he pulls the handle back again to position 2, till the head is clear of the forging, and then pushes it back to 3, holding it still while the forging is pushed forward. He repeats the squeezing operation until it has reduced the thickness of the forging equally throughout the full distance required.

But if the workman, instead of desiring to reduce the bar by an equal amount on successive portions, wishes to drive the head further down into

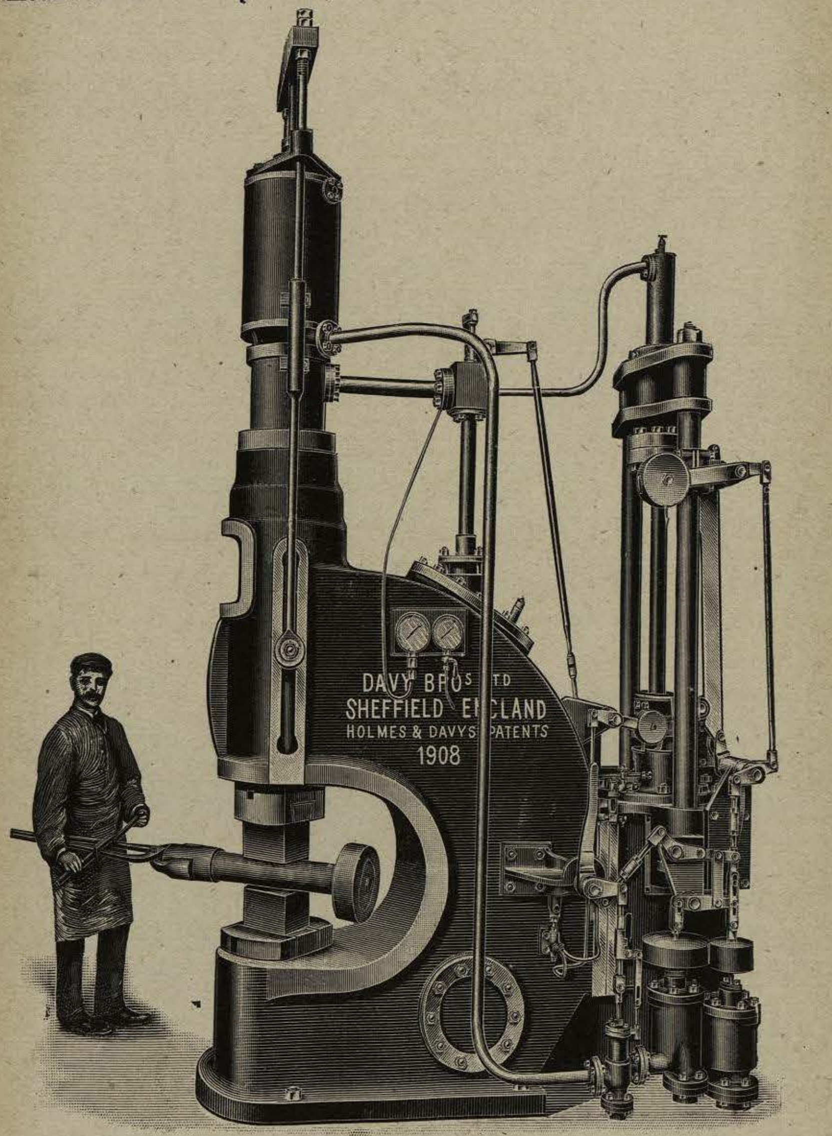

Fig. 538.—Davy's 150-ton High-speed Forging Press. Speed on Short Strokes, 150 per minute.

the heated mass than is possible in one operation, which has used up the whole of the available squeezing stroke, he can take a second bite. He pulls back the hand lever to position 1, and replaces it at 3. This releases the steam below the lifting pistons, allowing the head to fall on the forging, when the check valve, B, opens automatically and permits water to flow

in from the air vessel to fill up the vacant space in the press cylinder, J, so that when the intensifier piston rises again, the squeezing stroke is continued at the level where the last squeeze ceased. By a series of such strokes the press-head can be driven down until it meets the anvil.

There are special patented arrangements to allow of the rapid replacement of any packing leathers which may fail. There are no pumps; no pump valves, air and water check valves whatever; no valve between the intensifier, the equivalent of the pumps, and the press cylinder; no hydraulic valves requiring to be moved while the full squeezing pressure is upon them, and the only valve in the water column remains at rest while the full pressure is on it. The valves for regulating the steam are double-seated balanced drop valves, on which there is very little wear and tear, and which take very little power to handle, and all are controlled by one lever, so that it is scarcely possible to make any mistake in handling the press, which is as nearly "fool-proof" as anything can well be. The man can squeeze a steel ingot in the press almost as easily as he can squeeze a piece of putty in his hand.

Fig. 537 shows a 4,000-ton press of this type fitted with a device for changing the bottom tool, one of which is shown in position in the press, and one outside, which can be moved sideways by a hydraulic cylinder in a few minutes, to take its place for other work. There is also at right angles to it a hydraulic manipulator in the floor for holding the mandril, which can be moved backwards and forwards, when working on a hollow ingot.

Originally the press was devised for working large ingots for making guns or heavy shafting. Such huge masses retained their heat for a long time, and so much of the time consumed in the operation of forging was taken up in moving the ingot, that the advantage of a rapidly-moving press was not apparent, but the greater speed with which large ingots can now be handled has rendered necessary higher speeds in the presses for working them.

When presses of small power, moving at much the same speed as the larger ones, were employed for working small forgings, which could be rapidly handled, they offered no advantage over a rapidly moving steam hammer. But the great increase of speed recently attained in some of the modern presses driven directly by an intensifier, whose piston can move very rapidly, have quite changed the conditions. Messrs. Davy Bros. are now making presses of 100 to 200 tons similar to fig. 538, having a speed of 150 strokes per minute, capable of dealing with ingots and billets of 5 to 8 inches square more rapidly and economically than a steam hammer, and such presses are now taking the place of steam hammers in modern smithies.

