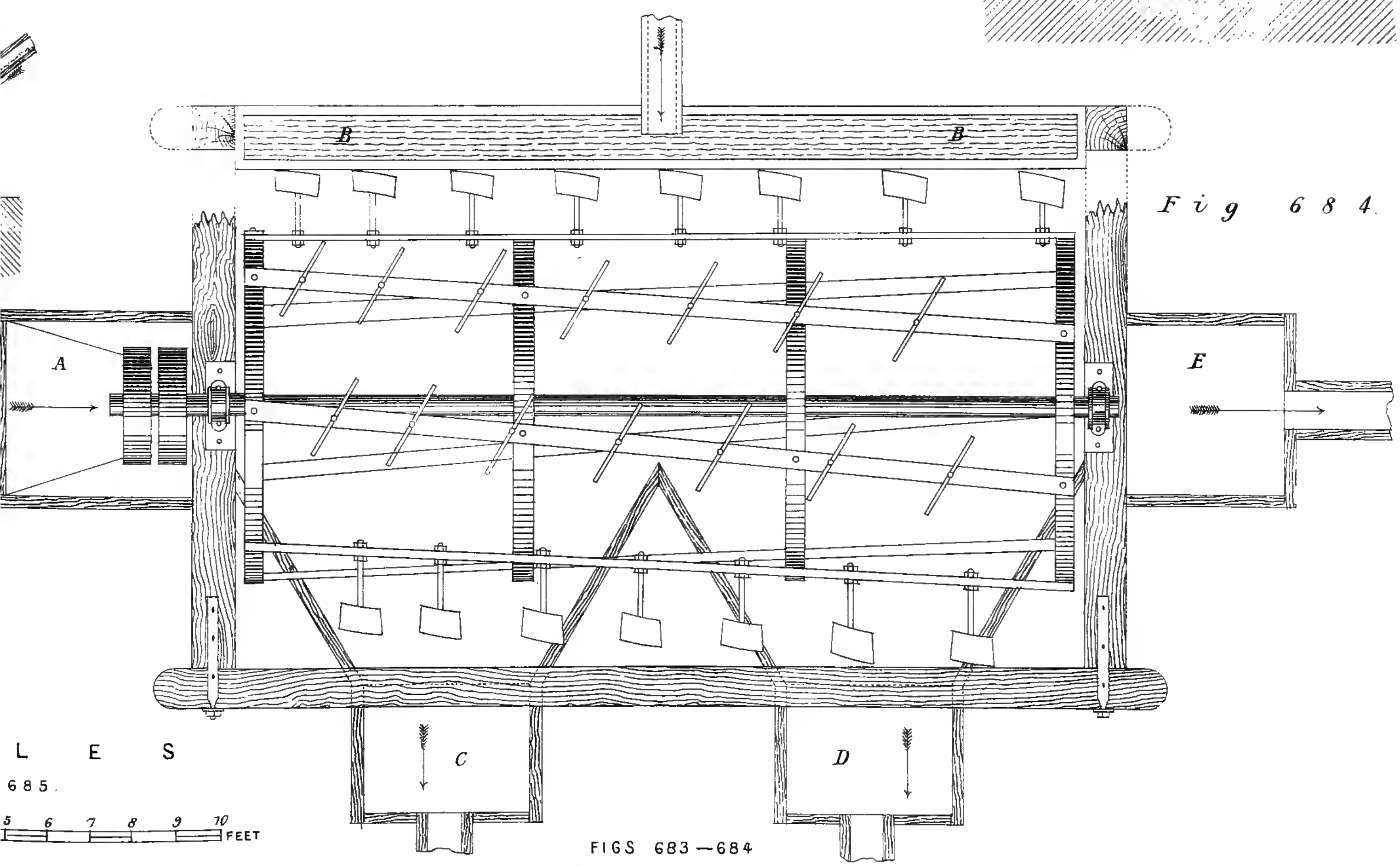


Fig 684.

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685.

5 6 7 8 9 10 FEET

FIGS 683—684

INCHES 12 9 6 3 0 1 2 3 4 5 6 7 8 9 10 FEET.

