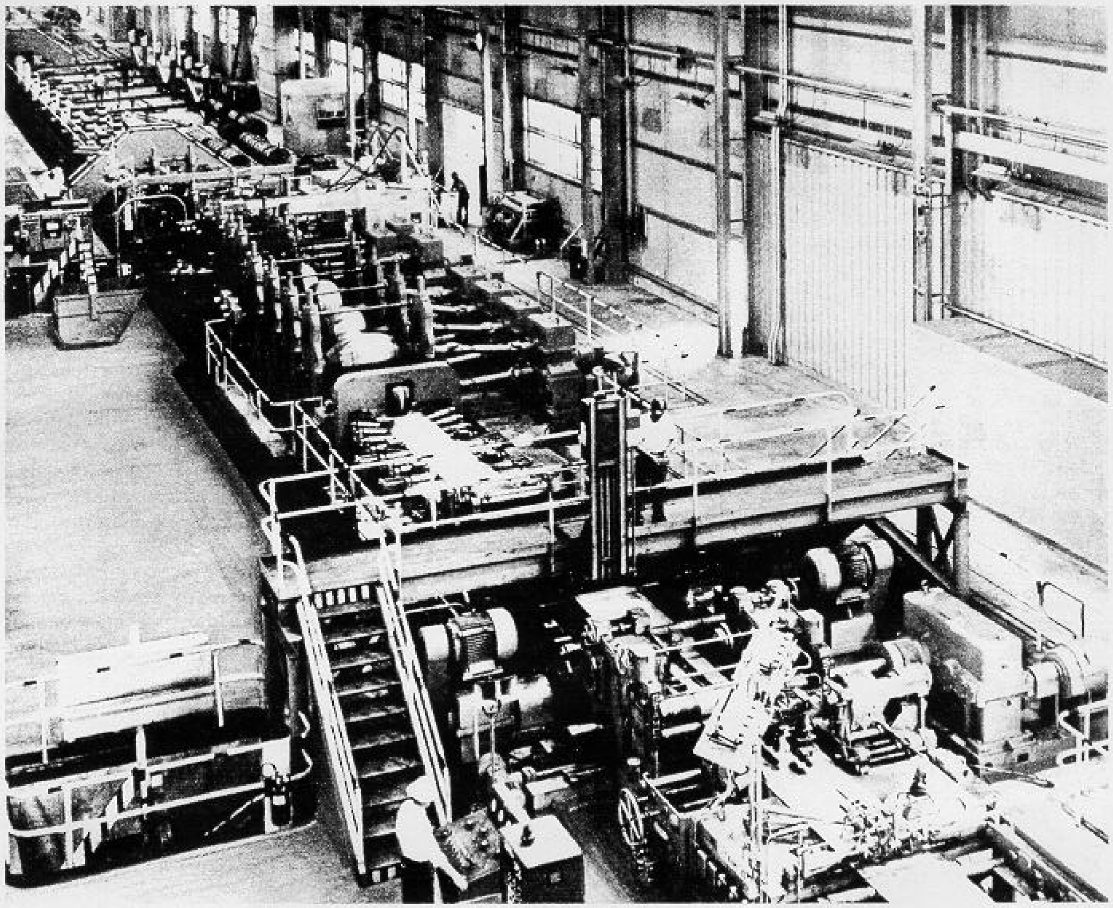

FIG. 32—15. Overall view of an electric-resistance weld (ERW) mill for producing line pipe in a wide range of diameters and wall thicknesses, up to 24.5 metres (80 feet) in length. Flat-rolled starting material enters the line at the lower right. Welded pipe is discharged at the end of the line at the upper left. Sequence of operations is described in the text.

wound between thin, steel disc spacers. The narrow strips of scrap from the edges of the wide strip pass over the recoiler onto the scrap winder.

After the strip has been threaded completely through the line, the recoiler and slitter motors are adjusted to pull it through the slitter knives with any desired tension. The slitter, recoiler, scrap winder, breaker rolls and pay-off reel are not synchronized with the others as they are used only when threading the strip.

When the entire coil has been slit and wound on the recoiler mandrel, steel bands are placed around each of the narrow coils. An unloading buggy is elevated under the coils which are then pushed off hydraulically onto the buggy. The banded coils are weighed, and are then ready for the welding mill.

Forming—Although the range of sizes handled by any mill is limited, the process of forming and welding the tubing is generally similar in mills of this type.

Coils are fed either directly into forming rolls or into a "looper" to permit continuous forming of strip welded end-to-end in the smaller sizes. The strip first passes through an edge trimmer where the desired width is established and the edge is made smooth and clean for good welding.

ERW mills normally make use of three types of rolls to progressively form the flat steel section into the round form prior to welding. These three types of rolls are: (1) Breakdown or forming rolls, (2) Idler vertical closing rolls, and (3) Fin pass rolls, as shown schematically in Figure 32—16.

In the cases of the breakdown and fin pass sections, the rolls are horizontal and are driven either by universal line shaft or by individual drives to allow perfect speed control of each stand. Breakdown rolls provide the initial shaping of the strip towards the round form. These are followed or interspersed by idler rolls which further close and guide the strip into the fin pass rolls. The fin pass rolls provide perfect guidance into the welding section and in addition coin the strip edges to provide the precise circumference.

