FORMING METHODS

FORMING BY SECTION AND TUBE BENDING

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FORMING BY SECTION AND TUBE BENDING

SECTION BENDING PROCESSES

1. Requirements of Section Bending.—The large number of both extruded and formed metal sections used in airplanes makes the bending of such sections an important phase of aircraft production. The bending, or forming, may be done by hand, by hand-operated bending machines, by power-operated bending machines, or by machines adapted to bending operations by the use of special fixtures. The bending of sections presents many problems, particularly when they are to be bent to small radii. For example, the prevention of wrinkling on the stem, or web, of a T section, when it is bent by hand, requires extreme skill and experience on the part of the worker. Therefore, in present practice, such sections are usually confined on all sides, to prevent wrinkling and undue stretching as well as to control the internal stresses, and are generally bent by mechanical means in or around dies that are shaped to suit the section being formed. The use of dies and the application of high pressure to the part as it is being formed, cause the metal to flow to the desired shape with no wrinkling. Also, as the metal being formed is under a constant pressure and is confined closely, the high internal stresses that exist in the case of hand bending are avoided in machine bending.

2. Section Bending by Hand.—Many parts, especially in relatively small quantities, are still formed by hand work, even though more dependable and faster methods are desirable. Also some parts partially formed by other methods are finished by hand to remove minute wrinkles or distortion. As an example, the channel *a*, Fig. 1, was rolled to approximately the required contour. Then in order to bring it exactly to the desired shape, it was clamped between the top form block *b* and the bottom form block *c*, by C-clamps, and its outer flange was formed to the block by an air-operated bumping hammer *d* applied to the

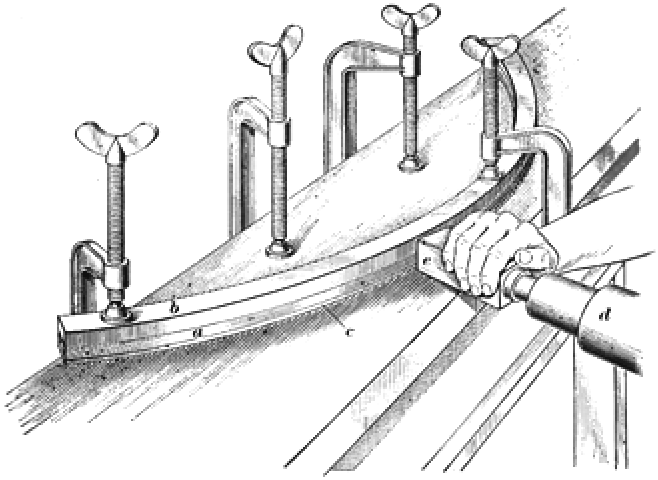

FIG. 1

FIG. 2

wooden block *e*. In a like manner, many other parts that have been formed in the hydro-press or by other means must be hand-worked to their respective form blocks. Mallets and lead straps are often used for this purpose. Such hand work is especially necessary to add joggles or to bring them to their exact shape, to finish sharply the bends that are made to small radii, and to remove wrinkles.

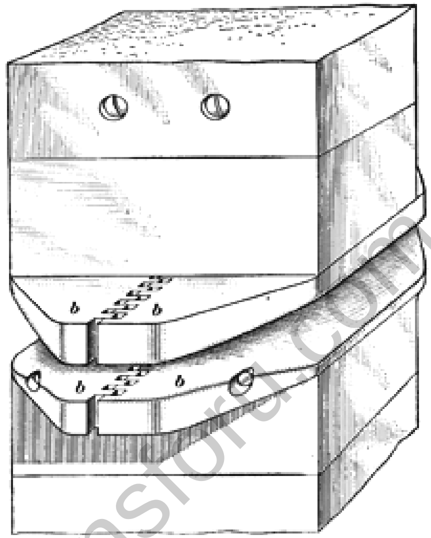

FIG. 3

3. Section Forming by Shrinking.—Even though the wrinkles on many formed parts are still removed by hand, it is more economical and faster to remove them by shrinking, or compressing, the metal in a shrinking machine. An operation of this character is illustrated in Fig. 2, in which the flange wrinkles on the hydro-pressed part *a* are removed by the jaws *b* of the shrinking machine as the part is fed through the machine. The jaws, shown separately in Fig. 3, do the actual shrinking of the metal. The two pairs of jaws are identical. The upper ones are mounted on an anvil attached to a reciprocating ram in the head of the machine, whereas the lower ones are on a similar anvil attached to the stationary tool post.

The jaws are wedge-shaped pieces of tool steel that are seated on inclined surfaces on the ends of the anvils and are held apart against pins in the anvils by coil springs set between the jaws. The working surfaces of the jaws, which are roughened to aid in holding the work, are parallel and grip the metal to be shrunk at two points at the same time. The stroke of the ram is so adjusted that the ram travels beyond the point where the work is gripped, and in doing so it forces the jaws to slide together on the inclined surfaces of their anvils, thus compressing the coil springs, closing the jaws, and shrinking the metal. The metal between the two points gripped by the jaws is compressed beyond its elastic limit and is thereby increased in thickness and reduced in length, so that any wrinkles in the compressed area are removed. On the upward stroke of the ram the jaws are again opened by the action of the coil springs.

4. If a straight piece is fed through the shrinking machine it will be shrunk on one side and assume a curved shape. Even double-curvature shapes may be formed, but the method is slow and not recommended for the forming of curved shapes unless only a few parts are required. Actually, parts are not designed to be formed on the shrinking machine; instead, the machine is used to aid in the finish-forming of parts that are not formed perfectly on the hydro-press, or other high productive equipment. If the metal is shrunk violently instead of gradually, an irregular surface is left on the material, but with normal operation the only surface change is a loss of polish. If an irregular surface is not objectionable, much more rapid shrinking can be done by using serrated jaws in the machine. Since the jaws are replaceable, special jaws can readily be installed. All metals commonly used in aircraft construction, including the aluminum alloys and mild and stainless steels, can be finish-formed in the shrinking machine.

5. Section Forming by Rolling.—A cam-type bending machine used for bending extrusions and formed metal sections by rolling is shown in Fig. 4. It is a rapid-production unit on which from 40 to 100 feet per minute can be formed, depending on the kind and temper of the material and on the difficulty

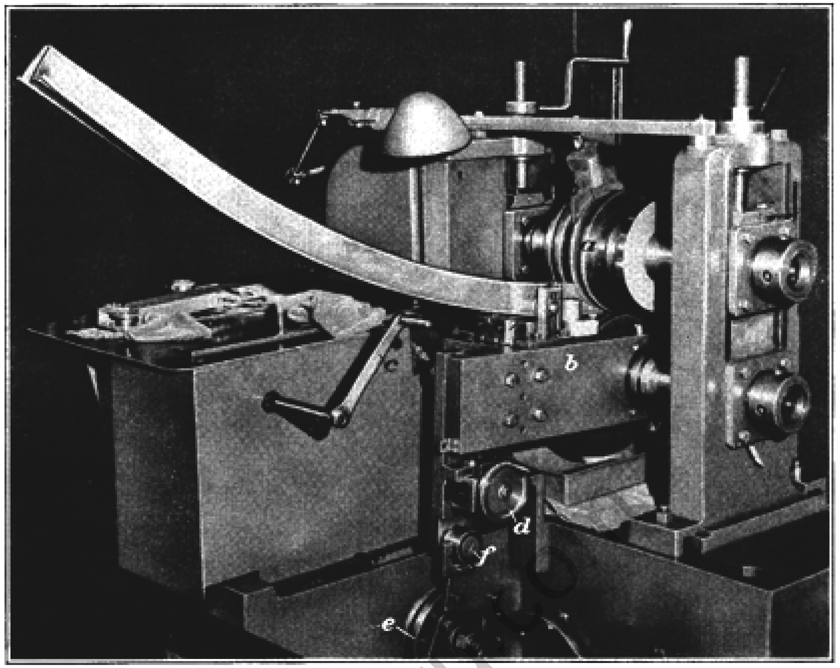

FIG. 4

of the forming operation. It can be used to form regular or irregular contours up to any length that can be handled within the space around the machine, and except for variations in material it does accurate forming.

6. The top and bottom rolls *a*, Fig. 4, are selected to fit the section being formed, in this case a rolled hat section. A pinch-type arrangement holds the material and prevents it from twisting as it is formed to the curvature desired. A rubbing shoe *b* that carries side guides for the section is adjustable and does the actual forming. The section to be formed is fed through the rolls with the rubbing shoe set in a horizontal position. Then as the material passes through the side guides, the shoe is swung up by a lever *c* to approximately the height required to produce the given radius on the part. Minor adjustments may then be made by the hand wheel *d*. Since the material must be fed through the rolls for a short distance before any forming is

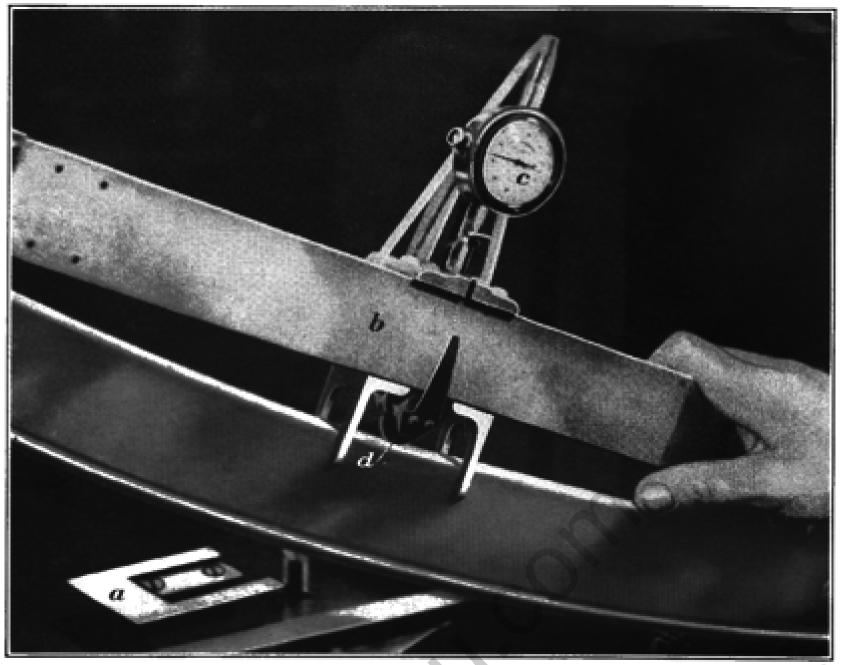

FIG. 5

done, the first 6 inches of the material is waste and there is approximately an equal loss on the tail end of the stock. When forming is done to a constant radius, the shoe is set in this manner and the section is passed through the machine. When varying radii are required on the part, a rotary cam *e* and its follower *f* are provided to move the shoe *b* up to varying heights as the material is fed through. For forming to an irregular contour, a separate cam must be made for each different contour.

7. The radius on the part is checked as the forming is being done. The width of the inside and that of the flanges of the hat-section are checked by the gage *a*, Fig. 5, and the radius is checked by the gage *b*. The latter gage has rollers on each end so that the sections can pass under it as it is held on the section. A dial indicator *c* operated from the roller *d* shows any variation in the curvature of the formed sections. Since the gage checks only the curvature on a small section of the part, calculations must be made to translate the tolerance on the radius of the part to tolerance as shown by the gage. These values are recorded and given to the operator so that gage tolerances are immediately available and need not be calculated in the shop. If desired, the calculated gage values can be plotted

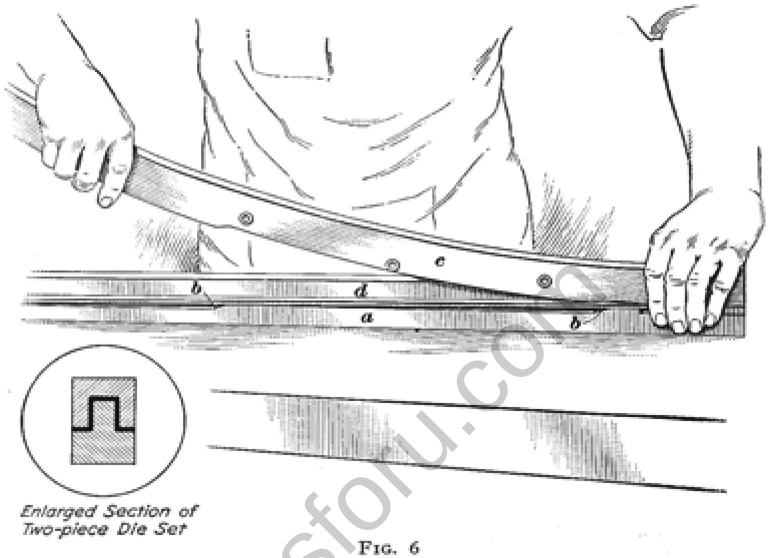

Fig. 6

against their corresponding radii and a curve drawn through the points so located. The gage value for any particular radius can then be selected quickly from the chart. As a final check, the formed part is fitted to knife-edged stops which are laid out to the required curvature on a large table.

