solution of sulphuric acid to remove the hard outer skin or scale that the finished forgings have. This is done so they can be machined more easily, as this skin or scale has a mineral hardness that will dull cutting tools very quickly.

Forgings that are made with a knowledge of metals, temperatures, etc., and with the proper skill and care, are stronger, and will stand the strains and stresses that are put upon them much better than the same steel when formed into shape in any other way, unless it be the rolled stock, which should be worked under the same temperatures.

HAND FORGING

When small pieces and but few of a kind are wanted, hand forging is undoubtedly the cheapest; but for large pieces, or where a large quantity is wanted, hand forging is the most expensive way of producing them and the strength is not apt to be as great as by any of the other methods. With a blacksmith shop properly equipped, a skilled smith can make forgings that are stronger than a rolled bar from the same ingot. To do this the piece must be hammered between the proper temperatures, which varies with the different grades of steel.

The steel that is the best adapted for forging under the hammer has about the following composition: carbon, 0.15%; silicon, 0.20%; manganese, 0.52%; phosphorus, 0.06%; sulphur, 0.04%. This steel in the annealed state will show the following physical characteristics: tensile strength, 55,000 pounds per square inch; elastic limit, 30,000 pounds per square inch; elongation in 8 inches, 29%; reduction of area, 60%. When fractured it will show a silky fiber.

But for many purposes a steel of much greater strength than this must be hand-forged and then it becomes necessary for the smith to understand the nature of its component parts so he can forge it successfully, as many of the high-grade alloy steels can be rendered no better or stronger than the ordinary carbon steels by over or under heating and poor workmanship.

In many cases welds are absolutely necessary to produce the required shapes, and a steel of the following composition is the best suitable for welding: carbon, 0.080%; silicon, 0.035%; manganese, 0.110%; phosphorus, 0.012%; sulphur, 0.007%. In the annealed state it should show the following physical characteristics: tensile strength, 48,000 pounds per square inch; elastic limit, 25,000 pounds per square inch; elongation in 2 inches, 27%; reduction of area, 69%.

STEAM-HAMMER FORGING

For pieces of considerable size and bulk the steam-hammer is substituted for the hand-forging process. These hammers vary in size,

from the small Bradley cushioned hammer that strikes a blow of about 500 pounds, as shown in Fig. 55, to those that strike a blow of many tons, as illustrated by Fig. 56, which is that of an 8-ton hammer, in use at the Bethlehem Steel Works. While this is not the largest hammer in use, it is about as large as is practical, owing to the difficulty of building a foundation that will prevent buildings near it from being wrecked, and other machine foundations ruined. Another style of steam hammer is shown in Fig. 57. This, however, is usually used for drop forgings.

In this method of forging, the hammer should be of a size to suit the size of the work. The hammer-man must exercise a good deal of skill and judgment as to the power and speed of the blows delivered to the

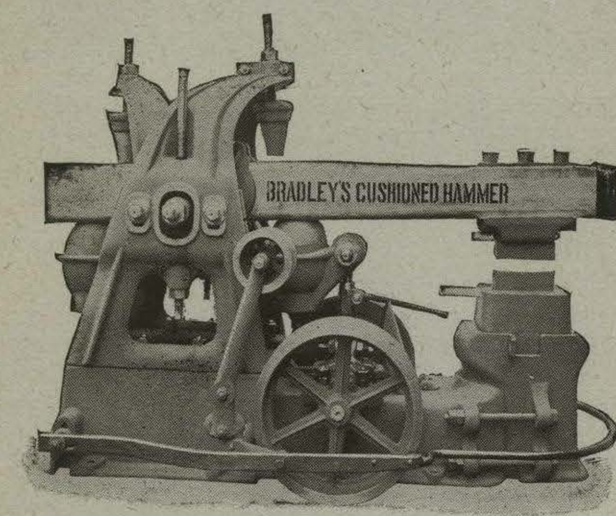

FIG. 55. — Bradley cushioned hammer.

piece, as a too powerful blow will crush it, and in the case of a high percentage of nickel, fissures and cracks are liable to develop which it will be difficult to get out, and which may show in the finished product.

This is especially true if the piece is allowed to fall below the forging temperature, or if the blows are not distributed evenly. If the blows are from a light trip-hammer, delivered at high speed, only the surface of the metal will be bruised and the core not affected, thus causing the core to be coarse-grained without the proper cohesion to insure the necessary strength.

With a heavy hammer, descending at a low speed on work that is held at the proper temperature, the force of the blow will penetrate the mass to the center and allow the particles of metal to flow to their proper position, insure a fine grain of even texture and be uniform throughout its entire size.

The keeping of the heat to a good forging temperature is more difficult than in the hand-forgings, owing chiefly to the difference in the size of the piece forged, as the hand-forged piece is usually small enough for the smith to put in the fire and reheat the minute the temperature falls below the best forging heat. But the hammer-forged piece is many times large enough to be handled with a crane, and is therefore liable to be kept under the hammer as long as a blow will have any effect on it.