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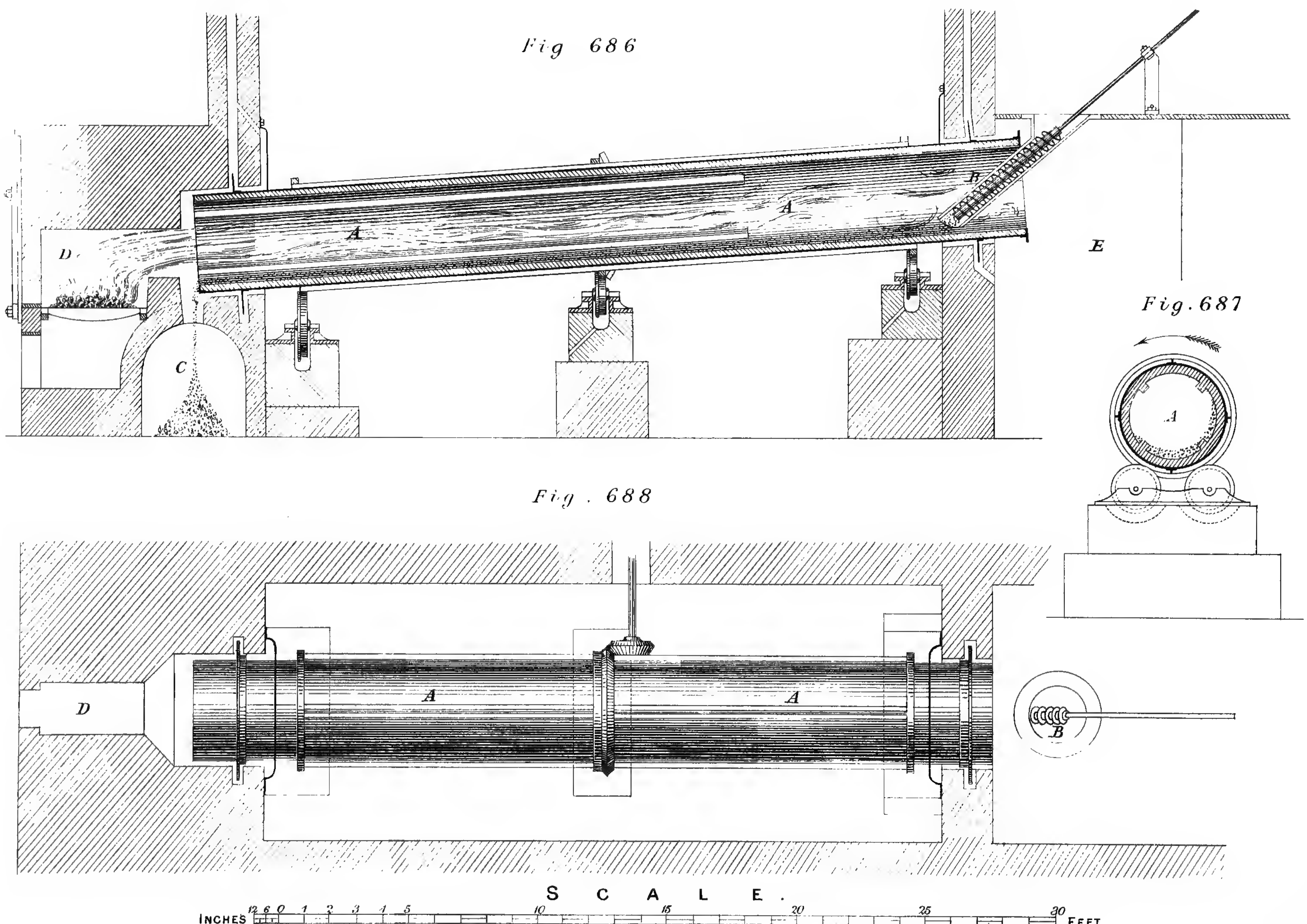
ORE DRESSING MACHINERY — OXLAND AND HOCKING'S CALCINER.



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ORE DRESSING MACHINERY — SELF ACTING SLIME FRAME.