8. Rolling Angle to Single Curvature.—Single contours can be formed satisfactorily in bending rolls by simply passing the stock through center rolls and forming it with a rubbing shoe or outer guide rolls. When a section, however, must be both formed to a curve and joggled on its curved surface, it is necessary to use a die in the rolling operation. A two-piece die set to be used for this purpose is shown in Fig. 6. The bottom part *a* of the die set is straight and has machined in its upper

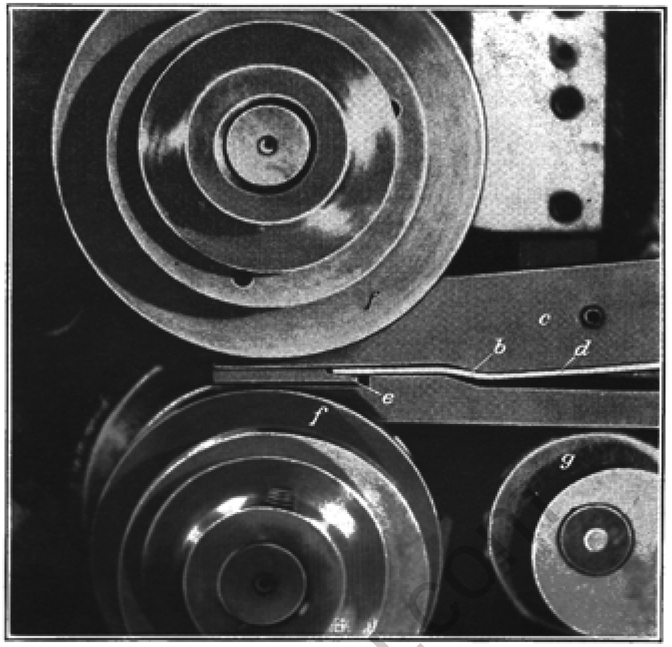

Fig. 7

surface three joggles *b*, one in the middle and one at each end. The upper die *c* has corresponding joggles, but instead of being straight it is shaped to approximately the desired contour of the finished part. Since the stock is to be formed in the heat-treated condition, it will spring back after forming; therefore, the upper die *c* must have a greater curvature than that desired on the finished part in order to overform the material and thus compensate for the springback.

9. To form the part, the angle *d*, Fig. 6, is placed between the two dies with one end caught under the projection *e* of the upper die, as shown in Fig. 7, and is fed through the rolls *f*. The upper roll is adjustable vertically and may be raised quickly by a hand lever for inserting the assembled dies, and then returned to its original position without disturbing the setting. As shown in the illustration, the dies and the angle have just

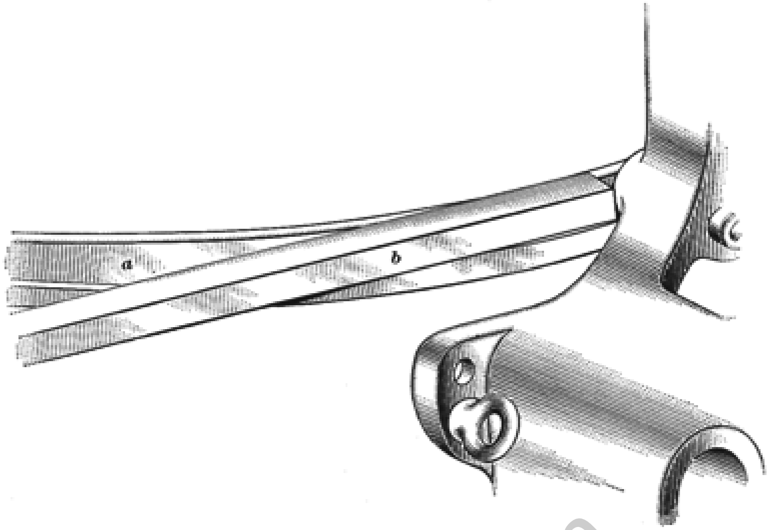

FIG. 8

passed through the center rolls *f* while being supported on the guide roll *g*. The action of the curved die *c* caused the material to follow its curvature, and joggles were formed on the angle, as shown at *b*, by the joggles in the surfaces of the die. In this case the guide roll *g* is not used in forming the section but it is used, together with a similar roll that can be mounted on the other side of the center rolls, to do the actual bending when a straight extrusion is to be bent to a single curvature without the aid of a die set.

10. Rolling Angle to Double Curvature.—When an angle section is to be formed to a double curvature in pinch-type bending rolls, it is necessary, as in the case of joggling the surface of single-curved parts, to use a die to aid in the forming operation. However, when the surface of the section is not to be joggled or given similar sharp bends, a single die can be used satisfactorily to form the desired contour. An operation employing a single die for bending an angle to a double curvature is illustrated in Figs. 8 and 9.

In performing this operation, first a steel die *a*, Fig. 8, must be accurately made, with an allowance for springback, to cor-

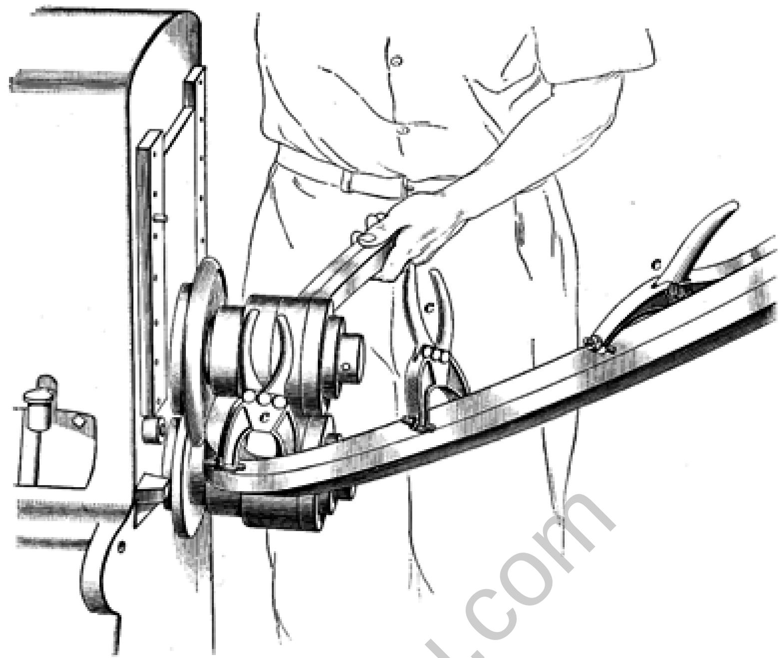

FIG. 9

respond to the shape of the finished part. The die and the straight angle *b* are then fed through the rolls and clamped together by a plier-type clamp *c*, Fig. 9. As the die and angle are fed through the rolls, additional clamps are put on at intervals in order to hold the angle firmly to the die. When the angle has been fed through practically its entire length, the die and angle are clamped together back of the rolls, the motion of which is then reversed to run the die and angle backwards. As each clamp approaches the rolls, it is removed and transferred to the other side of the rolls, so that the die and angle will be held together at that end also. This procedure of reversing the rolls and transferring the clamps is continued until the angle is given its required contour. By use of a die and bending rolls, it is possible in this manner to form a great variety of double-curved parts, each of which requires a die corresponding to the shape desired on the finished part.

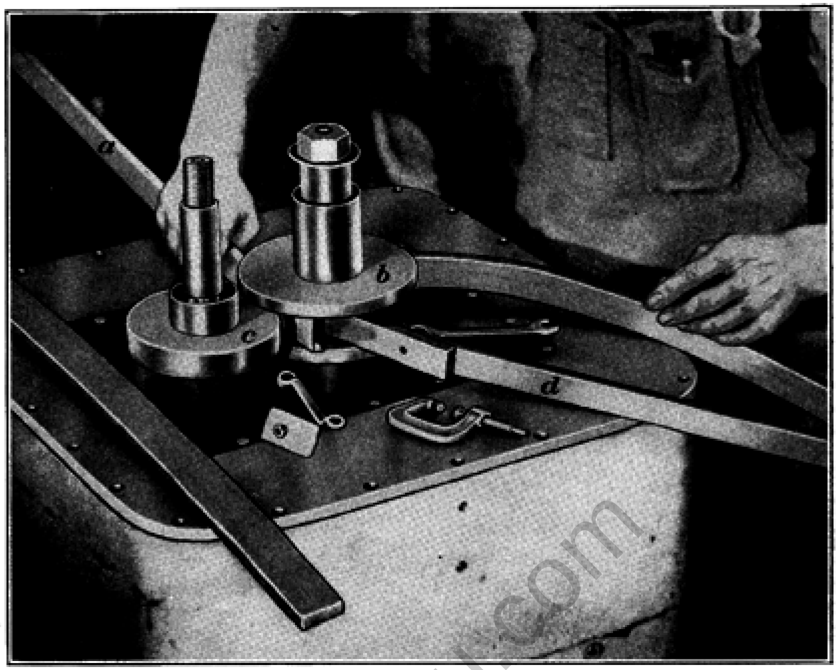

FIG. 10

11. Two-Roll Forming Machine.—The two-roll forming machine shown in Fig. 10 was developed by one aircraft manufacturer to form extrusions to various shapes. In this machine the extrusion *a* is shaped by rolling it back and forth between the two rolls *b* and *c*. The roll *b* at the center of the table rotates in fixed bearings; whereas, the roll *c* is mounted on a slide so that it can be moved toward the roll *b* to provide the necessary forming pressure. A form, or die, *d* that is shaped to the desired curve, plus an allowance for springback, is placed around the center roll. Both the center and the sliding rolls should have shapes suitable to the section being formed; that is, the center roll should have a recess of practically the same width as the extrusion, and the sliding roll should be wide enough to exert a uniform pressure on the material as it is being passed through the rolls.