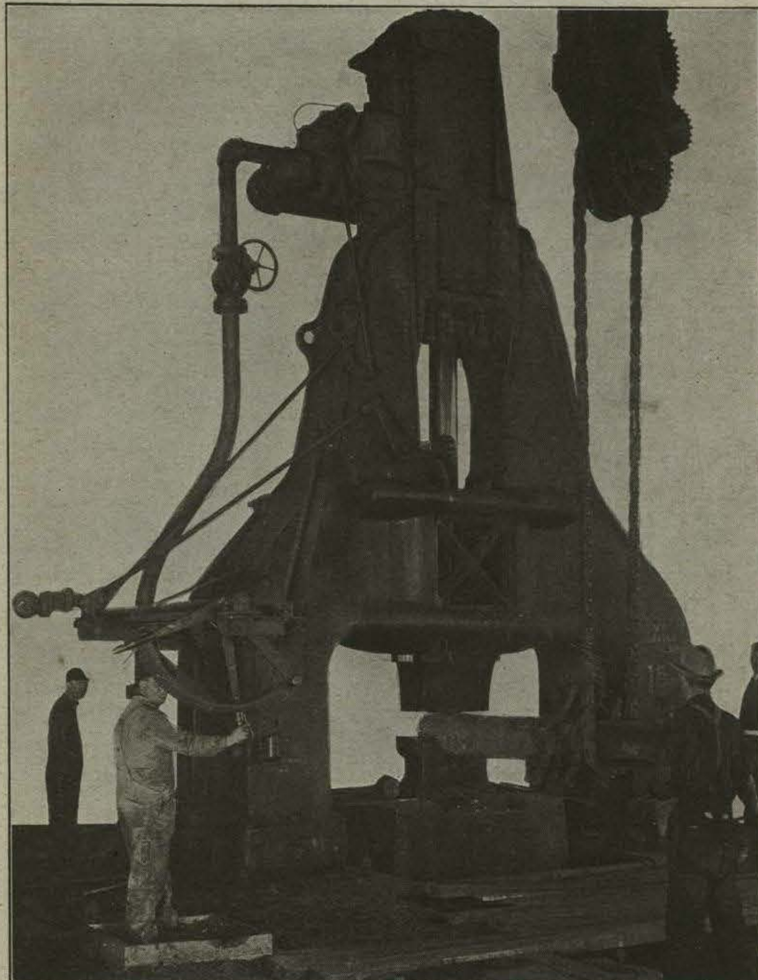

FIG. 56. — Steam forging hammer, 8-ton.

This results in a very uneven structure, as when the metal is hot the blows will penetrate to the center, and as it cools they have less and less penetration until only the skin is affected, and the annealing, which is resorted to afterward, cannot bring it back to the proper homogeneity, as some parts will have a denser grain than others, and therefore be stronger.

The effect on the metal when the blows are not powerful enough to penetrate to the center, or the steel is not hot enough to allow them to do so, is shown in Figs. 58 and 59. When too light a hammer is used, the effect shown in Fig. 60 is usually obtained. These same effects are often encountered in drop forgings and hand forgings, as well as in steam-hammer forgings. They are generally overcome by the use of a hydraulic

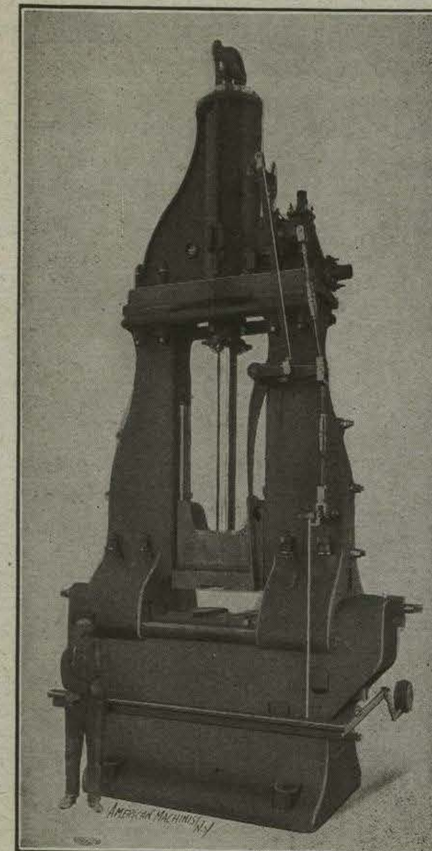

FIG. 57. — Erie steam hammer.

forging press, as with the press the metal is squeezed and consequently must be hot enough to flow into shape, and this affects it clear to the center.

DROP-HAMMER FORGING

When enough pieces, of one shape, are wanted to warrant making a set of dies, the cheapest and best way of producing these in either the common carbon or high-grade alloy steels is by the drop-forging process. They can then be made in one piece without welds, except in pieces which are many times longer than a section through them, and these are so difficult to keep at the proper temperature that they are usually forged in two or more pieces and then electrically welded together. The oxy-acetylene

FIG. 58. — Effect of hammer forging.

blowpipe has also been brought into use for welds of this character, as well as for other forms of welding, and good results are being obtained.

FIG. 59. — Another sample of hammer forging.

A good illustration of this is the front axle of an automobile, which is usually forged in I-beam section, 4 inches from the top to the bottom of the I, $2\frac{1}{2}$ inches across the flange, with the web $\frac{1}{4}$ of an inch thick, and

a length of from 48 to 54 inches. These are generally forged in two halves and electrically welded in the center, but a few of them are forged in one piece, although the first cost of the dies and the liability of their breaking, owing to the axle cooling before the forging operation is completed, has made this method very expensive.

The dies that are necessary for this kind of forging are usually made of a 60-point carbon steel and in two halves: an upper and a lower one. They are generally parted on the center line; but the shape of the piece controls the location of the parting line. The upper half of the die is fastened to a ram that is connected to the piston in a steam cylinder, and this is used as a hammer to strike the hot steel, held over the lower half of the die, a series of blows. This forces the metal to fill both halves of the die, and thus the piece is formed into shape. Dropping the upper half die onto the lower with a hammer-like blow has given this kind of forging the name of drop forgings.