Haniel & Lueg's Press.—This press* (fig. 539) is made by Messrs. Haniel & Lueg, of Düsseldorf-Grafenberg. The secondary hydraulic supply is furnished by engines which pump water into an accumulator weighted to give a pressure of 50 kilos. per square centimetre (711 lbs. per square inch), or a similar low pressure; a supply of water from this source is maintained constantly in the two counterpoise cylinders, G G, tending to lift the rams, F F, to which is attached the moving head, H, in which the upper pallet is secured.

In the most recent presses the height of the head is adjusted by admitting or releasing the steam below the pistons in two direct-acting lifting cylinders situated above the rams, F F, thus dispensing with the pumping engines, and making the press entirely self-contained.

* English Patent, No. 24,540, 1898.

By admitting water from this secondary supply to the pressing cylinder, D, whose ram, E, has an area considerably in excess of the combined effective areas of the counterpoise rams, F F, it overcomes the lifting power of these two smaller rams. The counterpoise cylinders, G G, are then in communication with the pressing cylinder, and the water displaced by them, combining

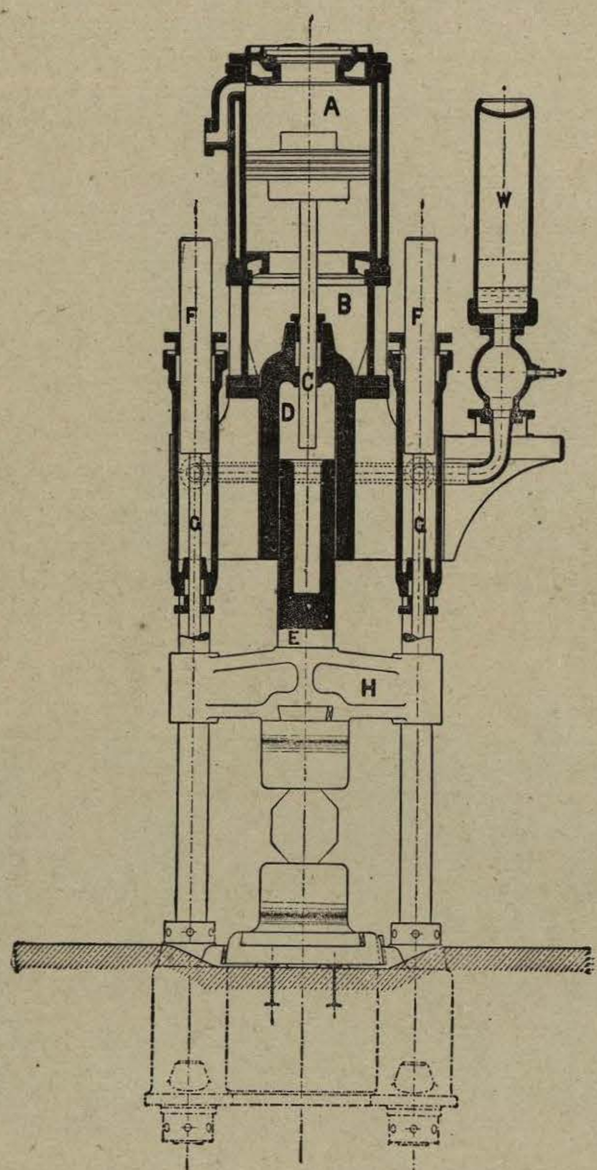

Fig. 539.—Haniel & Lueg's Forging Press.

with the water from the low-pressure main, flows into the pressing cylinder. The air vessel, W, which is thus in free communication with the counterpoise cylinders and with the low-pressure main, maintains the pressure in the cylinders, and the head then descends until the upper pallet touches the work on the anvil.

During the actual squeezing stroke the counterpoise cylinders are closed against the low-pressure main by a self-acting retaining valve, and only communicate with the air vessel. When the head descends the water from the counterpoise cylinders is driven back into the air vessel, raising the pressure in it to about 60 kilos. per square centimetre (853 lbs. per square inch).

When the head must be lifted through any considerable distance (for instance, to enable the ingot to be placed on the anvil, or to enable a forging to be turned on edge), a valve is opened which permits the water in the pressing cylinder, D, to escape; the compressed air in the air vessel then drives the water out of it into the counterpoise cylinders, and the head continues to rise until the flow of water from the cylinder, D, is stopped by the closing of the escape valve.

The movements described above are those used for adjusting the height from which the pressing ram shall commence its actual squeezing stroke, which, in the case of the press in question, is usually limited to 150 or 160 mm. (6 to 6½ inches). An adjustment of this nature is a necessity in any press having an intermittent stroke, or the range of sizes with which the press could deal would be limited to the length of the pressing stroke.

The head of the press, when lowered thus for adjustment purposes, of course presses on the forging, but the power so exerted is trifling when compared with that necessary to change its shape. The high pressure required for this purpose, which may be as much as 650 kilos. per square centimetre (4½ tons on the square inch), is given by the steam intensifier, which consists of a large direct-acting steam cylinder, A, mounted on the top of the press, the piston-rod, C, of this cylinder forming a forcing ram which works in the large pressing cylinder, D. When steam is admitted to the upper side of the piston, the forcing ram is driven downwards, compressing the water in the pressing cylinder, D, thus causing the head to descend through a less distance than the forcing ram, but with a proportionately greater power—in fact, with a force as many times greater than the total load on the steam piston as the area of the press ram exceeds that of the forcing ram of the intensifier. The whole arrangement is a mechanical equivalent for a powerful lever to convert the long stroke of the steam piston into a reduced travel of the pressing head against a correspondingly greater resistance.

To reduce the height of the press, the pressing ram has a hole bored in it, considerably larger than the forcing ram, which is thus able to work within it. Where there is not sufficient head room in the forge, the steam cylinder and forcing ram can be placed on the floor beside the press, or even in an adjacent building, and connected by a pipe to the pressing cylinder; this arrangement, however, not only adds to the cost, but necessitates the introduction of at least two joints subjected to the high-pressure water, none at all being required in the arrangement illustrated.