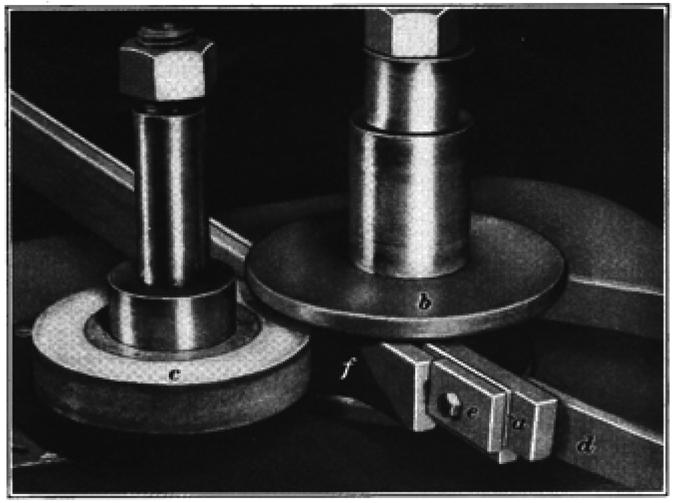

Fig. 11

Fig. 12

12. To form the extrusion to the desired shape, it is first inserted between the rolls and fastened securely to the die *d* by means of the clamp *e*, Fig. 11. A hole drilled at one end of the extrusion permits the clamp bolt to be passed through the extrusion and die and to be drawn tight by a nut on the inside of the die. A lead strip *f* is placed against the extrusion, and the roll *c* is brought to bear against the lead strip. As the roll *c* is somewhat narrower than the recess in the center roll *b*, the lead strip serves to transmit the forming pressure evenly and uniformly to the material. The operator then swings the die around the center roll with one hand, while he holds the lead strip and extrusion together at the far end and guides them into the rolls with his other hand. This operation is shown in Fig. 12. At the beginning of the swing, it is necessary to roll the material back and forth around the sharp bend at *g* in order to form it to this sharp curvature. At the completion of the swing, the end of the material is clamped to the die by a C-clamp. Then the die is swung back and forth several times around the center roll to set the material as much as possible to the curve of the die. Many different shapes can be formed in a similar manner by the use of the proper dies, such as, for example, the two-piece die shown in Fig. 6. As the die cost for the machine

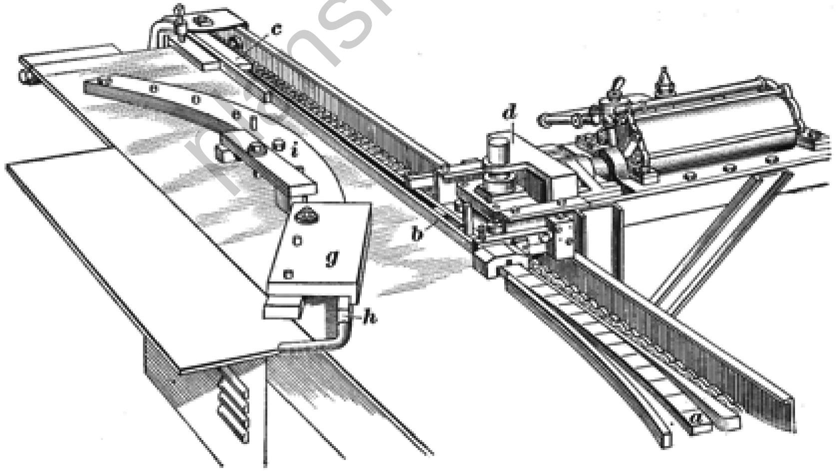

FIG. 13

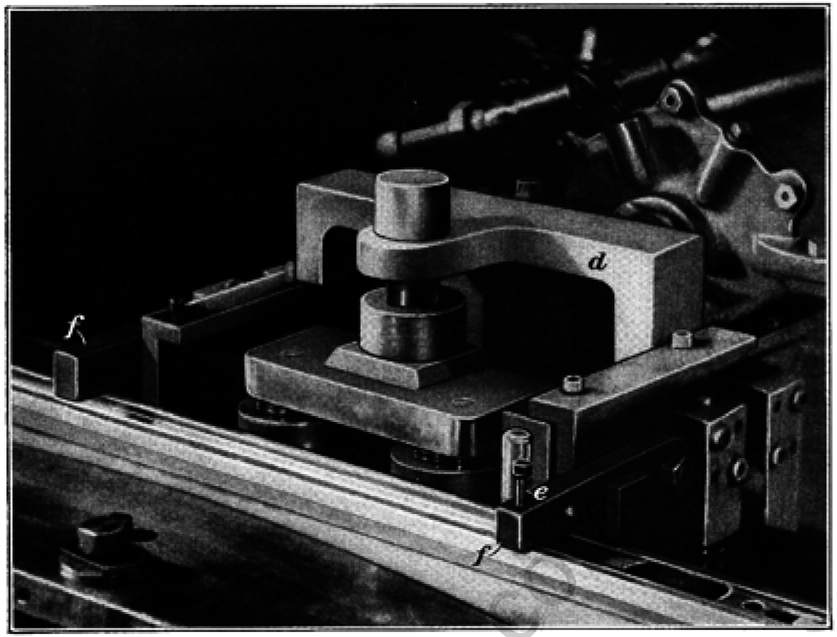

FIG. 14

is low, and the operation requires relatively unskilled labor, this machine affords an economical means to form small extrusions.

13. Roll-Bending of Channel Sections.—A machine designed for the roll-bending of long channels is shown in Fig. 13. To prevent wrinkling and buckling of the channel as it is being formed, a long, flexible filler *a*, which is made up of a series of lead blocks, is drawn into the channel *b* before any forming is done. The channel is held at one end on the table by blocks *c*, as the head *d* of the machine draws the filler in place. A pin *e*, Fig. 14, is inserted in a hole in the filler and projections *f* on the head draw the filler along. Since the head has only a limited travel along the table, the pin *e* must be removed when the head has reached its limit of travel, the head then run back, and the pin again inserted in its hole so that the forward projection *f* can complete the draw. The channel and filler are then slid under the plate *g*, Fig. 13, and clamped tightly in place at the end.

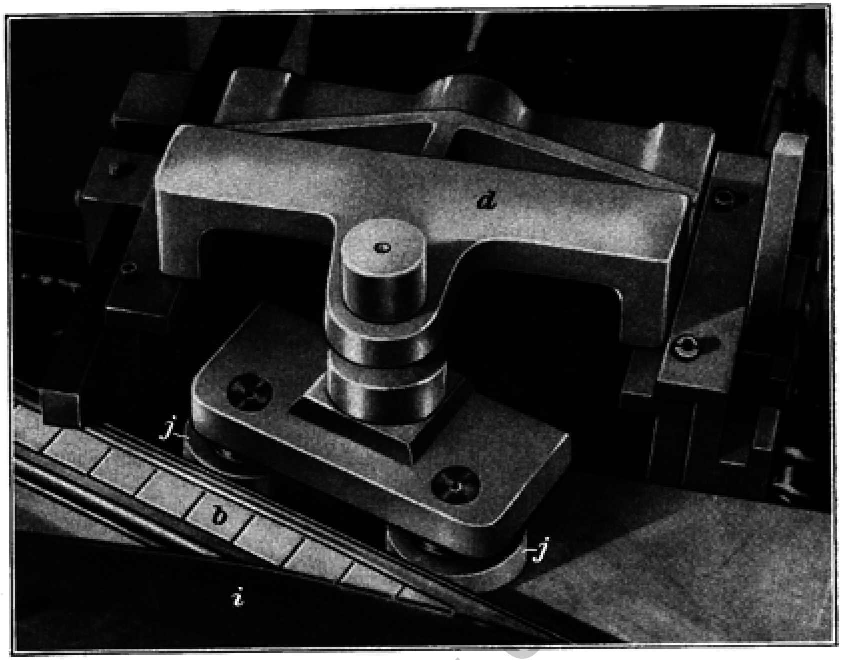

FIG. 15

The clamp *h* is wedge-shaped, and in the position shown it holds the plate *g* up far enough so that the channel can be inserted without any bending action. The clamp is then withdrawn, turned with its handle upward, and wedged back into place between the channel and the outer wall of the plate *g*. This type of clamp is inexpensive, yet quick-working and efficient. The channel is then formed to the curvature of the die *i* by rolling it with the rollers *j*, Fig. 15, that are swivelled to the head. The rollers are moved forward into contact with the channel by the plunger of a hydraulic cylinder, and are held against it at a constant pressure. The head of the machine is then run back and forth along the table so that the rollers gradually bend the channel to the die. Since the rollers can swivel, they both contact the channel and the forming pressure works over a longer area, and is thus more even and uniform than if only one roller were used. Other contours may be formed by simply changing the dies on the table.

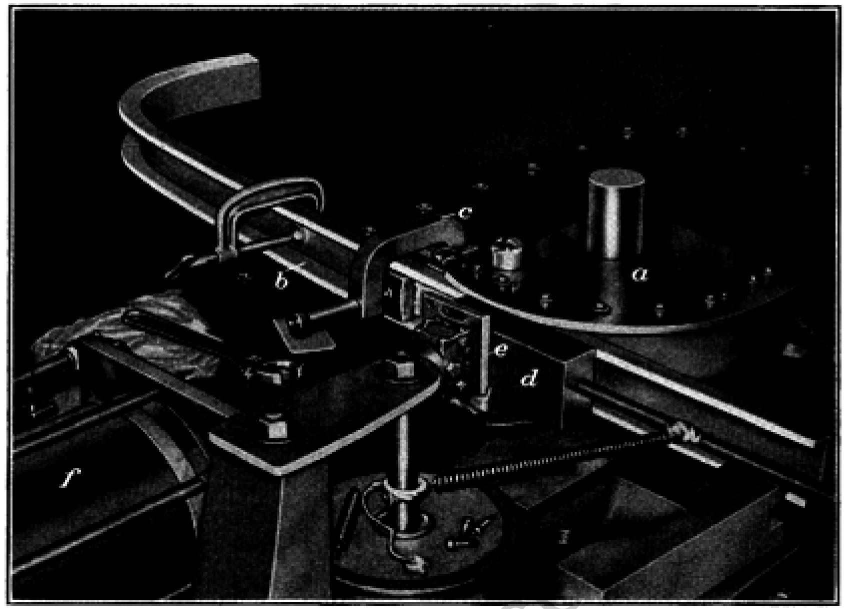

Fig. 16

14. Wrap-Forming of Sections.—Channels and other sections can be formed by rubbing, or wiping, the sections under high pressure into a form block, or die, having the desired contour, this process being known as warp forming. As shown in Fig. 16, the wrap-former consists of a turntable to which is fitted a steel, Kirksite, or Masonite, die *a* that is shaped to the section being formed. The die has a radius smaller than that desired on the finished part in order to compensate for springback. The section *b* is well lubricated and is clamped to the die by a C-clamp *c*. A rubbing, or pusher, block *d* that fits the section being formed is brought to bear against the section in such position that it is tangent to the curve of the die. The rubbing block is held against the section by the plate *e*, which is mounted at the end of the piston rod that extends from the pneumatic cylinder *f*. On this particular machine an air pressure of from 80 to 90 pounds is generally used, but it can be adjusted to take care of slight variations in springback. The air pressure varies, of course, in different machines as it depends

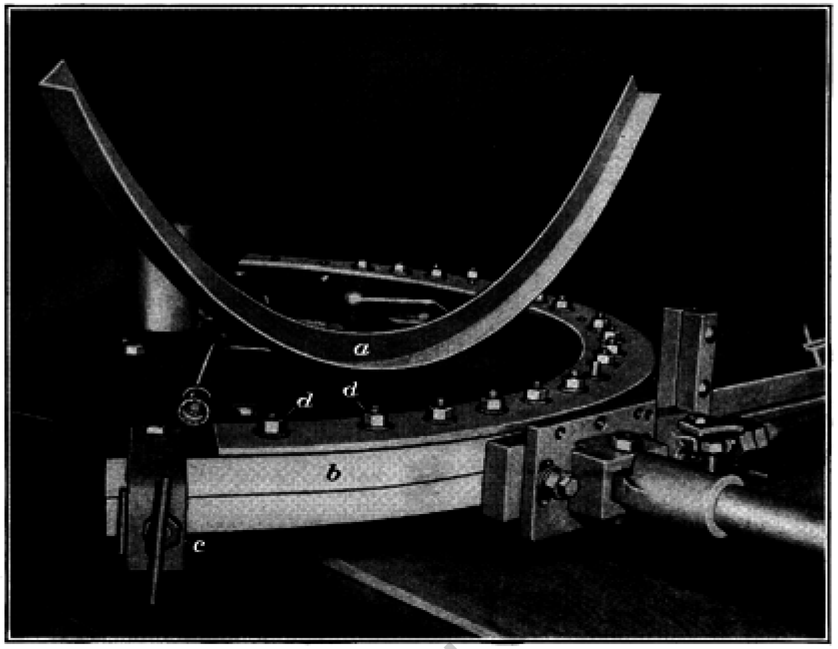

FIG. 17

on the size of the air cylinder, and should be determined for any part by actual use and experience.

To form the section, the material is well lubricated and the turntable is slowly rotated by an electric motor. As the material is bent around the form, the nuts on the edge of the die are tightened on their bolts in order to hold the section within the die. The turntable must be rotated back and forth a few times to cause the part to assume the proper curvature. After forming, some hand work is always required to make the section fit the die exactly. Some sections may be given a final forming in a stretch press.

15. A similar operation on the same machine is shown in Fig. 17. In this case an angle is being formed to the shape shown at *a*. The stock *b* is placed in the die and fastened at one end by a clamp *c* and bolts *d*. Then, as in the previous case, the section is formed to the contour of the die by rotating the turntable back and forth and tightening the rest of the bolts. An unbalanced section, such as this angle, requires that some part of it be held securely; otherwise, the tendency to twist and warp results in difficult forming. Since the material is formed by stretching and little compression takes place, there are definite limits as to the types of sections that can be formed by rubbing and there is a minimum radius for each particular section. Practically all sections must be wrap-formed in the soft condition. The preferable method is to heat-treat and form the material before it has age hardened.