FIG. 60. — Piece forged with relatively light hammer.

The dies are always given from 5° to 7° draft, so the forging will fall out easily, and they are left open on the parting line from $\frac{1}{8}$ to $\frac{1}{4}$ of an inch, according to the amount of metal in the forging. The amount of stock is always greater than in the finished forging, so it will completely fill the die, and the surplus is squeezed out at the opening on the parting line. This fin is afterward trimmed off. With hard or brittle steels it is best to make the dies with shorter steps between the different pairs than for the ordinary carbon steels.

One of the first and most important points in die forging is the setting of the dies, as the upper half, which is fastened to the ram, and the lower half, which is fastened to the anvil block, must come exactly in line to produce a perfect forging.

The lower half of the die should have a current of air blowing in it that is strong enough to remove all of the scale that works off from the piece being forged. The air blast should be directed so it will not cool the hot metal while being forged. Steel-wire brushes can be used for this purpose, but the air is quicker, and if well adjusted is more positive. The upper half of the die should be kept well oiled so the scale will not stick to that. This can be done by rubbing a swab, well soaked in oil, through the die every time it is raised off the work.

With the dies properly set and the press adjusted so the two dies will come together on the parting line, the work can be turned out to one thirty-second of an inch of the finished size, thus making much less machine

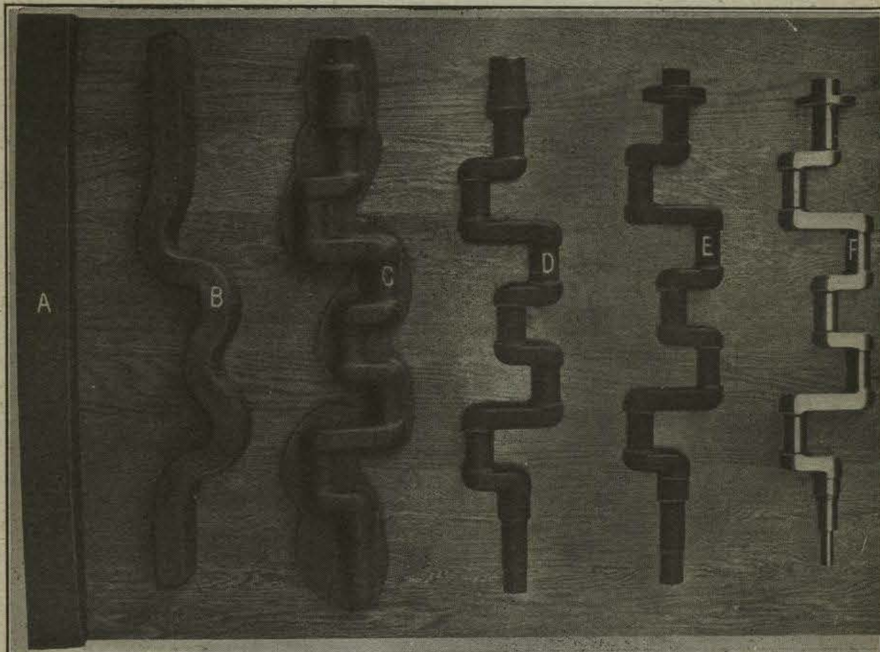

Fig. 61. — Different operations on forging a crank-shaft.

work than by the hand or steam-hammer forging processes, and when grinding is to be used in finishing, the work can be brought to within one one-hundredth of an inch.

The cost of drop forgings depends on the number needed, and the number that can be turned out at one setting of the dies, as well as on the quality of the steel used.

Some of the largest pieces that are being made by drop forging are the crank-shafts for internal combustion engines, and the different operations in forging these are shown in Fig. 61. At *A* is shown the straight bar, cut to the proper length. This is first bent to the shape shown at *B* in the bending press. It is then drop-forged, and when it leaves the dies, it is similar to the piece shown at *C*. The dies are usually left $\frac{1}{4}$ inch apart on the parting line for this size of forging, to allow the excess metal to squeeze out between them, which forms into the fin that is shown at *C*. This necessitates the making of an extra pair of dies for shearing off the fins. After this is done the crank has the appearance of that shown at *D*. On this particular shaft there was a comparatively large flange on one end, as shown in *E*. This would be difficult to form in the dies when forging the rest of the shaft, and for this reason an extra amount of metal is left on the shaft at this point and the flange is formed