The ingot is squeezed in the following manner:—The steam piston is normally supported at the upper end of its stroke by the power exerted by the counterpoise cylinders, which maintain a constant pressure in the pressing cylinder. These, by forcing the pressing ram, E, back into the pressing cylinder, D, maintain a sufficient pressure below the forcing ram, C, to keep the steam piston at the upper end of its stroke. The lifting power of the counterpoise cylinders is maintained by the air compressed in the air vessel, W. On admitting steam above the piston, the forcing ram exerts pressure on the body of water imprisoned in the pressing cylinder, and thus forces down the pressing ram, E, through its normal stroke of 6 inches. On releasing this steam, the elasticity of the air in the air vessel lifts the upper tool so promptly that as many as 40 strokes per minute may be obtained when finishing or planishing the work. Only so much of the steam used to give the pressure need be released as will just balance the lifting power of the cylinders, G G; the head will then remain stationary at any height necessary to enable any small adjustment of the forging on the anvil to be effected. The makers claim that in practice no longer stroke and no more steam need be used than is absolutely necessary for the work in hand.

To distribute the steam, double-beat equilibrium valves are used, which are worked by levers so constructed as to lift the valves slowly from their seats, and, when lifted, move them at a rapidly increasing speed. By this means rapid action of the press is secured, without danger of shocks.

For certain purposes—such, for instance, as driving a punch through a thick forging, or bending an armour-plate—the head must be forced down through a greater distance than can be accomplished in one stroke only. This can be effected when the steam is released from the cylinder, by opening a connection to the secondary supply, whereby the excess of pressure on the large area of the pressing ram will more than balance the power of the lifting cylinders, and the upper tool will remain in contact with the forging, while the water, flowing in from the secondary supply, will raise the forcing ram ready for the next stroke. If steam is then admitted above the piston, the head will be driven down through a second 6 inches. This manœuvre may be repeated until the head has travelled, step by step, through its entire downward travel of about $1\frac{1}{2}$ metres (5 feet), exerting each time the maximum pressure obtainable.

It should be noted that, in this press, there are no clack valves, nor other valves for distributing the water, situated in the moving column of water during the periods in which high pressure is exerted, nor any distributing valves requiring to be moved under that pressure. The valves which have to sustain the full pressure are closed before the high pressure is developed.

A good number of presses have been constructed on this system for powers of 600 to 6,000 tons.

Breuer & Schumacher's Press.—This press, the invention of Messrs. Breuer & Schumacher, of Kalk, near Cologne, is made in this country by Messrs. Greenwood & Batley, of Leeds, who have supplied the block for fig. 540. The squeeze is applied by means of a steam-driven intensifier, which stands beside the press. The hydraulic cylinder of the intensifier is connected by a pipe to the cylinder of the press, and the pipe and the two cylinders are kept filled with water from an overhead tank through a valve which opens downwards to admit water from without, but closes against any pressure from within the cylinders. The area of the steam piston and that of the ram of the intensifier are so proportioned to each other that a pressure of steam of 60 or 80 lbs. per square inch on the piston, produces a pressure of 2 or 3 tons per square inch on the water above the forcing ram.

To squeeze the forging the workman depresses a hand lever, which moves a valve admitting steam below the piston of the intensifier, causing the forcing ram to drive the water into the cylinder of the press, whose head is in this manner thrust downwards. By raising this lever the steam is allowed to escape from below the piston of the intensifier, when the piston and ram fall by gravity.

The lifting of the moving head of the press is performed, as in other presses, by two counterpoise cylinders on the top of the press, but in this

press steam instead of water is employed to do the lifting, the admission of steam to the lifting cylinders being controlled at pleasure by a small three-way cock, which enables the press to be worked in two distinct ways.

In the usual method of working the pressure of steam is maintained continuously below the pistons of the lifting cylinders, thus holding the head up until steam is admitted below the piston of the intensifier, which