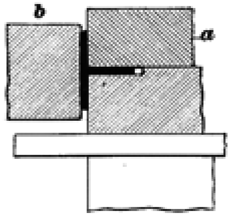

FIG. 18

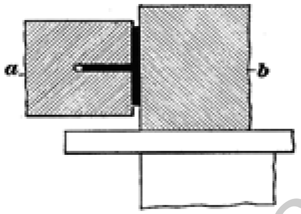

FIG. 19

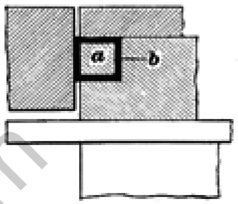

FIG. 20

16. In addition to channels and angles, it is possible to wrap-form hat, Z, and T sections, and hollow tubing. For instance, when a T section is to be formed with its web on the inside of the curve, the web must be confined within the die *a*, as shown in Fig. 18. The rubbing block *b* is made flat on its contacting surface. In this case the die is made in two parts, but more parts are employed if more than one section is to be formed at a time. The die is given a clearance of approximately .003 inch, so that no wrinkles can develop in the web of the section. This type of die is used for the forming of any sections the web of which extends toward the center of the bend radius. When the web of a T section, however, is on the outside of the bend, it must be confined within the rubbing block, as shown in Fig. 19. The slot in the rubbing block *a* is given a .010 inch clearance, whereas the contact surface of the die *b* is flat.

17. The forming of tubing by using a filler, or mandrel, is shown in Fig. 20. Since it is not possible for the rubbing block to fill the hollow portion when closed tubing is being formed, a mandrel *a* is used to prevent collapse of the walls of the tubing *b*. It may be made of the same material as the die and usually a length of 3 inches is satisfactory. The mandrel is held in position and in line with the ram by a cable or a rod. The ends of the mandrel should be well-rounded off to clear the wall of the formed portion of the part as it passes by the rubbing block.

18. Wrap-Forming of Long Sections.—Long sections may be wrap-formed in the same manner as the short sections already shown. A much larger machine, however, is required to receive the forming die and apply the necessary forming pres-

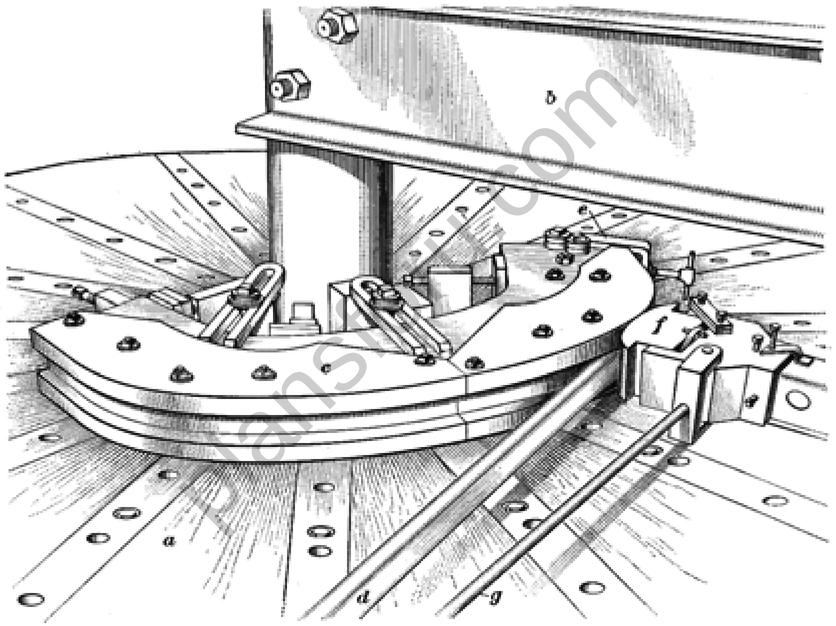

FIG. 21

sure. A large wrap-former, caple of forming sections varying from 4 to 15 feet in diameter, is shown in Fig. 21. The machine consists essentially of a large circular turntable *a* that is driven electrically through reduction gears, and a heavy framework *b* that supports an air cylinder and its attachments. The inner end

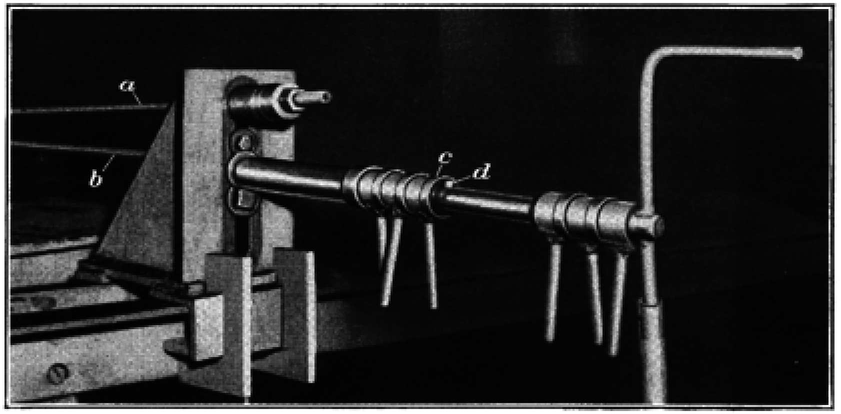

Fig. 22

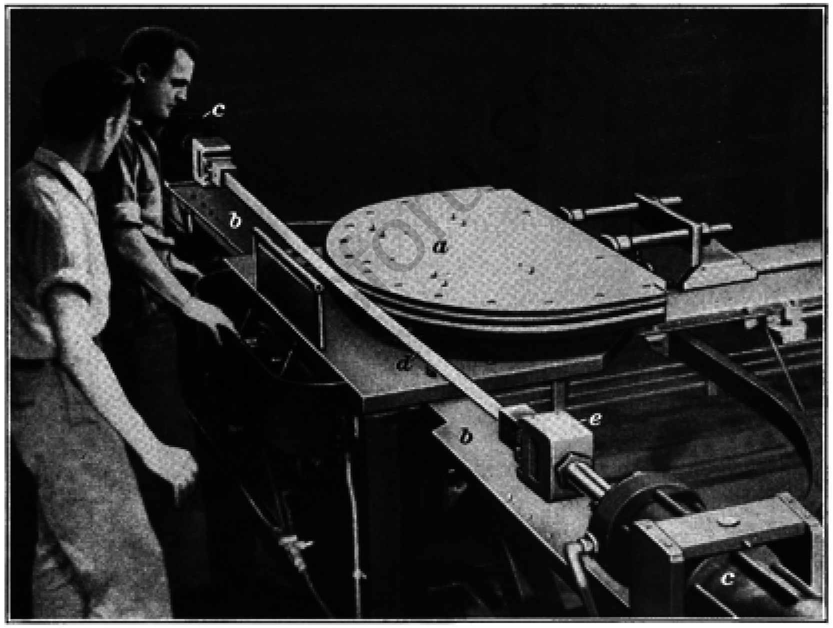

Fig. 23

of the framework is supported on a column that passes through the center of the turntable, and the outer end is supported by a similar column that is beyond the limits of the table. The die *c* is clamped to the table and held in position against the forming pressure by jacks butting against the rear edge of the table. The stock, which in this case is a hollow, rectangular section *d*, is clamped at one end to the die by the clamp *e*. A flexible mandrel is inserted in the section and positioned opposite the rubbing block *f*, which is held against the section by the piston of the air cylinder. The section is then formed around the die by rotating the turntable. A tie rod *g* attached to a brace at the side of the table prevents the rubbing shoe from shifting as the forming is done.

19. When the die has a varying radius, the mandrel within the hollow section will change its position relative to the rubbing block as the die is rotated, and will not remain opposite the rubbing block, that is, tangent to the die. Since it is necessary to keep the mandrel opposite the rubbing block to prevent buckling and wrinkling of the material, the arrangement shown in Fig. 22 has been devised. The upper rod *a* is fastened to the rubbing block. The lower rod *b* is fastened to the mandrel. As the radius on the die changes, spacers *c* are used either to draw the mandrel back or to advance it farther into the section. As the radius increases, it is necessary to advance the mandrel by removing spacers from behind the pin *d* so that the rod can slide forward. Each spacer can be removed by turning it until a slot in its web is alined with the pin and then slipping it back. In like manner, spacers can be added to withdraw the rod and therefore the mandrel when the radius of the die decreases.

20. Stretching Wrap-Former.—A machine incorporating the good features of both the wrap-former and the stretch press and adaptable to the forming of extrusions of many types is shown in Fig. 23. It consists of a central table on which the die *a* is mounted and two swinging arms *b* carrying hydraulic cylinders *c*. The extrusion, in this case a bulb T section *d*, is gripped at its ends in clamps *e*, fastened to the piston rods that extend from the cylinders. Then by means of controls located at the front of the machine, the piston rods are drawn back into their cylinders to put an initial tension on the material. The

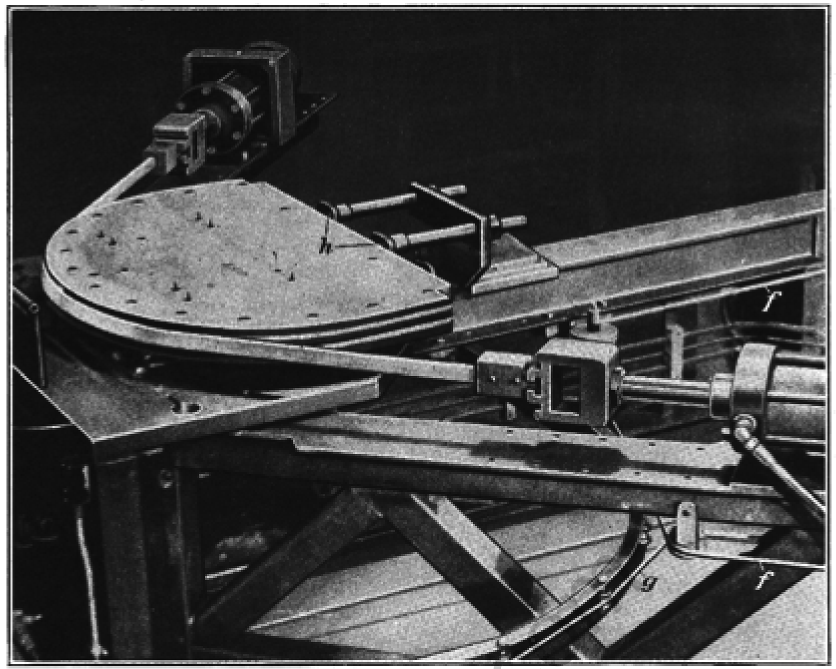

FIG. 24

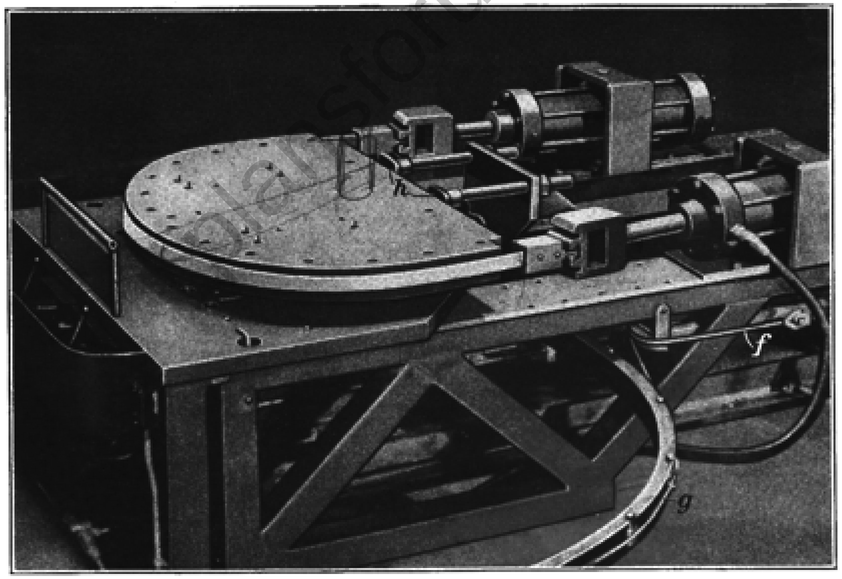

FIG. 25

tension placed on the material depends on the oil pressure in the cylinders, as shown on a pressure gage located in the line between the oil pump and the cylinders. The arms *b* are then swung around the die, as shown in Figs. 24 and 25, to bend the extrusion to the desired contour.