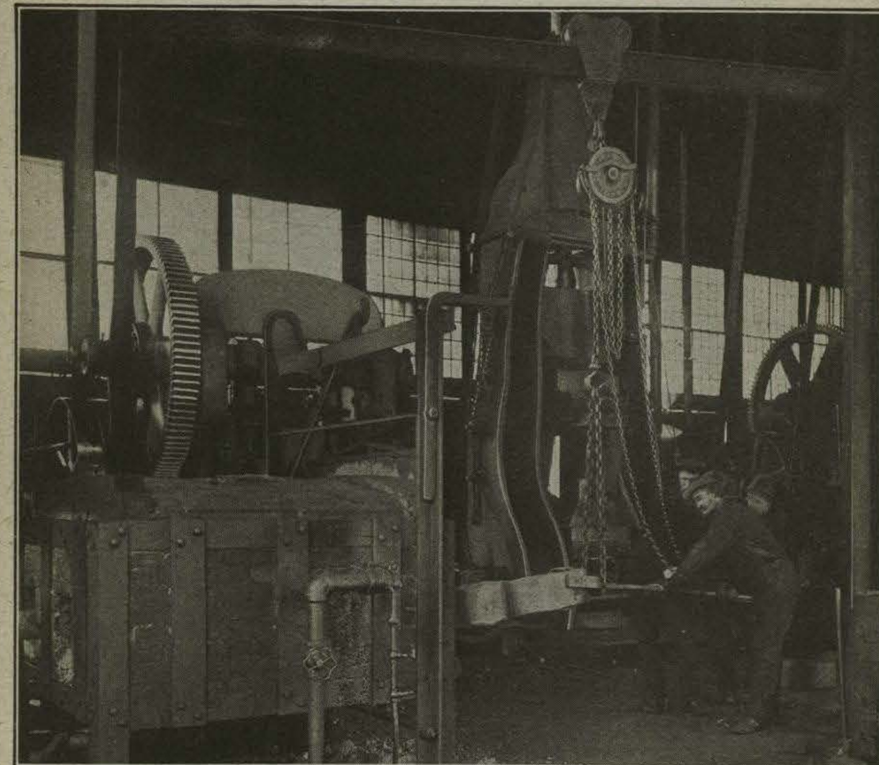

Fig. 62. — Taking crank-shaft from furnace to hammer for first operation.

in another set of dies after the rest of it has been forged. This completes the forging operations and the shaft is ready to be machined; the machined crank-shaft being shown at *F*.

One of the largest drop forgings that has so far been made (June, 1910) is a two-throw crank-shaft, made by the Bethlehem Steel Company, that when finished weighs 400 pounds. The operations are similar to those shown in Fig. 61. Fig. 62 shows the piece, after it has been bent and heated, as it is being taken from the furnace to the 5000-pound drop-hammer for the first operation. Back of the furnace can be seen the top of the bending press, which bends the straight bar to the shape shown by the partially forged crank in Fig. 64. Fig. 63 shows the piece being held under the hammer ready to drop the die on it. Fig. 64 shows the crank-shaft after it has been partly formed and as it is being taken back to the furnace to be reheated for the final forging operation under the hammer. Fig. 65 shows the crank-shaft as it was being taken out of the dies after

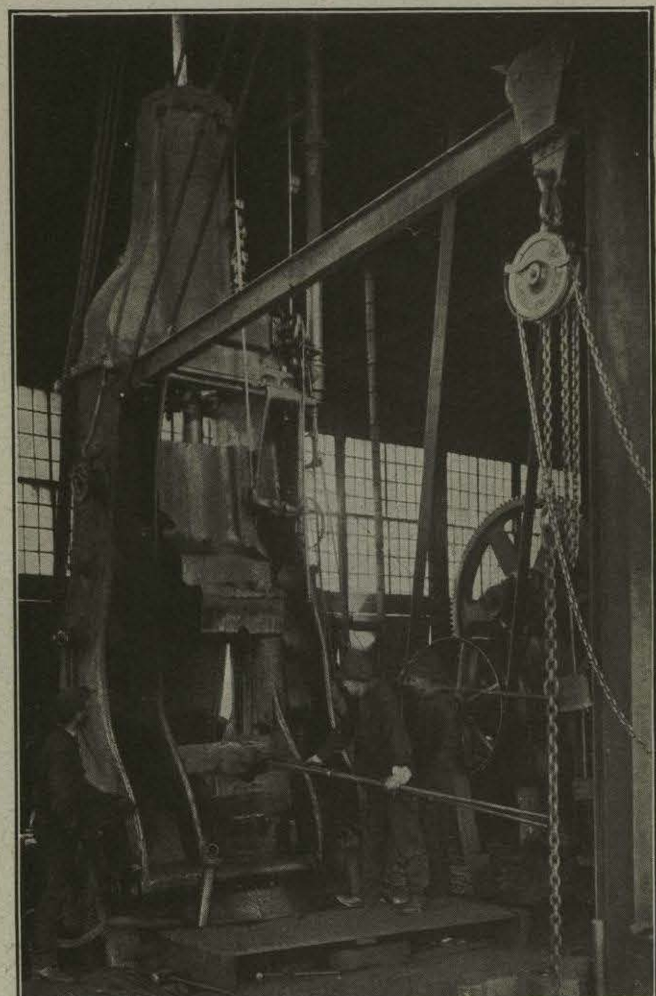

FIG. 63.—400-pound crank-shaft under hammer ready to drop the die.

the final forming operation. In front of the hammer is shown a finished crank-shaft with a 5-foot rule standing beside it to show its length.

An idea of the variety of shapes, sizes, and styles of machine parts that can be economically made by the drop-forging process can be obtained from Fig. 66. At the lower edge of the half-tone is laid a 5-foot folding rule, and just above it is the 400-pound crank-shaft that has just been

described in its forging operations; while at the top of the picture are forgings that will require about twenty to weigh one pound.

PRESSED FORGINGS

The inferior quality of many die forgings is undoubtedly due to the drop-hammer process, as this has a tendency to produce only a bruising

FIG. 64. — Removing partially forged 400-pound crank-shaft.

effect, owing to the top die descending at a high speed and delivering a light blow which has no penetration. The hydraulic, pneumatic or steam press, on the other hand, produces forgings of a far superior quality because it slowly squeezes the metal into the shape of the die, thus allowing it more time to flow into place and assume its new shape, and therefore making it more uniform in quality and with less internal strains.