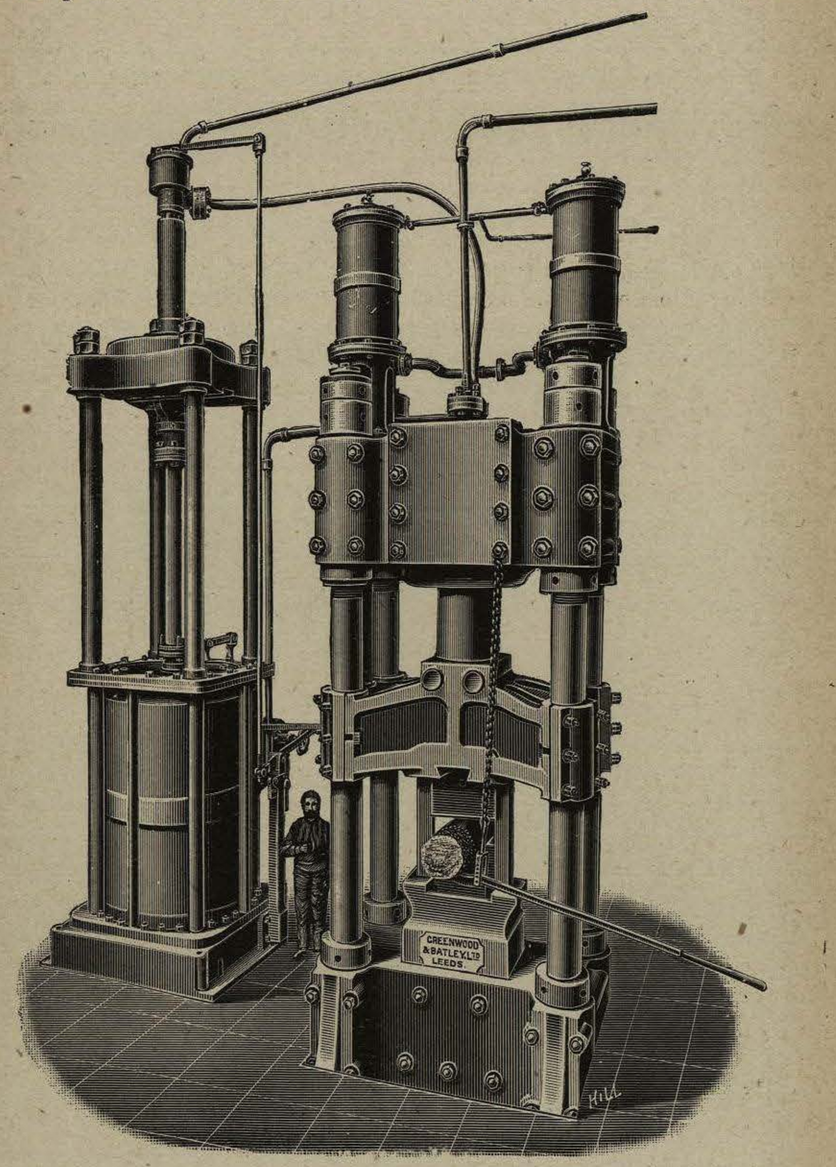

Fig. 540.—Breuer & Schumacher's Forging Press.

overcomes the pressure of the steam in the lifting cylinders, and drives it back into the boiler. On again releasing the steam from below the piston of the intensifier the lifting pistons regain their power, and force the water back into the top of the intensifier; but as the quantity of water contained in the pressing cylinder and intensifier with their connecting pipe remains constant, the moving head of the press rises and falls through a clearly defined distance due to the influence of the pressing and lifting cylinders. These prevail alternately one over the other, the rise and fall between the two fixed points being in practical unison with the rise and fall of the workman's hand, thus squeezing the forging and permitting it to be moved along after each stroke ready for a fresh squeeze to be taken on a new part.

If the normal stroke of the head is insufficient, it can be made to travel down through a second and lower interval by merely turning the three-way cock. This shuts off the constant supply of the steam below the pistons of the lifting cylinders, with the result that the head remains stationary, and therefore water flows in from the overhead tank, and fills the vacant space left by the descent of the forcing ram of the intensifier. Then, as soon as steam is admitted below the piston of the intensifier, the press head descends through a second interval. This action may be repeated until the whole available stroke of the press head is used up, or until the material under treatment offers so much resistance that it must be moved into a new position for another part to be dealt with.

When working the press in either of the above ways, all the workman has to do to lift the head high enough for the forging to be turned over, is to raise his hand into an *extra* high position, thereby opening a valve which allows some portion of the imprisoned water to escape, and admits steam below the lifting pistons (if steam is not already there). The head will then continue to rise until the man returns the lever controlling the press into the ordinary higher position, the head remaining suspended, while the forging is adjusted correctly for another squeeze.

It will be observed that this press requires no secondary supply of water under reduced pressure.

There is a 10,000-ton press on this system at Abouchoff in Russia, and another at Dillingen in Germany. Both these presses are provided with three intensifiers, one or more of which can be used as may be necessary for the work in hand.

Brown's Press, made by Mr. A. B. Brown, of Edinburgh, is very similar in its construction and action: the lifting of the pressing head, however, is performed by a cylinder, to which is admitted a constant supply of water, at a pressure of 800 lbs. per square inch, from a steam-loaded accumulator, which also serves the cranes. The forcing cylinder, or steam intensifier, which gives a pressure up to 3 tons per square inch, is arranged with the steam cylinder above the water cylinder, and the valve is worked by a relay cylinder controlled by a special form of differential gear, by means of which the steam piston can be set to stop when it has performed any predetermined portion of its stroke. The pressing head is lifted by releasing the pressure above the steam piston when the pressure in the lifting cylinder raises the head, and by driving back into the forcing cylinder some of the water contained in the cylinder of the press, raises the steam piston ready for a fresh stroke. The pressing head can be moved down on to the work by admitting water from the accumulator cylinder at 800 lbs. pressure, but the actual squeezing is done by the steam cylinder.

Tweddell's Press, made by Messrs. Fielding & Platt, of Gloucester, is shown in fig. 541. In this press the pressing head is raised by lifting cylinders situated in the base of the press (only one is visible in the cut) actuated by water at a pressure of 1,500 lbs. per square inch from a steam-loaded accumulator. The pressure water is supplied at a pressure usually not exceeding 6,000 lbs. per square inch by a direct-acting steam cylinder, as in the three previous presses. This pressure is used only for the actual operation of forging, the cylinder being supplied with water from an overhead tank when making the idle portion of its stroke. The high pressure comes only upon one valve, which is actuated by either steam or hydraulic pressure. These presses are arranged to work up to as much as 60 strokes per minute for planishing finished work, and Messrs. Fielding & Platt consider that "the output of such presses is from two to three times as much as that of a steam hammer capable of dealing with the same class of work."

It will be obvious that any one of the last three presses just described could be made to act practically continuously, by laying the steam cylinder horizontally and providing a hydraulic cylinder at each end of the steam cylinder, so that water could be pumped into the press when the steam piston was travelling in each direction, thus affording a practically continuous stream. The welding press patented by Haswell, of Vienna, in 1861 was

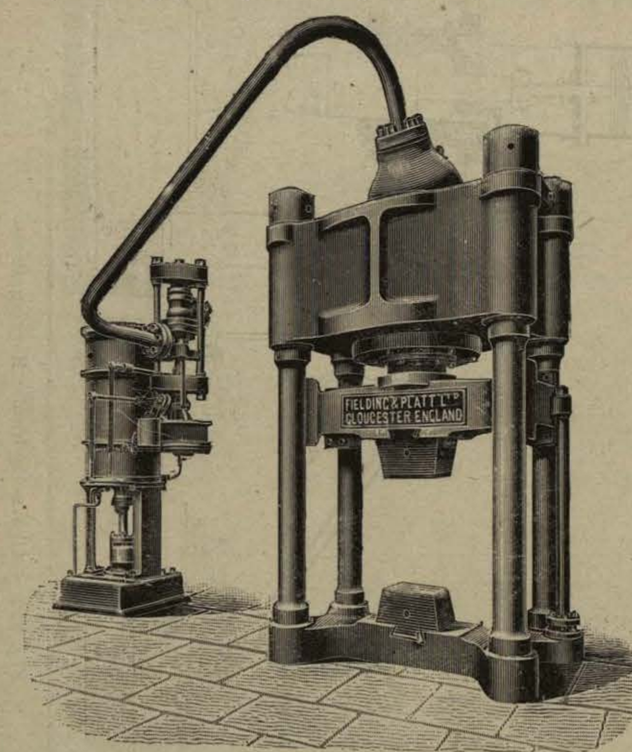

Fig. 541.—Tweddell's Forging Press.