Cables *f* and *g*, Figs. 24 and 25, are attached to each arm and are wound in opposite directions on an electric winch located at the rear of the machine. The movement of the arms is controlled by the direction of rotation of the winch. The cable *f* pulls the arm directly backward, whereas, the cable *g* passes over a pulley at the front of the machine and therefore pulls the arm forward. Jacks *h* butt against the rear edge of the die and resist the forces developed as the arms swing backward.

21. The stretch wrap-former, Fig. 23, may be used for forming SO, ST or SW sections. The die or form block may be made of hard wood or Kirksite and must be undercut to allow for spring-back which will vary to some extent. Stretching the part during forming prevents compression at any one point and therefore reduces to a minimum the distortion that results from heat treating SO material. Parts formed from ST and SW material are brought to close limits and require little hand finishing. Any distortion, that may result from heat treating the formed part, is removed in a second stretcher in which the part is stretched beyond its elastic limit. This second stretching improves the physical properties of the metal. In one case, the tensile strength of a part formed in 24 SO condition, then heat treated, increased from 62,000 to 67,000 lbs. per sq. in. and the yield strength increased from 41,000 to 53,500 lbs. per sq. in. A 3 per cent stretch was used after a 15-minute aging period. The physical properties of ST and SW material may also be improved by the stretch-forming operation.

22. Work Clamps of Stretching Wrap-Former.—The work clamps *e*, Fig. 23, are an important feature of the machine since on their success or failure to hold the material depends the successful operation of the machine. As shown in Fig. 26, the

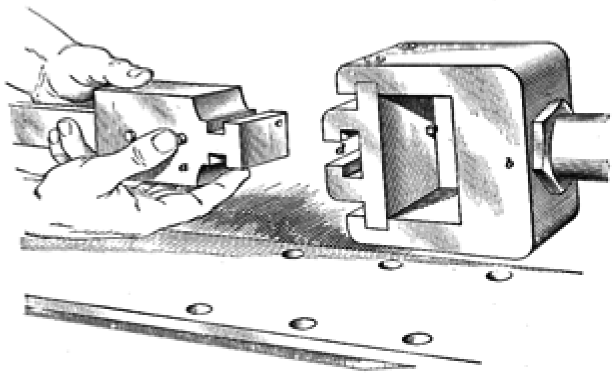

FIG. 26

clamps are made in two main parts. Part *a* carries the jaws that grip the extrusion and part *b* is screwed on the end of the piston rod. After the extrusion has been inserted into the jaws, the two parts are assembled by sliding the tongue *c* into the T slot *d*.

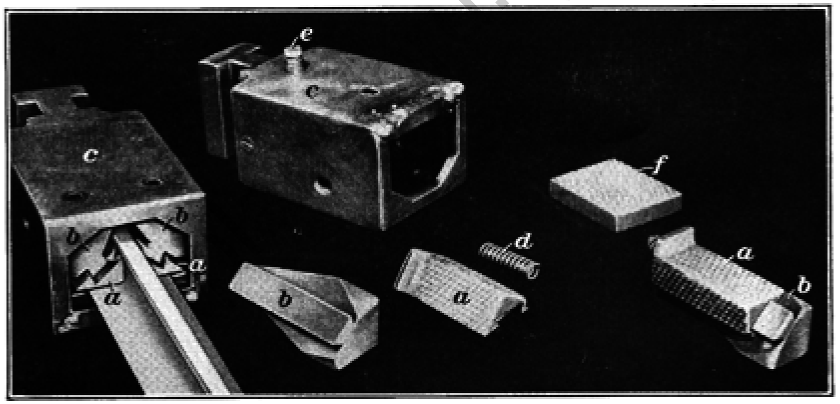

FIG. 27

The details of the clamp are shown in Fig. 27. The scored jaws *a* are dovetailed to fit tapered, wedge-shaped pieces *b* which are held by screws in the casing *c*. At the end of each jaw there is a coil spring *d*, which, when the clamp is assembled,

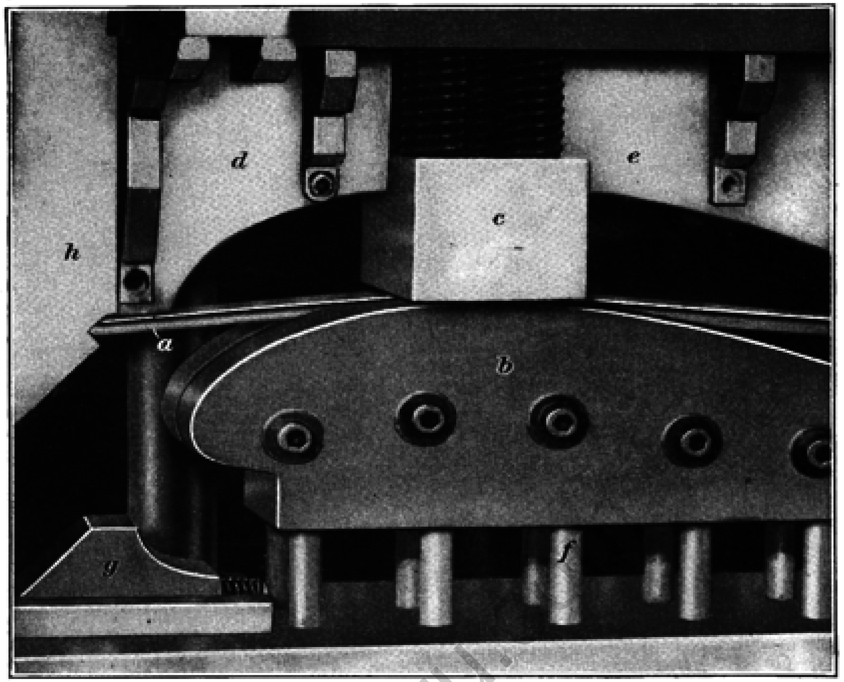

FIG. 28

as shown at the left, forces the jaw to slide up the tapered surface of the piece *b* when a catch holding the jaws is released by pressing the button *e*. The section to be formed is inserted as illustrated, between the jaws *a* and the flat, scored jaw *f* which is fastened by screws to the opposite side of the casing, and is gripped by pressing the button *e*. Since the jaws slide against a tapered surface, they are tightened still more when the extrusion is stretched lengthwise. After the section is formed, it can be released easily from the jaws by slipping the part holding the work from the part fastened to the piston rod, and by pressing the clamp endwise against the table until the jaws are pushed back far enough to be held by the catch.

23. Extrusion Bending on Double-Action Press.—Many types of extrusions may be bent, or formed, to shape by the use of dies in double-action presses. The double action provides

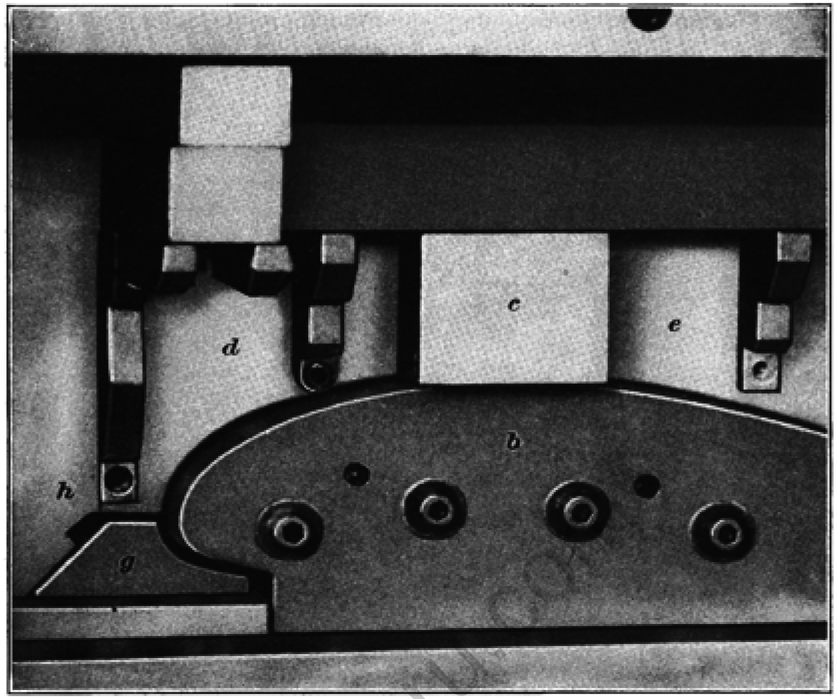

Fig. 29

means of meeting the important requirements of holding the material firmly and applying high pressure while the forming is being done. For example, in Fig. 28, is shown a die set-up in a double-action press for the bending of cowl stiffeners. The stock, a *24SO* T extrusion *a*, is located on the die *b* in approximately the position shown. When the ram of the press is lowered, the block *c* first contacts the stock and serves as a pressure pad to hold it during the forming. Then as the ram continues its descent, the springs supporting the block *c* are compressed to allow the parts *d* and *e* to come into contact with the extrusion, as shown in Fig. 29, and form it to the shape of the lower die *b*. At the same time the lower die is forced down to the bed of the press against the action of the air cushion on which the die is supported by the rods *f*.

FIG. 30

24. Since the extrusion must be curved under the lower die at its left end and the part *d*, Fig. 29, of the upper die cannot make this bend with only its vertical motion, some other means must be provided to complete the forming operation. Therefore, a block *g* is located on the bed of the press and so mounted that it can slide toward the die *b*. It is tapered on one end, and a block *h* that is correspondingly tapered is attached to the upper die. Then as the ram descends, the block *g* is moved toward the lower die by the block *h* and the descending die *b* finish-forms the extrusion under the curved part of the die. Since there is a certain springback when the stock is released, allowance must be made on the die to over-form the material sufficiently to compensate for the springback.

25. Bending Large Extrusions in Bending Fixtures.—Since great pressure is required for bending large extrusions, they must be formed in machines that are capable of exerting such

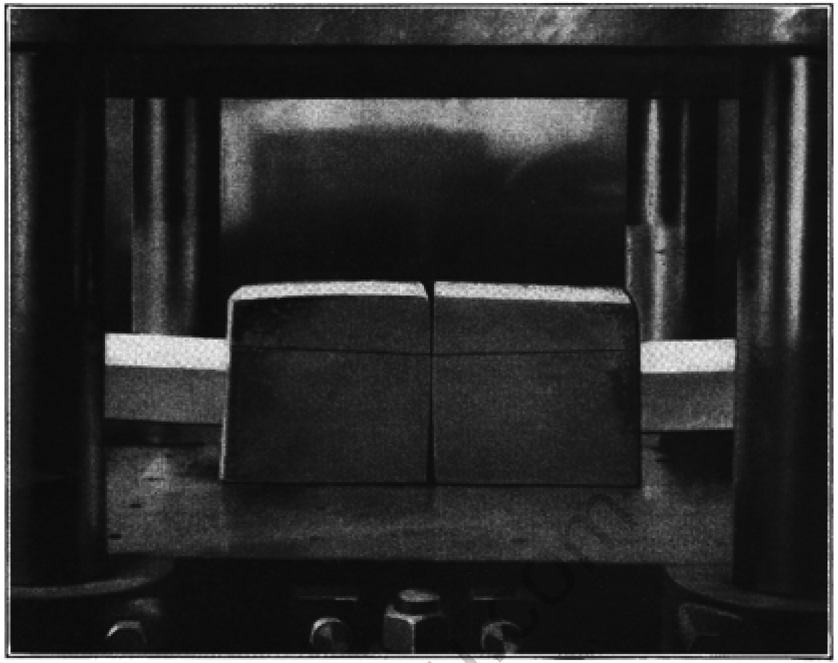

FIG. 31

pressure. A typical example of this operation is the bending of wing spar caps in a hydraulic press. Wing spar caps may either be bent to only one angle, usually the dihedral angle of the wing, or to two different angles, one being the dihedral angle and the other either the forward or the backward sweep. In order to apply the pressure of the hydraulic press, it is necessary to use either a die or a bending fixture that will receive the section and control the angle of bend. Such a fixture may be made of four cast-iron blocks that can be bolted firmly around the extrusion. As shown in Fig. 30, two blocks *a* are placed side by side, the extrusion *b* is inserted, and the two top blocks *c* are bolted to their corresponding bottom blocks. Four fairly large bolts are used in each part of the fixture to assure rigid clamping. When the extrusion is clamped in place, the blocks do not lie flat on the table of the press but rather are supported at their outer edges only and are raised in the middle. This