With the hammer blow in forging a wavy grain is obtained, as shown in Figs. 58 and 59, *i.e.*, directly under each blow of the hammer a dense grain is produced, while around the edge of the blow it is less dense. This causes the ridges shown in the fracture of the fine-grained metal around the outside of the bar. In conjunction with this is the inability of the blow to penetrate to the center. In one or two places, where one blow did not overlap another, the shape of the metal affected by the blow can be plainly traced. Where the steel is pressed or squeezed into shape this

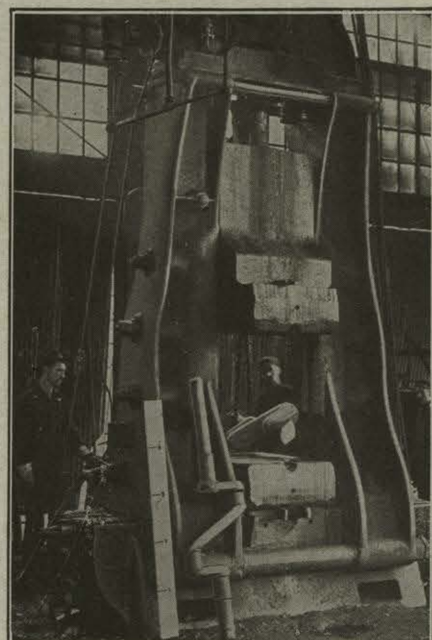

Fig. 65. — Final forging operation.

variation in the density of the grain of the piece would not show, and it would be condensed clear to the center, as the steel being operated on would have to be hot enough to flow into the shape desired under the high pressure used, or it could not be worked.

That the press makes a more homogeneous metal than the hammer, or even the rolls, and hence a stronger and tougher one, is well illustrated by the German government specifications for steel forgings worked by rolls, hammer, or press which says: "Forgings made from rolled or hammered steel must have the initial section at least eight times that of the finished section; while those made from pressed steel need have an initial section only four times the finished section."

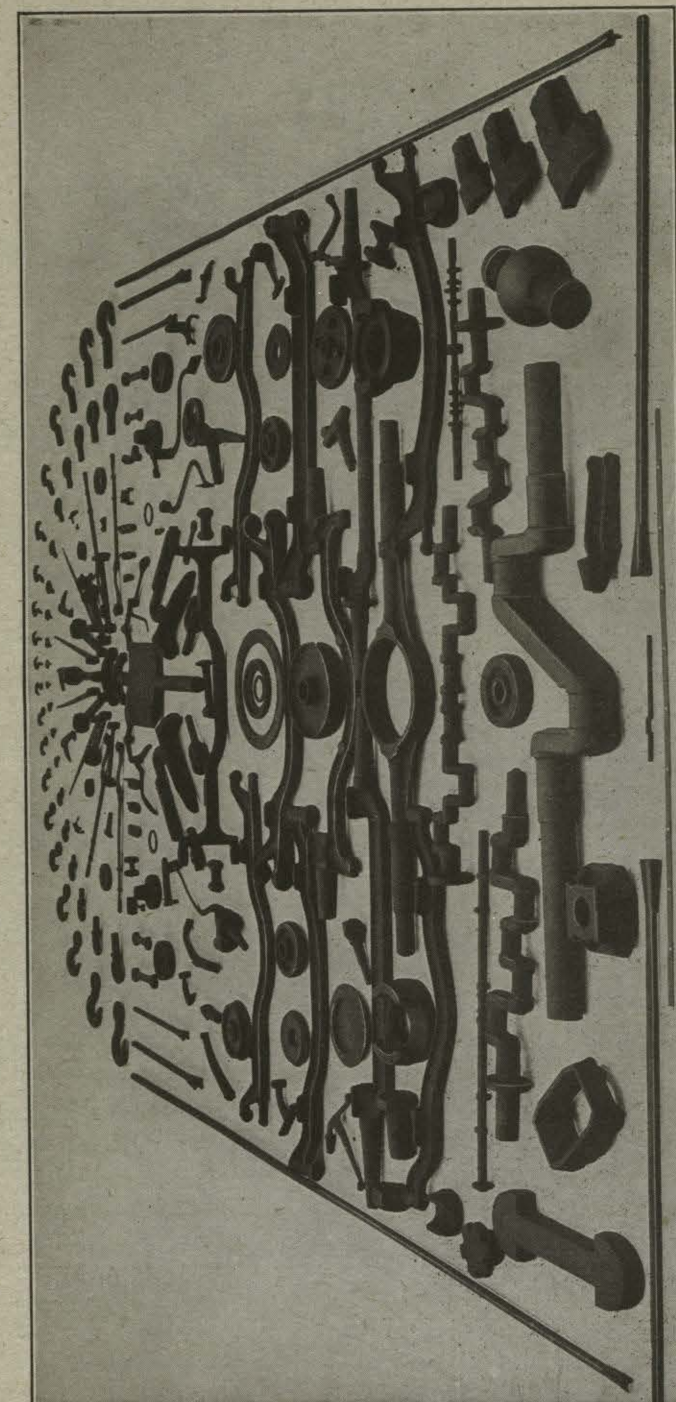

Fig. 66. — Group of drop forgings made by the Bethlehem Steel Company.