operated precisely in this way. Such an arrangement, however, involves the use of at least one suction and one delivery valve for each cylinder, or four additional valves subjected to the full pressure, and situated in the moving column of water, while, by the present arrangement, there are no valves at all in the moving column of water to be clapped on to their seats under heavy pressure. Whatever valves there are, are closed on their seats before the piston puts on the pressure.

Allen's Press, used at Messrs. Bessemer's works, and made by Messrs. Galloways, of Manchester (fig. 542), is the best known of the class of press having an intermittent action derived from rotating engines. The pressure in this case is obtained by two plungers facing each other in a single cylinder, which are caused to approach and recede, not by the direct action of the steam, as in the last three presses, but by eccentrics on a rotating crank-shaft. Like the three previous presses, there are no clack valves between the forcing cylinder and the press cylinder, but instead of the head maintaining a fairly regular speed of travel until it has completed its stroke, and then pausing until the attendant moves the requisite valves to start

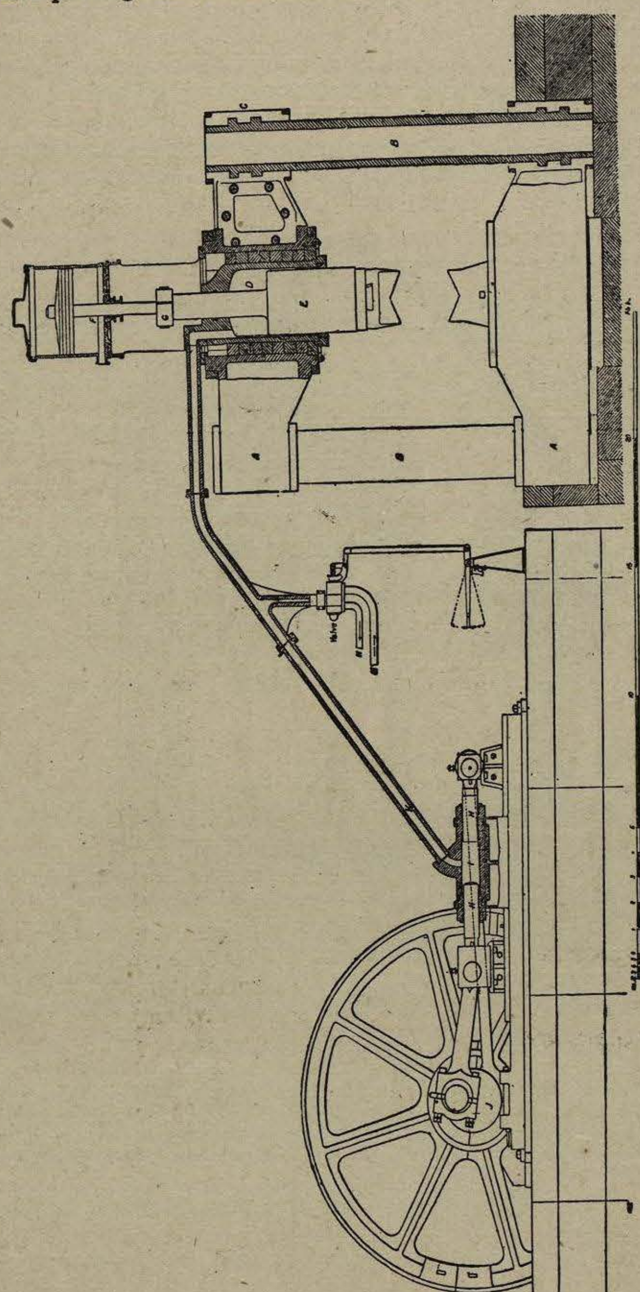

Fig. 542.—Allen's Hydraulic Forging Press.

a similar regular stroke, the head of the Allen press starts slowly, its speed increasing regularly until the middle of the stroke, when it slows down regularly, pauses while the forcing cylinder fills, and then makes an

exactly similar advance, unless the action is prevented by the attendant. There are no valves of any kind between what may be termed the pump and the cylinder of the press. The principle is essentially the same as Bessemer's press.* The forcing plungers, by driving the water into the cylinder of the press, overcome the lifting power of the steam cylinder on the top (below the piston of which cylinder a constant pressure of steam is maintained), and thus depress the forging tool. When the plungers recede, the steam below the piston of the lifting cylinder keeps the water in contact with them, and raises the head, which thus travels up and down for a short distance with each revolution made by the engines, always between the same two points. To prevent breakages a steam-loaded relief valve is provided, which can lift should too cold an ingot be placed between the tools.

To adjust the height of the pressing tool before the squeeze is made, a supply of water is provided at a pressure of 250 lbs. per square inch, which is sufficient to overcome the action of the steam cylinder. If the connection is opened to this source of supply when the tool is at the bottom of its stroke, the latter is kept in contact with the forging, and as the plungers recede this water flows in and fills the whole space between the plungers and the ram, so that when the plungers again approach each other the ram is driven down through a second step in its descent: by moving the valve so as to permit the water to flow out, the steam cylinder raises the ram until the requisite height is obtained, when the valve is closed again. All the workman has to do, therefore, is to push the lever one way until he has taken in as much water as is needed to make the next stroke, or to push it in the opposite direction until he has released as much water as is needed to raise the head to the height he wishes. If he keeps the lever stationary in the centre, the head merely oscillates up and down through a distance of $2\frac{7}{8}$ inches at each revolution of the engine, always at the same distance from the anvil.