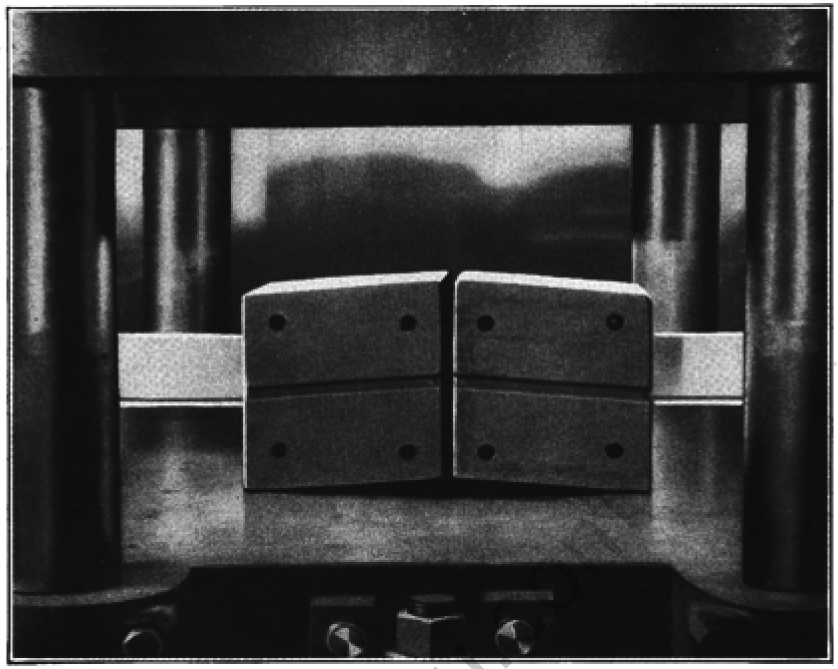

FIG. 32

condition is obtained by machining the recess within the blocks at a vertical angle to their ends Then when the ram of the press is lowered, the blocks are forced flat on the table, as shown in Fig. 31. Their relative motion causes the extrusion to be bent down in the middle to the same angle as that to which the recess in the blocks was originally made. This first operation forms the dihedral angle in the spar cap.

26. To form the angle of forward sweep, the entire assembly of fixture and extrusion is turned over on its side, as shown in Fig. 32. Again the blocks rest only at their outer edges and are raised in the middle. As with the dihedral angle, the recess within the blocks was made to this angle with the ends of the blocks. In the first case, however, the angle was offset in a vertical plane, whereas the angle corresponding to the forward sweep was offset in the horizontal plane. When the ram of the

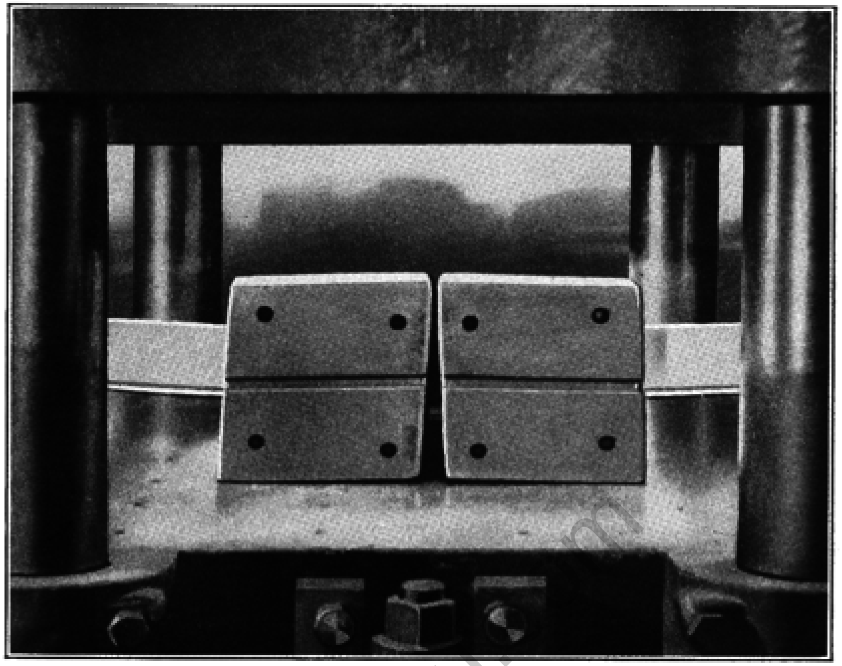

FIG. 33

press is again lowered, the blocks are forced to the position shown in Fig. 33, thus bending the angle of forward sweep. The extrusion is released by removing the assembly from the press, unscrewing the bolts, and lifting the top blocks off by means of handles that are screwed into the blocks. When the pressure on the spar cap is released, it springs back a certain amount. This springback must be taken into consideration and allowance made on the angles of the recesses within the die blocks.

27. Bending Large Extrusions in Dies.—The use of dies instead of a fixture for the bending of a wing spar cap is illustrated in Fig. 34. The die set is mounted in a hydraulic press, as in the previous case. The lower die *a* has a recess to receive the T section and the upper die *b* is slotted to receive the web of the section. Both dies are shaped to the angle required on the spar cap plus an allowance for springback. This par-

Fig. 34

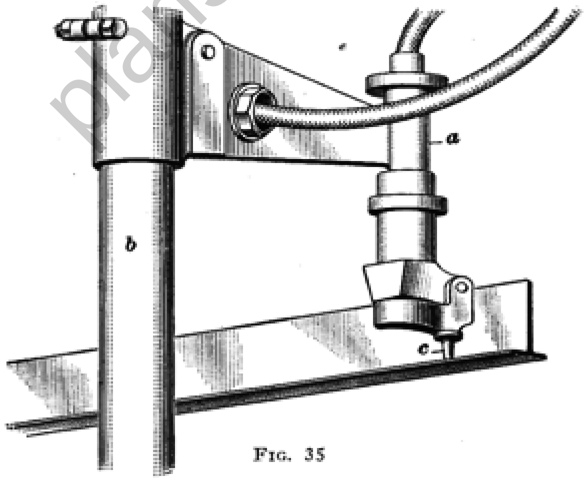

Fig. 35

ticular spar cap is to be bent to only one angle. The straight extrusion is placed in the lower die, and the upper die is brought down carefully until the stock seats itself in the dies. Then the forming pressure is applied and the extrusion is bent to the required angle as indicated by an end gage. As the extrusion is bent down in the middle, its ends rise; hence, the angle of bend can be controlled by limiting the rise of one end by means of the gage *a*, Fig. 35. Since this gage is adjustable vertically along its standard *b*, the stop *c* can be set to the height required to allow for the angle of bend desired plus the springback. The extrusion is bent far enough that it just makes contact with the stop. Then when the pressure is released the extrusion will spring back to the angle required on the finished piece.

TUBE-BENDING PROCESSES

28. Requirements of Tube Bending.—The wide use of thin-wall tubing for fuel and oil lines in aircraft construction has made the accurate bending of the tubing to given radii an important production operation. If such tubing were bent with the hollow portion unfilled, the tube would invariably flatten out at the point of bend. To prevent this condition, some form of filler is required except for small tubing. Among the fillers used for this purpose are internal mandrels, spiral springs, bismuth alloys, sand, lead, resin, and tar. These fillers are satisfactory with varying degrees of success, in preventing flattening, buckling, or rupture of the tube wall.

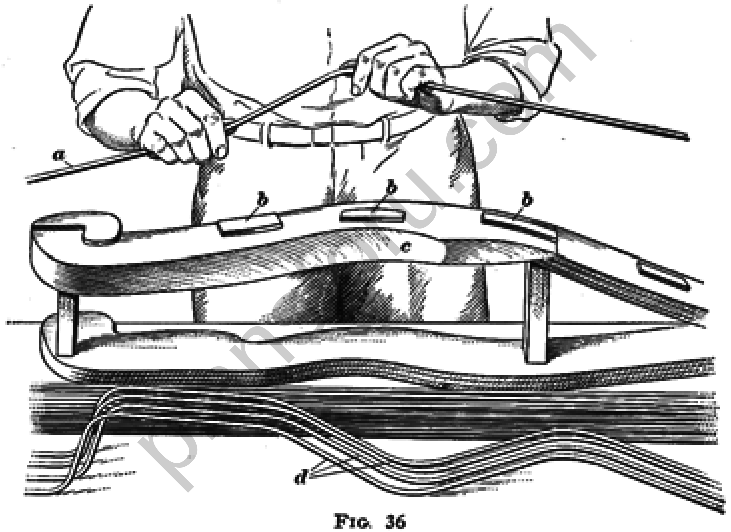

FIG. 36

29. Tube Bending by Hand.—When very small tubing is to be bent, especially when the tube walls are relatively heavy in comparison to the size of the bore, it may be bent without a filler. In many cases the tubing has so many different bends and twists that hand bending is necessary to attain the required form. In Fig. 36, for example, the tube *a* is to be bent to fit around radius blocks *b* that are attached to the surface of the fixture *c*.

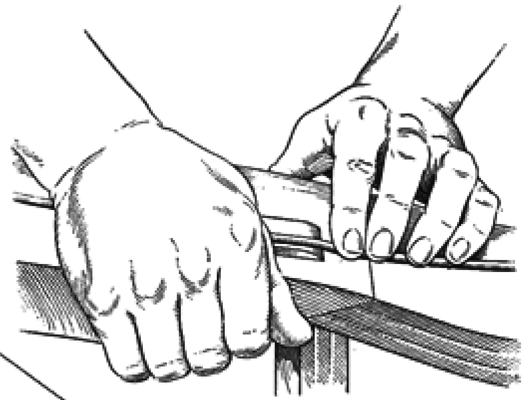

Fig. 37

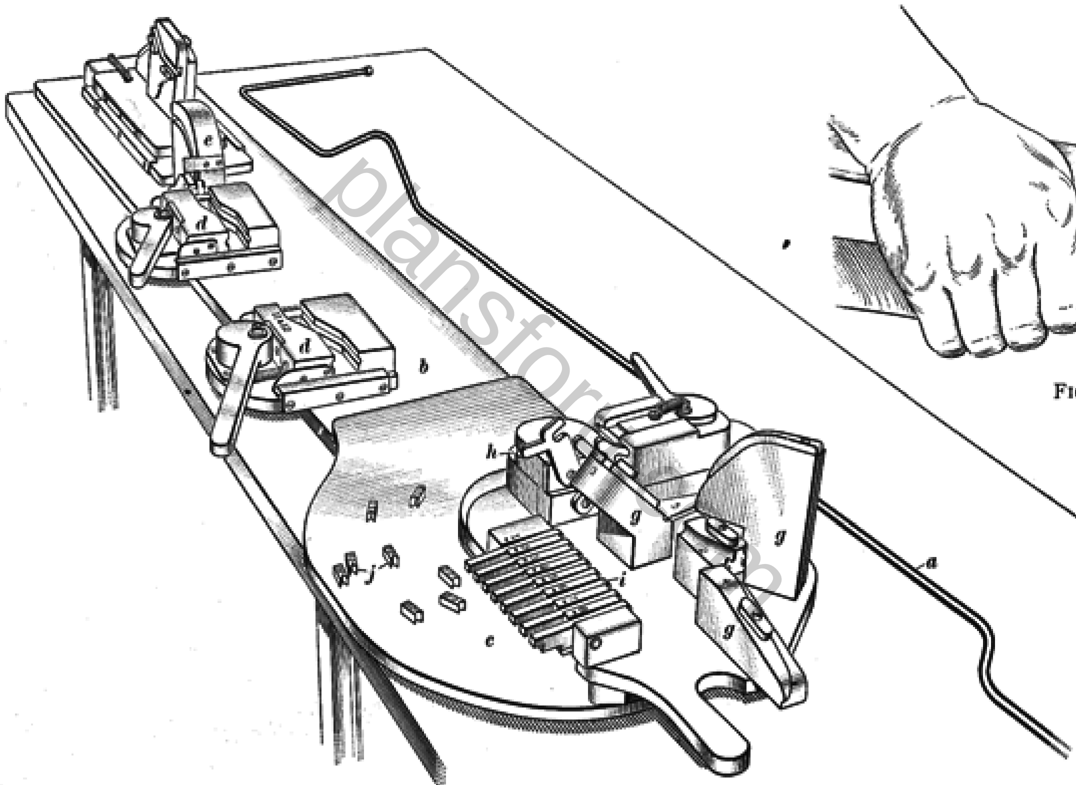

Fig. 38

Finished pieces are shown at *d*. The first operation is to bend the tube in the middle to fit around the middle block. Then with the tube held as firmly as possible against the fixture, the one end is bent gradually to lie closely to the fixture blocks at that end. The other end of the tube is bent to fit the sloping end of the fixture.