With the press, rounds, flats, squares, and irregular shapes can be forged without dies, as with the steam hammer, or two halves of a die can be pressed together to make die forgings, the same as with the drop hammer. When forging metal into shape, a much greater force can be brought against it, with the press, than with the hammer, owing to the

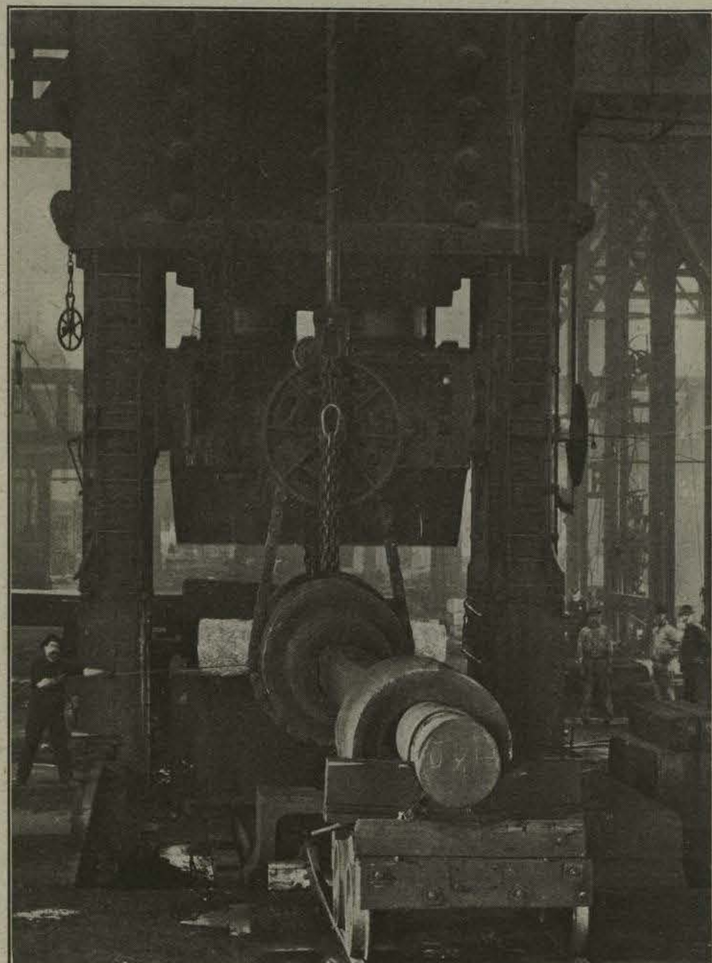

Fig. 67. — A 1400-ton forging press.

absence of any jarring. As a consequence of this the steel works are all adopting presses for their heavier work. Some of these operate at a very high speed, when compared with the hydraulic presses of a few years back.

The power behind the press is obtained by the use of either water, air, or steam, but the hydraulic press is the one that has been almost universally adopted. A large-sized press of this kind is shown in Fig. 67.

This is a 14,000-ton press at work on a forging, but it is typical of the style of hydraulic presses, and they can be obtained in much smaller sizes.