Handling the Ingot.—The ingot is carried by a porter bar much in the same way as at the steam hammer, but as there is no appreciable jar caused by the press, a

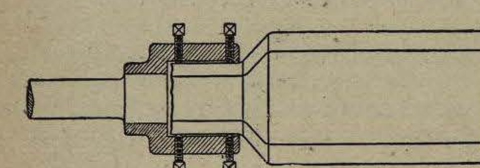

Fig. 543.—Porter Bar for Holding Ingot while it is Forged in the Press.

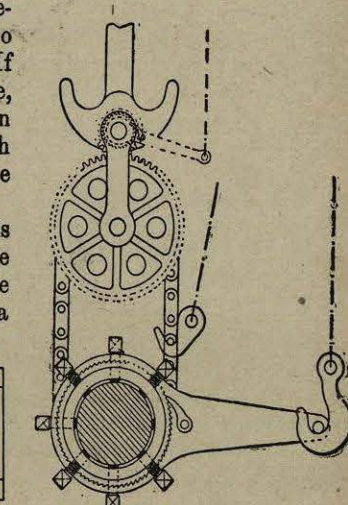

Fig. 544.—Method for Turning Round the Forging while in the Press.

hollow collar on the end of the bar provided with set screws, as shown in fig. 543, suffices to hold the ingot. The bar is slung from an overhead travelling crane in a loop of chain, as at the hammer, but means must be provided for turning the heavy ingots round by power. A hook at the end of a small chain may be inserted in a link of the carrying chain, as shown at the right hand in fig. 544, and by hauling on the small chain with a winch the forging can be rotated. This process is slow, and

* Patent No. 37, 1863.

has been generally superseded by the employment of a large ratchet and lever secured to the porter bar and actuated by a chain from the crane, as shown at the bottom of fig. 544; or the ratchet is attached to a pinion gearing into the wheel over which the loop of carrying chain runs, as at the top of fig. 544; or, finally, the pinion may be driven by telescopic shafts actuated by gearing provided for that purpose on the crane. The forging can even be rotated by simply pulling on a chain previously wound round it.

Comparison of various Systems.—Engines with flywheels, which run practically continuously, should use less steam than those which make a few turns only during the period of the actual squeeze, because the latter cannot take advantage of the economy obtainable by expanding the steam; moreover, the flywheel engine may be smaller. The direct-acting steam intensifier might be expected, for the same reason, to use more steam than either, but actual experience seems to show that such is not necessarily the case. Though the engines pumping the water into the accumulator may perform that part of the work very economically, yet, when any water is drawn from the accumulator, the whole of the power expended previously in pumping such water as is withdrawn is used up, although the work required might have been accomplished by only a fraction of the pressure thus drawn upon, and thus the economy of the pumping engines may be neutralised by having to use the water at one needlessly high pressure. On the other hand, when the water is pumped direct into the press, the steam may be throttled so that the engines may use only such a weight of steam as is necessary to overcome the resistance, in which case, though little advantage may be taken of the economy due to expanding steam, no loss is involved by the use of water at a needlessly high pressure. It is to avoid this loss that three accumulators are employed in some of the Tannett-Walker presses, and three steam intensifiers in the presses at Abouchoff and Dillegen, whereby three different pressures of water are obtainable. For the same reason three variations in the capacity of the press cylinder are provided in the Bochum press, while retaining the same pressure. Provided no additional complications are introduced, reducing the quantity of water is preferable to reducing the pressure, because in the former case the speed of the press is increased in proportion as the quantity of water is reduced, but reducing the pressure does not enable the speed to be increased, because the pump plungers cannot be run at more than about 200 feet per minute without causing serious shocks.

By employing an accumulator from which it is theoretically possible to draw off instantly all the water which the engines have been pumping in for some time previously, it might be expected that it would be possible to obtain the maximum speed of action of the press. Sudden withdrawal of water at high pressure, however, sets up vibrations in the pipes which severely try the joints; and, if the accumulator is loaded with a dead weight, a great increase of pressure occurs when the flow ceases, owing to the momentum stored in the falling weight. This is so serious, when pressures are already as high as can be safely carried, as to limit the flow to moderate speeds. But the engines must be larger if the accumulator is omitted, because then they have to supply as much water during the period of the squeeze only, as is furnished by those which deliver into an accumulator, not only during the short period of the squeeze, but also during the much longer period while the ingot is being adjusted on the anvil.

The heating of large ingots takes so much longer than the forging, that even where several furnaces are provided, a large press is idle for the greater part of the day; when the heated ingot is under the press more time is

usually occupied in adjusting it on the anvil than in actually squeezing it, so that the speed at which the pressing head moves is less important than the speed with which the forging can be handled. Tightness is the essential condition of success. A serious failure in any joint, packing, or valve stops the press at once, and a trivial one means much loss of power and time, so that it is desirable, as far as possible, to obviate all such weak spots. Water must be pumped continuously into any continuous acting press, requiring clack valves subject to the full working pressure, whereas intermittent acting presses can be so arranged as to have no clack valves. Any valves in intermittent presses can be closed on their seats before the pressure is exerted; the pipes and connections are few and simple, and the low-pressure water supply unimportant—in the Breuer & Schumacher press there is no secondary service at all.

Water at high pressures leaks so fast that, in any case, it seems preferable to take it direct from a pump working only during the actual period of pressing, rather than to pump it continuously and store it in accumulators, and most forge-managers would prefer a press driven by a steam intensifier to one driven by any pumps, even though the former consumed twice as much steam. The larger part of the steam can usually be raised by waste heat from the furnaces used to heat the ingots, but even if gas furnaces are employed, which give out no waste heat, it is more satisfactory to pay regularly for additional steam coal, than to face the cost of repairing clack valves at uncertain times: not only are such valves expensive to maintain, but the failure of one, or of a joint, may, at any moment, stop the whole of a costly plant, causing the waste of much fuel and steel at the furnaces, until the necessary repairs are completed. For these reasons the use of the simpler and cheaper intemittent press seems likely to extend in the future.