Fig. 689

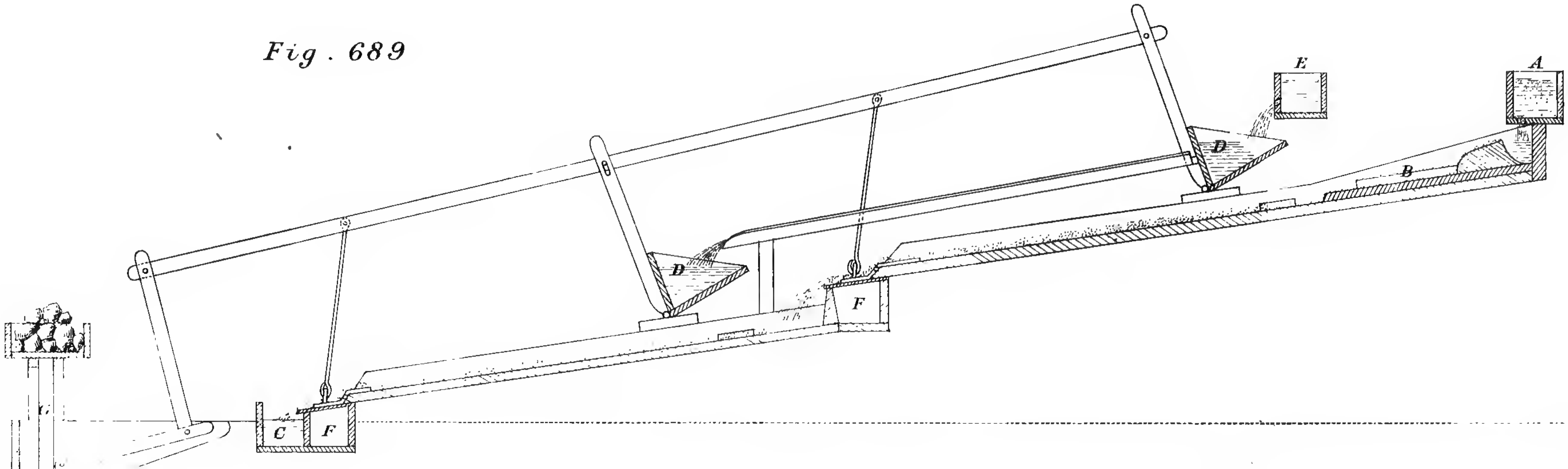
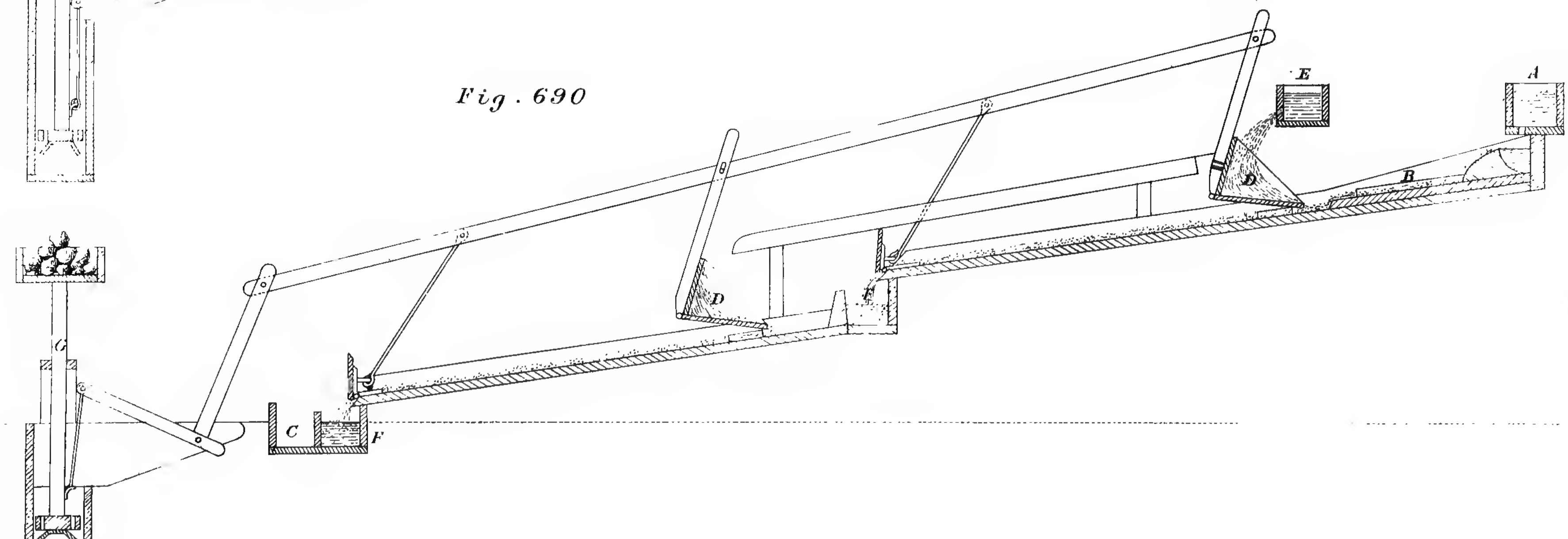


Fig. 690



SCALE.