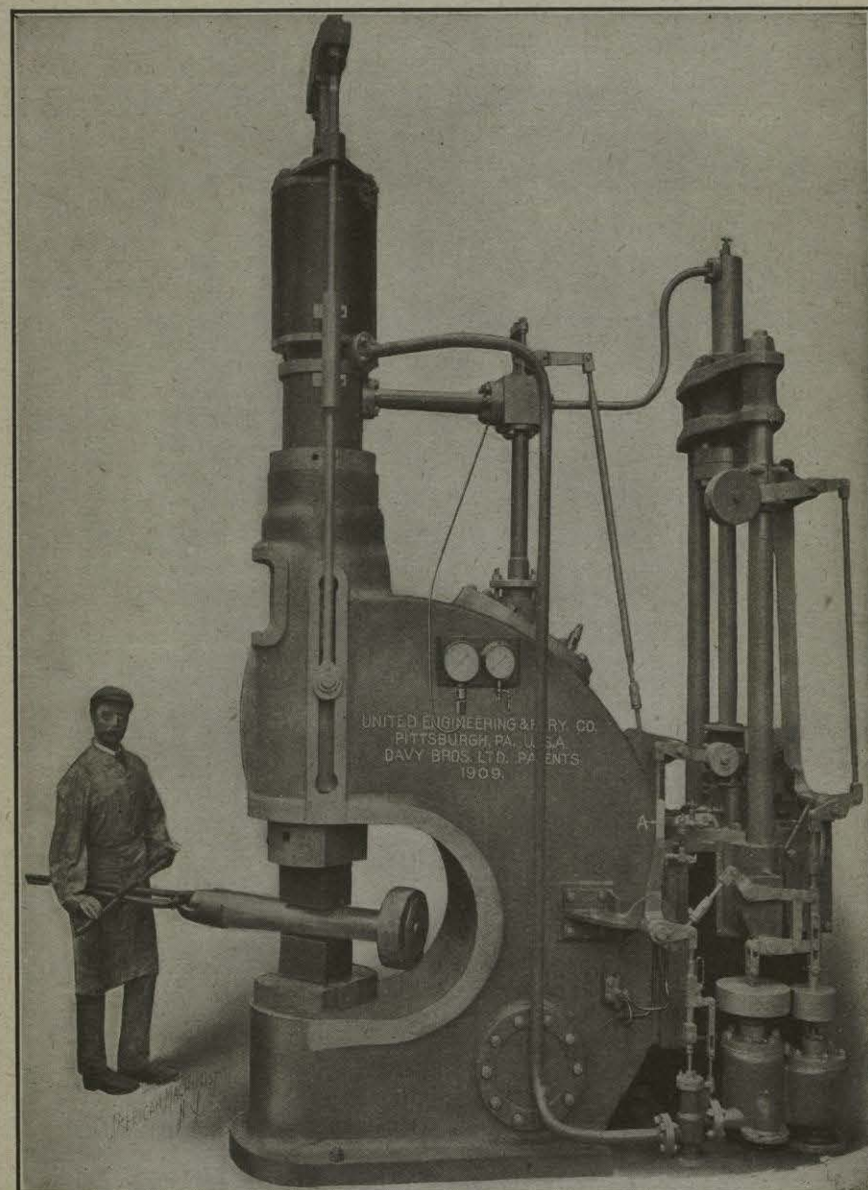

Fig. 68. — Small high-speed steam-hydraulic forging press.

In place of the upper and lower press blocks used, others can be inserted that will form rounds, octagons, etc., or the two halves of a die can be put in their place to form irregular shaped pieces.

A combination of the steam-hammer and hydraulic press has recently been placed on the market, and this promises to have a very useful field.

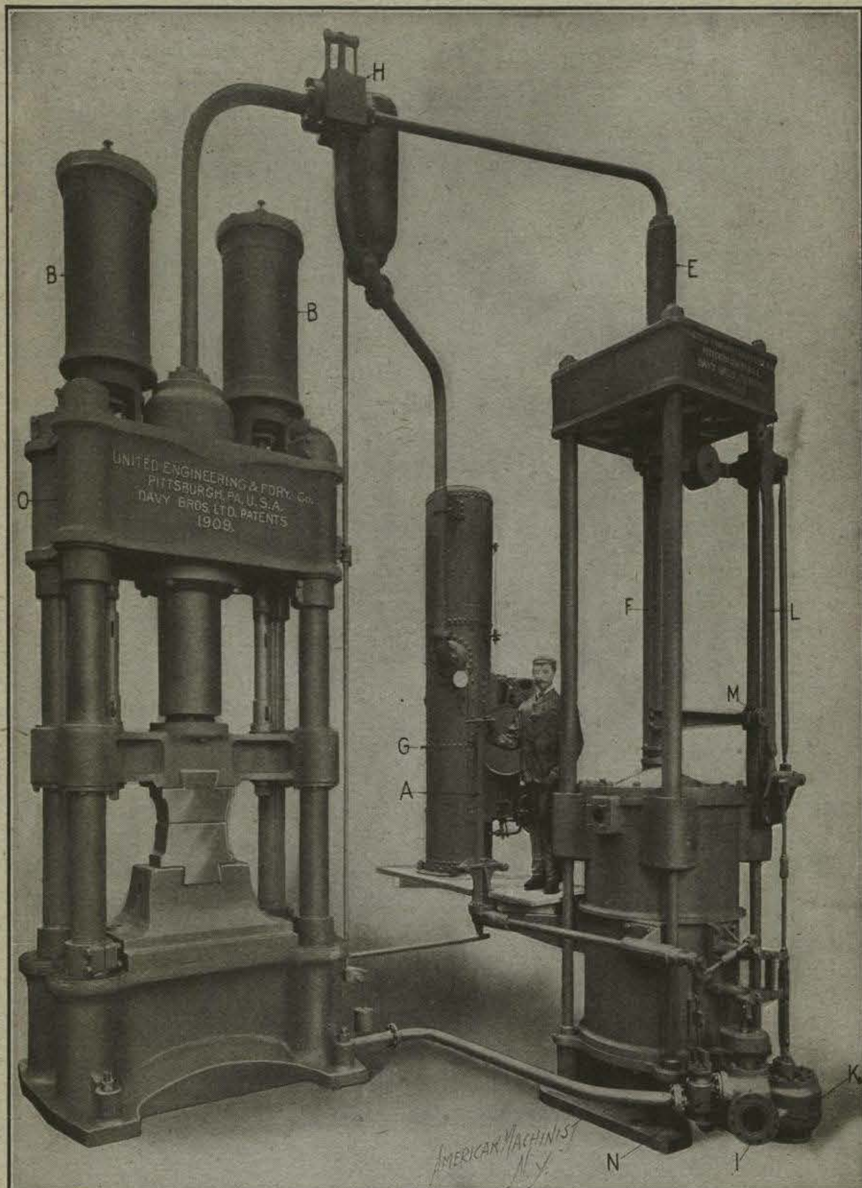

FIG. 69. — Large high-speed steam hydraulic forging press.

One of the smaller sizes, with a single frame, that is built in sizes from 150 to 400 tons, is shown in Fig. 68, and a large size with four columns, in sizes from 300 to 12,000 tons, is shown in Fig. 69. These machines raise the

ram and lower it onto the work, which can be done with a blow if desired, and then the water pressure is turned on to squeeze the piece into shape. It also can be used with or without finished dies in the making of forgings.

With the hydraulic press it is possible to make simple, inexpensive dies that will forge quite complicated pieces. Pieces that are impossible to make in the drop-hammer and are very expensive to make by hand-forging can be made remarkably cheaply and accurately. As an example of this, the piece shown in Fig. 70, after the machine work was done, was forged in a hydraulic press with the apparatus described below.