Comparison of Press and Hammer.—Besides working the metal more thoroughly, the forgings made under the press are more accurate to dimensions than those produced by the hammer, and fewer men are required to work the press; these men, moreover, requiring less skilled training. It can deal with ingots until they are comparatively cool, thus reducing the number of heats and the consumption of furnace coal. While a steam hammer requires to drive it from ½ to 1 ton of coal per ton of forgings made, Messrs. Davy Bros. say their new presses can do the same work with from 3 to 5 cwts. The repairs to a press are not nearly so expensive as those to a hammer, the rod of which is frequently broken. The press is more rapid in working than a hammer, and turns out a greater weight of work in a given time. The cylinder and base of a press are rigidly connected, and all the energy exerted in the cylinder is transmitted to the forging, but the anvil block of a steam hammer must be permitted a considerable amount of spring by placing it on an elastic bed, which must uselessly absorb much of the power developed, or the buildings and connections will be destroyed by the shock; even then a further portion of the power is wasted in setting up destructive vibrations in the neighbourhood, which, in some places, may render its employment impossible. The hammer causes so much vibration in the piece struck by it, that the end of a long bar farthest from the anvil is sometimes actually broken by the jar, and drops off without any warning. The shaft, 148 feet long in one piece, exhibited by Krupp at the Dusseldorf Exhibition of 1902, would require the greatest care, even to transport or put in position, and its production by a steam hammer may be considered a practical impossibility.

As a rule, a press is more expensive to construct than a hammer of equivalent power, but it requires fewer boilers to drive it, and, being self-contained, needs scarcely any foundations, while those necessary for a hammer, if the ground is soft, may be so costly as to more than compensate for any difference in the cost of the tools themselves. The anvil block of a steam hammer must, to withstand the force of the blow, be fully 6 or 8 times heavier than the falling weight, and is better 10 or 12 times as heavy. This weight cannot be made up of a large number of pieces of small weight, or they will be broken in detail, three or at most four pieces being the usual limit permissible. This means that for large hammers the anvil block must be cast on the spot, as it would be too heavy to transport, and a foundry must be improvised on the ground for the purpose of running it. The block generally continues to sink for a year or two, constantly requiring new tools to raise the working face, and is very apt to settle unevenly and cause considerable trouble.

A press is not so lofty as a hammer, and will allow a travelling crane to pass over it, so that an ingot can be taken from any one of a large number of furnaces, while only four furnaces can be served by the two jib cranes usually provided for a steam hammer.

Mr. Capron gives the following list of the sizes of press required to deal with various sizes of ingots :—

Power of Press.	Maximum Diameter of Ingot.
300 tons,	10 inches.
500 „	14 „
800 „	20 „
1,200 „	27 „
1,500 „	36 „
2,000 „	48 „
3,000 „	60 „
4,000 „	72 „

It is not easy to say what size of press is equivalent to a given size of hammer, but certainly the advantages of the press increase much more rapidly than those of the hammer as the size of the respective tools increases. For working ingots, as distinct from mere stamping or pressing into shape in dies material which has been already worked, it used to be said that a press giving a pressure of less than 1,000 tons, showed no marked superiority over a steam hammer, and presses of 3,000 tons were generally regarded as the smallest it was advisable to employ for such a purpose, but modern high-speed presses have altered this view.

The following comparison of the powers of presses, and the size of hammer to which each is equivalent, are given by Messrs. Davy Bros. :—

Press.	Hammer.	Press.	Hammer.
100 tons,	10 cwts.	600 tons,	5 tons.
150 „	15 „	800 „	7 „
200 „	25 „	1,000 „	10 „
300 „	2 tons.	1,200 „	15 „
400 „	3 „	1,500 „	20 „
500 „	4 „	2,000 „	40 „

M. Gauthier gives, with all reserve, the following table of equivalents :—

Size of Hydraulic Press.	Equivalent Size of Steam Hammer.
5,000 tons.	150 tons.
4,000 „	120 „
2,000 „	75 „
1,200 „	30 „
1,000 „	25 „
600 „	20 „

This does not state if the hammer is double-acting, the height through which the head falls, nor the weight of the anvil block, all of which are important factors; there is little doubt that in the smaller sizes the presses would be less, and in the larger more, effective than the corresponding sizes of hammers given in the table.

M. Dufour, quoting * Mr. Charles Davy's observations as to a 3,500-ton press being comparable with at least a 100-ton hammer, states that he himself believed, from his experience of the two tools, that a 4,000-ton press was nearly equivalent to a 100-ton hammer.

M. Bresson, at an Engineer's Congress in 1899, stated that a 25-ton hammer employed at Reschitza for forging shafts gave bad results, while a Haswell press of 1,200 tons, employed on the same work, gave results which were quite satisfactory.

Mr. Capron states that pressures of 3 to 5 tons per square inch of surface of the tools are sufficient for mild steel, but when swages or dies are used quite double these pressures are necessary, and Dr. Coleman Sellers states that pressures of 3,000 to 4,000 lbs. per square inch will deform hot steel, but that at least 15,000 lbs. is required to fill up the corners of a mould, and 20,000 if the corners are square, this pressure being needed in presses using closed dies.

Experience seems to show that to produce good work rapidly it is necessary to provide a pressure of 5½ to 6½ tons per square inch of surface of the ingot treated, though at first, when the ingot is very hot, pressures of 3¾ to 4½ tons per square inch of surfaces may suffice.

The sizes of presses have been steadily increasing, the earlier ones being of 2,000 to 3,000 tons; there are several presses of 5,000 to 6,000 tons, and some of 10,000 tons in existence, while Messrs. Beardmore, of Parkhead, have one of 12,000 tons, and the Homestead Works in America one of 14,000 tons capacity. Several of the larger works have two or more presses, and it is no uncommon practice to draw down the ingot first under a press, and then, when of a size more easily worked, to finish it under a steam hammer, while, for many purposes, this combination seems convenient.