To make small bends in the tube in order to bring it to shape, a small wedge is placed under certain points and the tube is bent down over the wedge, as shown in Fig. 37. Using the wedge in this manner permits kinking the tube slightly at the points where the fixture changes curvature, and enables the operator to form the tube closely to the desired curve. If at these points the tube were bent freely by hand instead of with the wedge, the results attained would vary and make the forming far more difficult.

30. Tube-Bending Fixture.—Although tubing can be bent fairly accurately by hand to fit the radius blocks of a fixture, better results can be obtained if the tubing is bent around the radius blocks by mechanical means that permit no variation from one piece to another. A bending fixture designed for making accurate, properly spaced bends is shown in Fig. 38. The finished tube *a* is to form a hydraulic line for the dive brake and is made from *52SO* tubing, $\frac{3}{8}$ inch in diameter, and .042 inch in wall thickness.

The fixture consists essentially of the base *b* on which are mounted the swinging head *c*, joggle blocks *d*, and holding blocks *e* and *f*. The swinging head *c* carries various other holding blocks *g*, the radius blocks *h*, and the stop levers *i*. The holding blocks, which are so shaped as to locate the tube accurately endwise, are numbered to show which one should be used for any particular bend. In all, twelve bends are made in the fixture. Of the two radius blocks *h*, the top one is used for all bends, except the joggles, and the fifth bend which requires a greater radius and which therefore is made in the lower radius block. The bends are determined accurately by the stop levers *i*, which contact their respective stops *j* when the head is swung to make the bend. The stops *i* are so located on the base as to allow for springback of the material.

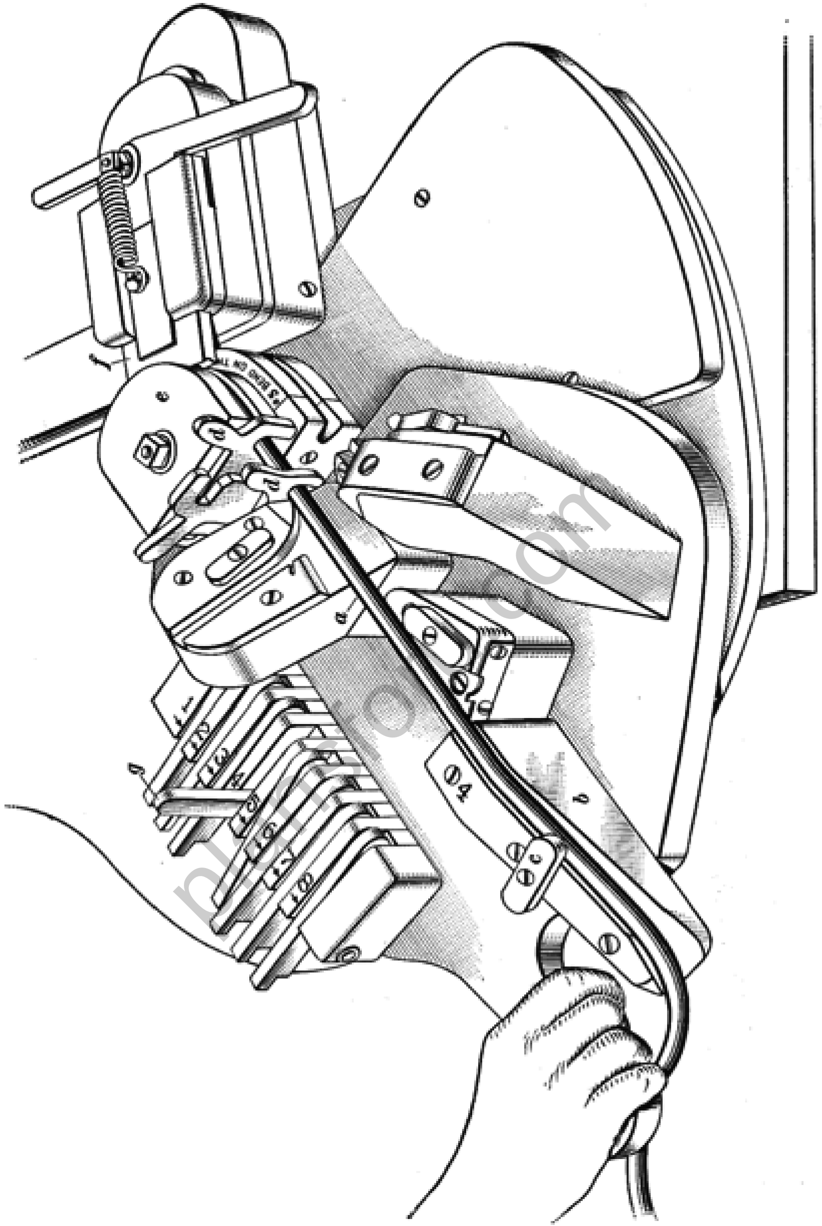

Fig. 39

31. The tubing is bent by clamping it in the holding block corresponding to the bend being made, raising the proper stop lever, and then swinging the head until the stop lever makes contact with its corresponding stop on the base. For example, in Fig. 39, the fourth bend is being made. With the head swung back to its original position, the tube *a* is fitted to the No. 4 holding block *b*, which is curved to locate the tube from the two previous bends, and is held to the block by a latch *c*. Hooks *d*

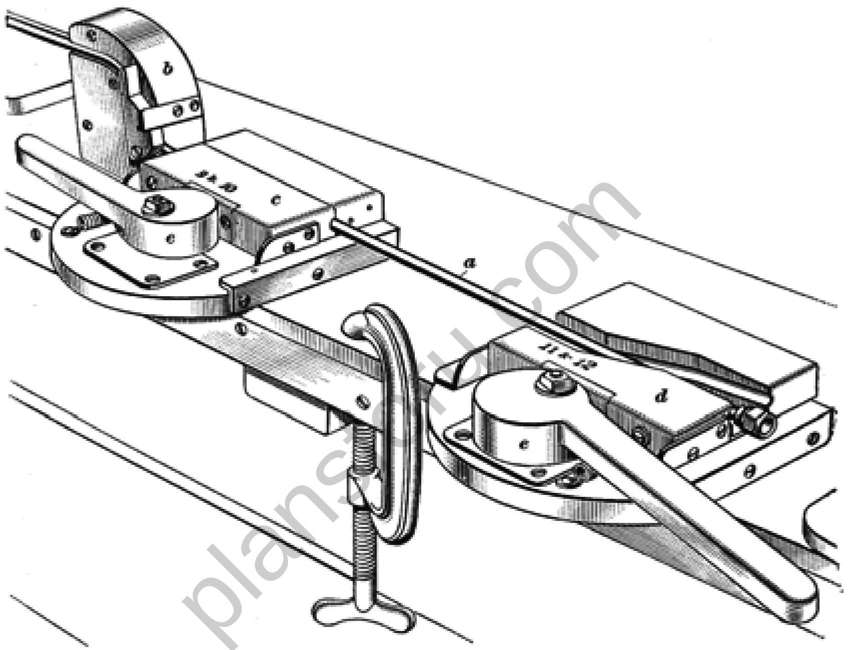

Fig. 40

are then thrown over the tube to hold it in line with the radius block *e*. A cam-actuated slide *f*, which is shaped to fit the outside of the tube, provides enough pressure to hold it against the radius blocks as the forming is being done. Then with the other end of the tube held securely to the end holding block on the fixture, the head is swung until the No. 4 stop lever *g* contacts its stop. The other bends are made in the same way, except that after the sixth bend the tube is reversed, end for end, and

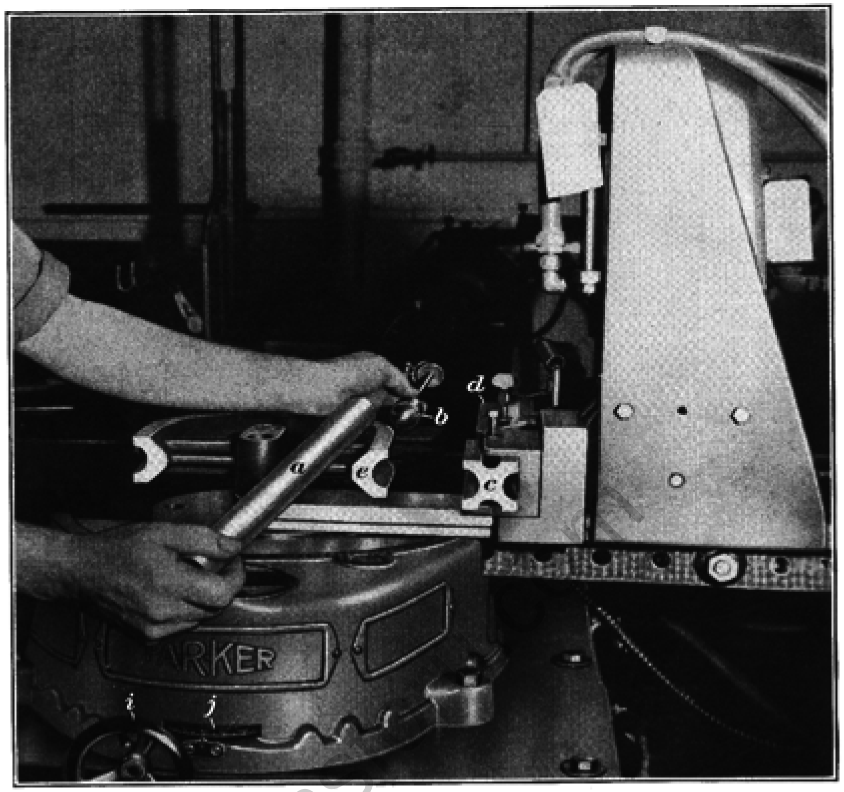

FIG. 41

bends are made on the other end of the tube. Since the tube is drawn forward when each bend is made, the end holding block *f*, Fig. 38, is arranged to slide lengthwise, against the action of a spring, to permit the forward motion of the tube.

32. The last four bends, numbered from 9 to 12 on the fixture, are joggle, or offset, bends. The tube *a*, Fig. 40, is held in the block *b* and located in the two joggle blocks *c* and *d*. The block *c* is shown in its closed position with the bend made, whereas the block *d* is shown open before the joggle has been formed. The joggle blocks are operated by cam-type levers *e*, which permit the bends to be made with little exertion.