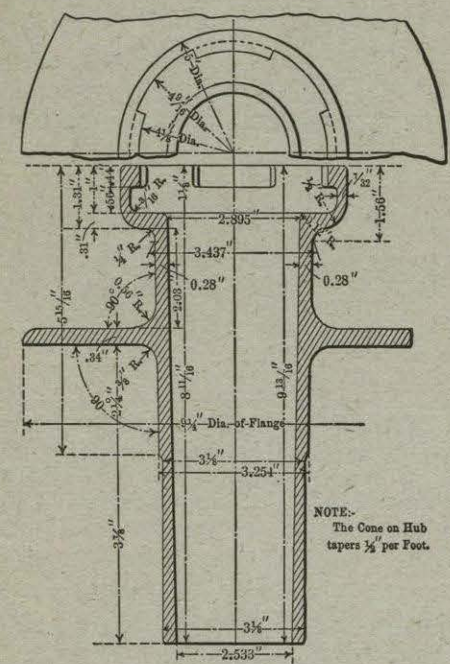

FIG. 70. — Wheel hub to be forged in hydraulic press.

A piece of $3\frac{1}{2}$-inch round stock was cut the required length and put in the die, as shown at *G* in Fig. 71. Here, *A* is the die-holder; *C* the die block, which is put in loose, and *E* the flanging punch. A loose block is put under the piece *G* and when it leaves the press it is the shape shown in Fig. 72. The next operation is to punch out the center and spread out the top to form the shoulder, and this is shown in Fig. 73. Here the die in Fig. 71 has had the loose block in the bottom taken out, and the two halves of the die block, *D*, *B* (Fig. 73), placed on top of the forging. When the punch is pressed down it forms the piece into the shape shown in Fig. 74, and when the bottom of this is trimmed off it leaves $\frac{1}{8}$ of an inch finish all over.

Thus, while the press makes forgings with much better metal than those turned out with any kind of a hammer, it also presents greater possibili-

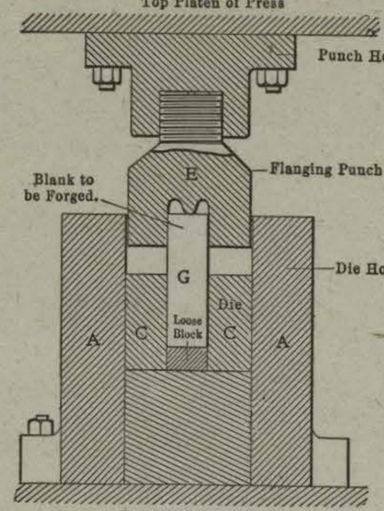

Fig. 71. — Stock in die ready for first operation.

ties to the maker and user of forgings in the way of difficult shapes that can be economically made. The example given is merely one of a large variety of shapes that can be made in a similar way with the use of loose

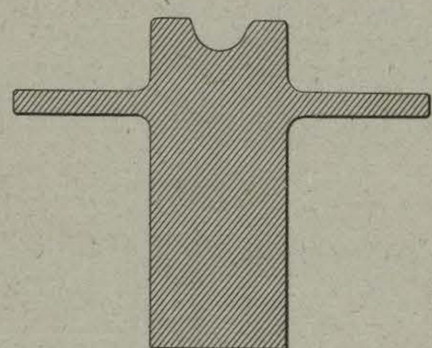

Fig. 72. — Cross-section of forging after first operation.

dies. Fig. 75 shows a few more shapes that have been made in the hydraulic press; some of which were made with loose die blocks, and these will doubtless suggest to the student many more that can be made.

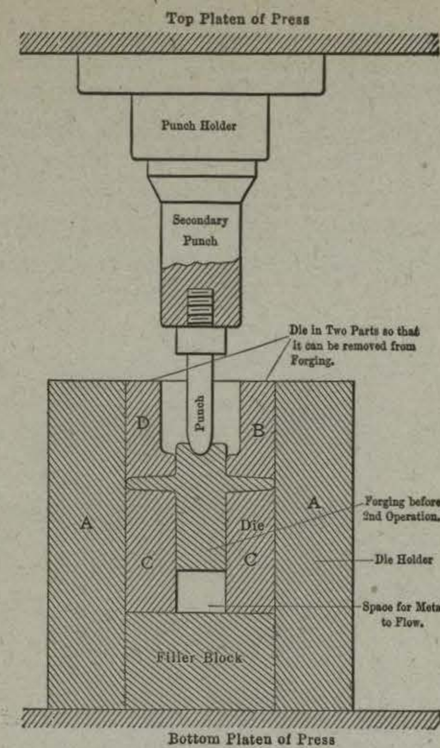

Fig. 73. — Forging in die ready for second operation.

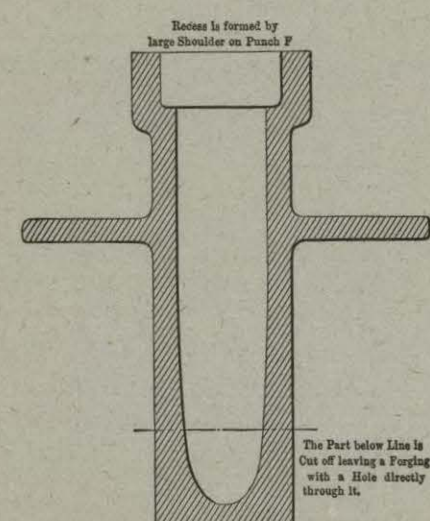

Fig. 74. — Forging after second operation, ready for machine shop.