Output of the Press.—In addition to making better work, a press does more in a given time than a hammer. According to Daelen, given the same amount of steam, a press will turn out twice as much work as a steam hammer, while the experience in English works would seem to be that the time required to do a given piece of work by the press and hammer respectively is as 2 is to 5, while twice the number of heats are needed for the latter, which nevertheless can keep only two to four heating furnaces occupied, while the press needs four or six to work it to its full capacity. Ledebur, in his book, says that the press usually does three times as much work in a given time as a steam hammer, and gives an instance of the manufacture of a 36-ton gun forging, which required three weeks and 33 heats to finish under a 50-ton steam hammer, and only four days and 15 heats when made by a 4,000-ton press. Gauthier and Demange say the number of heats needed when an ingot is worked under a press is only half as many as when worked under a hammer, and the time taken to effect a given reduction is only four-fifths as much; while Gomez says he is not sure if the difference is not greater, and states that by a 2,000-ton press an octagonal ingot 35½ inches wide across flats and 4 feet long, which would require two heatings and two hammerings of an hour's duration each to reduce under a 50- or

* *Min. Proc. Inst. C.E.*, vol. cxvii., p. 46.

60-ton steam hammer, has been reduced at one heat to less than 14 inches square. This means two and a-half times as long taken in working, without reckoning the time taken up by the extra heating.

The following are some instances of the work done by forging presses:—At Messrs. Vickers' Works in Sheffield an ingot 4 feet 3 inches in diameter has been drawn down to 14 inches in diameter at one heat, the size of the press being 4,000 tons. According to *The Engineer*,* Messrs. Firth's 3,000-ton press has reduced a 30-ton ingot from 49 inches to 28 inches in diameter in half an hour, and the same press is reported on another occasion to have reduce an ingot 51 inches in diameter to 26 inches in diameter in 65 minutes. It is within the author's own knowledge that an ingot 52 inches in diameter and 12 feet long has had one end drawn down under this press to 25 inches diameter by 21 feet long, at one heat, in less than an hour. A 50-ton armour plate has been reduced 2 inches in thickness at each squeeze, and has been advanced 6 inches after each squeeze, under the 10,000-ton press at the Homestead Works.†

Hollow Shafting.—The weakening effect, which a trifling notch has on a piece of metal, is clearly seen in the method which every smith employs for cutting a piece off the end of a bar of iron or steel: when nicked with a chisel the toughest bar can be easily broken by bending it over the edge of the anvil, because the extension of the fibres caused by the bending is concentrated in one small spot, instead of being distributed over a larger area, as is the case when the bar has not been notched. Now, a shaft when in use is bent backwards and forwards through a trifling angle at each revolution, and small though this bending may be, so small indeed as to be invisible, yet it may suffice to develop any flaw originally existing in the centre of the ingot from which the shaft has been forged, until the crack may extend through nearly the whole section of the shaft without betraying its presence on the surface. In such cases the shaft fails, to all appearance, quite suddenly. To render impossible the presence of such a flaw, which may serve as a starting point for a crack, a hole is bored axially right through the centre of large steel shafts, the removal of doubtful material more than compensating for the loss of some portion of the section.

Removing the centre, even if the core is perfectly sound, reduces the strength of the shaft very little, because the portions removed are too near to the centre to add appreciably to the power of the shaft to resist twisting. The strength of a circular shaft is proportional to the cube of its diameter, so that removing metal, by boring a hole as large as half the diameter of the shaft, only reduces its torsional strength 6¼ per cent., while the weight of the hollow shaft is 25 per cent. less than the solid one—a reduction in weight which, under many circumstances, would alone justify the boring. When the shaft is forged under the steam hammer, this hole is bored out of the solid by a drill or trepanning tool, after the shaft has been turned to nearly its finished size, leaving sufficient metal to be removed by the finishing cut to true up the outside, in case the removal of the centre portion should, by relieving internal stresses, cause the shaft to spring out of the straight. When the hollow shaft is forged under a press the ingot is usually bored before reheating, and then threaded while hot on to a slightly tapered mandril cooled by water running through it, upon which it is pressed. This latter method is preferable, because the mandril serves as an internal anvil, so that when forging a hollow shaft in this manner the squeeze has to be conveyed through less than one-third the thickness through which it has to be transmitted when the shaft is forged solid, and the material is, therefore, much better worked throughout. The taper of the mandril enables it to be easily withdrawn from the hot forging by a small hydraulic jack.

* June 22, 1894, p. 550.

† *Engineering News*, New York, vol. xxxv., p. 159.

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CHAPTER XLI.

COMPRESSING STEEL WHILE FLUID.

History of the Introduction of the Process.—The first suggestion for increasing the soundness of metals by compression while in a fluid condition, would seem to have emanated from Mr. James Hollingrake,* whose patent describes the "casting of metallic substances into various forms and shapes, with improved closeness and soundness of texture," by pouring the metal into suitably shaped moulds and applying pressure by means of movable pistons or plugs. According to Mr. Reynolds,† the process had been used regularly at the works of the Broughton Copper Company, Manchester, for twenty years before Sir Joseph Whitworth took out his patent in 1865,‡ while Bessemer had obtained a patent in 1856§ for compressing the ingot while in a plastic state. Sir Joseph states in his patent that he knew fluid compression had been proposed, but the moulds employed were too weak to withstand such pressures as he considered were necessary, and to him the credit is due, not only for first applying the process to steel on a commercial scale, but also for having perfected the process and the appliances by which the operation is at present carried out. His first endeavour was to shape the steel shell, intended to be fired by his steel guns, by pouring fluid steel into an iron mould of the requisite form, and to produce

* Patent No. 4,371, 1819.

† *Min. Proc. Inst. C.E.*, vol. xcviii., p. 169.

‡ Patent No. 3,018, 1865.

§ Patent No. 1,392, 1856.