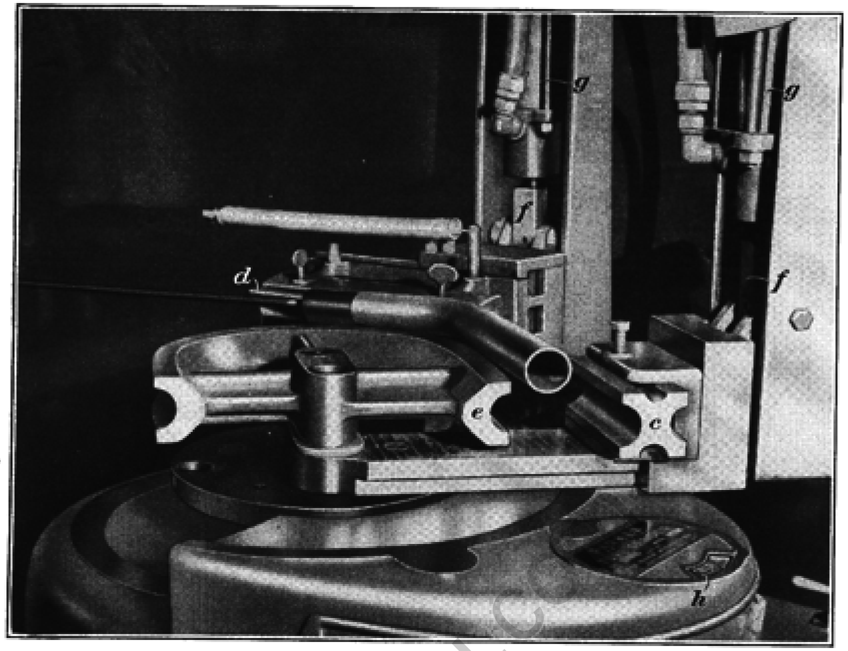

FIG. 42

33. Tube Bending with Internal Mandrel.—A tube bender employing an internal mandrel to support the walls of the tubing is shown in Fig. 41. The tube *a* is slipped over the mandrel *b* and placed between the clamp blocks *c* and *d* and the bend radius block *e*. The clamps are then closed by toggle-levers, shown at *f*, Fig. 42, which are operated by plungers from the cylinders *g*. To made the bend, the arm carrying the bend radius block *e* and the clamp block *c* is rotated by power through the required number of degrees, as shown on the dial *h*. An automatic stop is provided to control accurately the angle of bend so that any number of tubes may be bent to the same exact angle. By means of the hand wheel *i* and the graduated dial *j*, Fig. 41, the stop may be set so that any desired angle of bend is obtained. In the illustration, the clamps have been opened and the bent tube, with the mandrel in place, has been lifted out.

34. When long tubing is to be bent into compound angles in varying planes, it is necessary to determine the degree of angle between the bends. A graduated universal side-angle indicator is provided for that purpose and is supplied with a vernier for accurate reading. It clips on the end of the tube to be bent and slides forward with the tubing as the bending progresses. When the second bend is close to the first bend, however, a special radius block and a clamp block are required. In Fig. 43 the radius block and clamp block have cut-outs *a* and *b*, respectively, to receive the part of the tube that has already

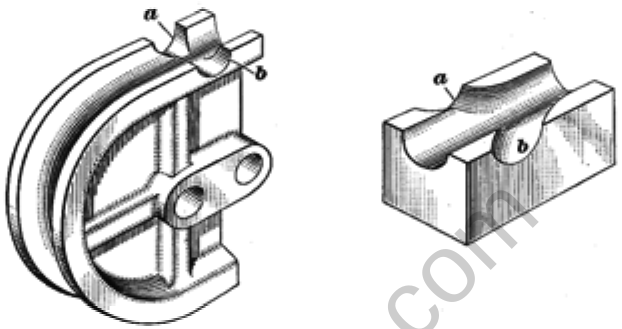

Fig. 43

been bent. These blocks are necessary on tubes of at least $\frac{3}{4}$ inch outside diameter, when the two bends are closer than twice the outside diameter. On smaller tubes, they are necessary when the distance between bends is less than $1\frac{1}{2}$ inches.

35. **Hand-Operated Tube Bender.**—The hand-operated tube bender shown in Fig. 44 is similar in construction to the power bender previously shown. The tube *a* is, in the same way, clamped between the radius block *b* and the clamp blocks *c* and *d*. The clamps on this machine are hand operated, the clamp *c* being advanced by a screw and the clamp *d* by a toggle-lever *e*. The tube is then bent to the radius of the block *b* by swinging the arm carrying the blocks *b* and *c* around the center pivot by hand. The clamp and radius blocks can be changed quickly to adapt the machine for bending tubing of different sizes.

36. **Tube Bending with Bismuth Alloys.**—Of the various materials used to pack tubing for bending purposes, bismuth alloys are most successful and most extensively used in aircraft

Fig. 44

production. Practically all the other materials are unsatisfactory in some respect. For instance, packing sand tightly enough to give adequate support to the wall of the tubing is difficult and requires considerable time. Lead is unsatisfactory in that its relatively high melting point makes it practically useless for aluminum-alloy tubing. Also, since lead shrinks on solidifying, it provides comparatively poor support to the tubing wall. Resin and tar give fairly good results but fail on the sharper bends, and in addition are unsatisfactory in that they too must be melted and are somewhat dangerous to handle. A very serious objection to the use of sand, lead, resin, or tar is that it is difficult to remove all traces of such fillers after the tubing is bent. If the tubing is not cleaned thoroughly, small particles of filler on becoming dislodged may cause trouble in service, or they may weaken the tube wall by causing interference during heat treatment.

37. Of the bismuth alloys, modifications of Wood's metal are most used, since they have been developed especially for bending applications and have properties that make them an ideal filler material. One of these alloys, Cerrobend, consists of 50 per cent of bismuth, 26.7 per cent of lead, 13.3 per cent of tin, and 10 per cent of cadmium. Its low melting point of 160° F. permits the use of boiling water for melting it, and the melting point is low enough that aluminum-alloy tubing is not damaged by the heat. Since this alloy is extremely fluid in the molten condition, tubes can be filled easily and pin holes or similar defects can be detected easily by escape of the alloy through the defect.

During solidification such bismuth alloys expand slightly, or approximately .006 inch per inch. The expansion causes the alloy to conform so snugly to the inside of the tube that the latter can then be bent as though it were a solid bar. The alloy holds the tube wall in tension at every point, thus affording excellent support and enabling bends to be made to small radii. The expansion of the bismuth alloy also shows up any thin spot in the tubing wall by raising a blister at that point.

38. Before a tube is bent, it should be inspected carefully for deep scratches, pin holes, and other defects. Then it should be cleaned thoroughly by a pull-through to remove any scale or dirt, and be closed at one end with a tapered hardwood or rubber plug. To prevent tinning of the tube wall on the inside, the tube may be filled with a light-grade oil, preferably S.A.E. 10, most of which is then poured out, leaving a small amount in the bottom of the tube. The oil prevents the alloy from coming in contact with the tube wall since the wall retains the oil film at the temperature, 212° F., to which the alloy is heated by the boiling water. The tube is then filled with the molten alloy. If the filler alloy is required only in small quantities, it may be

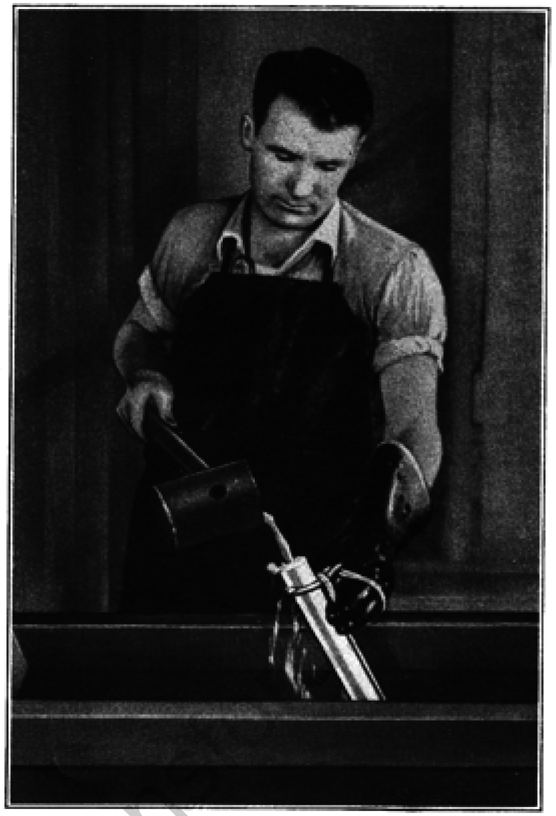

Fig. 45

melted by placing it in a clean ladle, covering it with water, and heating the ladle until the water is at its boiling point. The boiling water is poured from the ladle into the tube to preheat the tube and so prevent cold setting of the alloy. Then as the alloy is poured into the tube, it displaces the water since the water is lighter in weight than the bismuth alloy. As soon as the tube is filled, it is plunged, corked end first, into a tank of cold water and left there until it attains room temperature, requiring generally about 15 minutes for 1-inch tubing and more for larger tubing. For best results, the filled tube should then be re-warmed to about body temperature before bending.

The quick cooling caused by the cold-water quench imparts to the bismuth alloy a fine-grained structure which makes it highly ductile and easy to bend. The progressive cooling from corked end to open end, that results from the endwise quench is necessary to prevent in the alloy cavities that might cause trouble in bending.

39. Instead of being heated in a ladle, the alloy may be melted for continuous production work in an installation, such as shown in Fig. 45, in which a stainless-steel tank holding the alloy is surrounded by a hot-water jacket, or it may be melted in a separate container suspended in boiling water. In either case the tube should be first preheated by hot water at 160° F. and then filled with alloy, which is poured carefully down the inner sides of the tube in order to avoid air pockets. If the tubing is so small that it cannot be filled from a ladle, the alloy may be drawn into it by suction. This practice may even be followed with tubes $\frac{1}{4}$ inch or slightly less in diameter, or the tubes may be placed in boiling water while being filled in order to keep the alloy fluid enough to run into the tubes.

40. After the bismuth alloy hardens, the tube may be bent in almost any type of tube bender as long as the bends are made at a slow, uniform speed. Too much speed or an uneven application of power may cause failure of the tube wall. An alloy filled tube being bent is shown in Fig. 46. The bend blocks *a* and *b* of this machine are mounted on a swinging arm and can be turned around their pivot by the lever *c*. The amount of bend is shown in degrees on the graduated dial *d*. The tube is first gripped between the bend blocks *a* and *b*, and a long block *e* is provided to steady the tube and force it to follow the curve of the bend block *a* as the latter is swung around its pivot. All three bend blocks are grooved to fit exactly the outside of the tube. The far end of the tube is gripped in a chuck *f* that is moved forward as the different bends are made.

41. After the tube is bent, the alloy filler is removed by plunging the formed tube into boiling water, or by heating it in a steam bath or in hot air at a temperature of approximately that

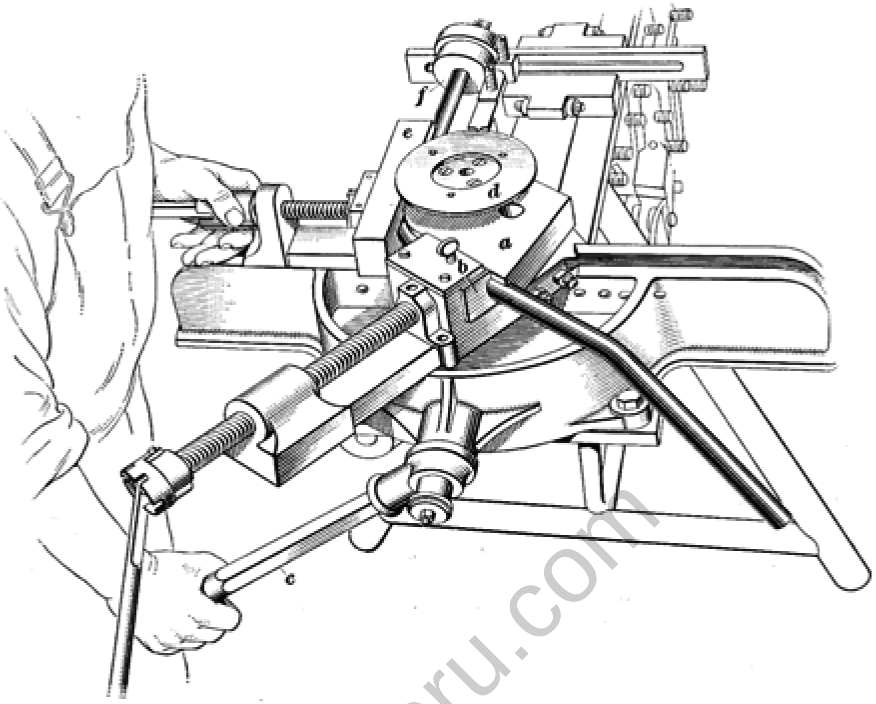

FIG. 46

of boiling water. The use of an open flame is not advisable since the tube wall may be overheated. The molten alloy may then be drained out of the tube, and returned to the container for reuse. When the alloy is removed from the tube by means of boiling water, it can be easily recovered as it sinks to the bottom of the tank and can be drawn off through a drain cock. The tube should be shaken to remove the alloy as completely as possible, and while still hot it should be plunged into cold water for about two minutes to solidify any small drops of alloy retained in the oil film. The oil and any solid particles of the alloy can then be removed by flushing the tube with a cold grease solvent and using a pull-through for final cleaning.