INCHES 12 9 6 3 0 1 2 3 4 5 6 7 8 9 10 FEET

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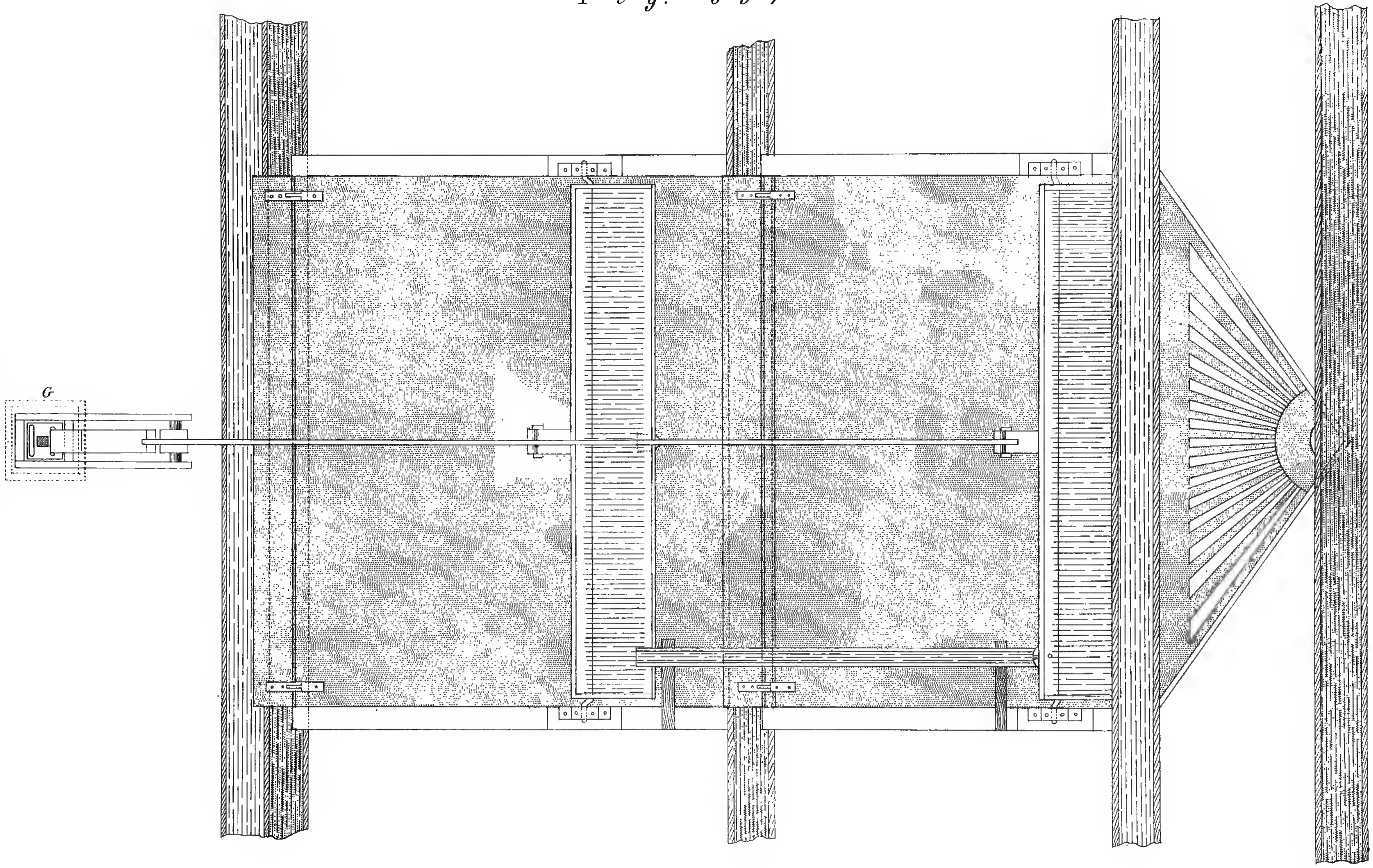
ORE DRESSING MACHINERY — SELF ACTING SLIME FRAME.

Fig. 691



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