Welding the Tube—After forming has occurred, the open tube passes directly into the welding section of the mill. Here the tube is held in squeeze rolls at the

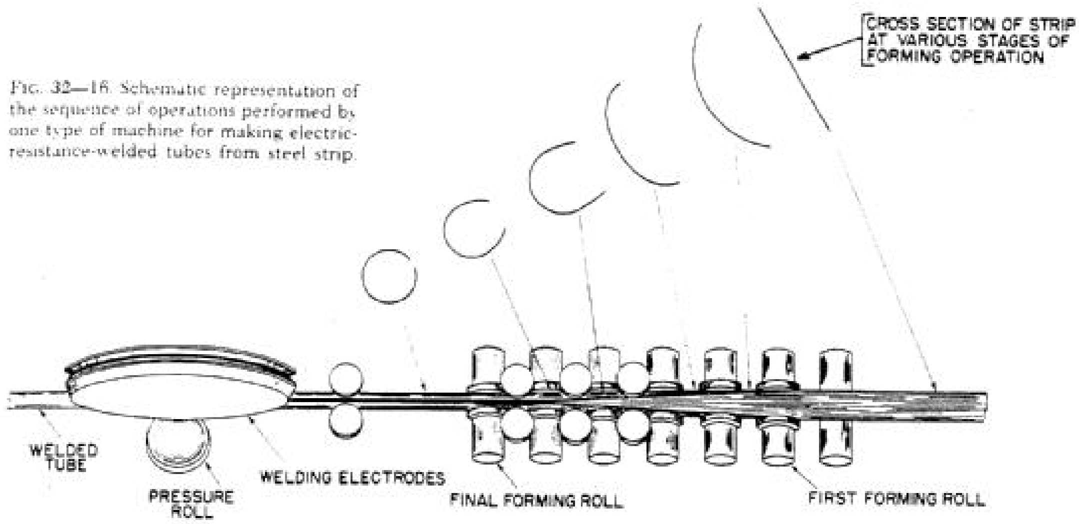

FIG. 32—16. Schematic representation of the sequence of operations performed by one type of machine for making electric-resistance-welded tubes from steel strip.

FIG. 32—17. View of the welding operation in the pipe mill shown in Figure 32—15. Two concave rolls (only one is visible here) force the edges of the joint together while sliding contacts supply 480 000-hertz (480 000 cycles per second) power to generate heat for welding.

correct pressure to provide the desired weld as the edges are heated at this point to welding temperature.

The heat for welding is provided either by low-frequency power through electrode wheels (Figure 32—16), or radio-frequency power through sliding contacts or coil induction. Typical radio-frequency power for welding is supplied at 450 000 hertz (cycles per second); higher or lower frequencies may be used (Figure 32—17).

The welded tube then passes under a cutting tool which removes the outside flash resulting from the pressure during welding. Inside flash is likewise removed by cutting tools in this area. After removing the flash, the tube is subjected to proper post-weld treatment as metallurgically required, e.g., such treatment may involve sub-critical annealing or normalizing of the welded seam or normalizing of the full cross-section of the tube.

Sizing the Welded Tube—After cooling, the tube is sized to obtain a round finished product of the desired

FIG. 32—18. Flying cut-off for the pipe mill illustrated in Figure 32—15. Parting tools (or discs) are used in this machine for cutting pipe. Pipe can be seen emerging from concave rolls of the last stand of the sizing mill that precedes the cut-off. Product travels from right to left in this view.

less pipe and specialty tubing made for the oil industry include oil-well tubing, pump tubing, and line pipe.

The oil-refining, chemical and high-pressure-steam industries also demand special seamless pipe. Satisfactory alloy-steel tubing and pipe are made to withstand temperatures up to 650°C (1200°F) coincident with pressures as high as 34 500 kilopascals (5000 psi). These industries also use pressure pipe lines at temperatures as low as −268°C (−450°F), and steel pipe which is tough and strong at these low temperatures is now produced in considerable quantities.

Sequence of Seamless-Pipe-Mill Operations—The sequence of operations in seamless-pipe mills varies slightly from mill to mill. At the Lorain Works of United States Steel it follows three general patterns determined by the size of the pipe to be produced. The round billets are first uniformly heated to piercing temperature in special gas- or liquid-fuel-fired furnaces. They are then processed through the various operations in the following order, depending upon the diameter of tube to be produced:

Pipe Size—NPS 2 to NPS 4
- Piercing Mill
- Multi-Stand Mandrel Mill
- Reheating Furnace
- Sizing Mill, or
- Stretch-Reducing Mill

Pipe Size—NPS 3½ to NPS 9⅝
- Press Piercing Mill
- Rotary Elongator
- Multiple-Stand Pipe Mill
- Reheating Furnace
- Stretch-Reducing Mill

Pipe Size—NPS 5½ to NPS 16
- First Piercing Mill
- Second Piercing Mill
- Reheating Furnace
- Plug Rolling Mill
- Reeling Machine
- Sizing Mill

Pipe Size—NPS 14 to NPS 26
- First Piercing Mill
- Second Piercing Mill
- Reheating Furnace
- Plug Rolling Mill
- Reheating Furnace
- Rotary Rolling Mill
- Reeling Machine
- Reheating Furnace
- Sizing Mill

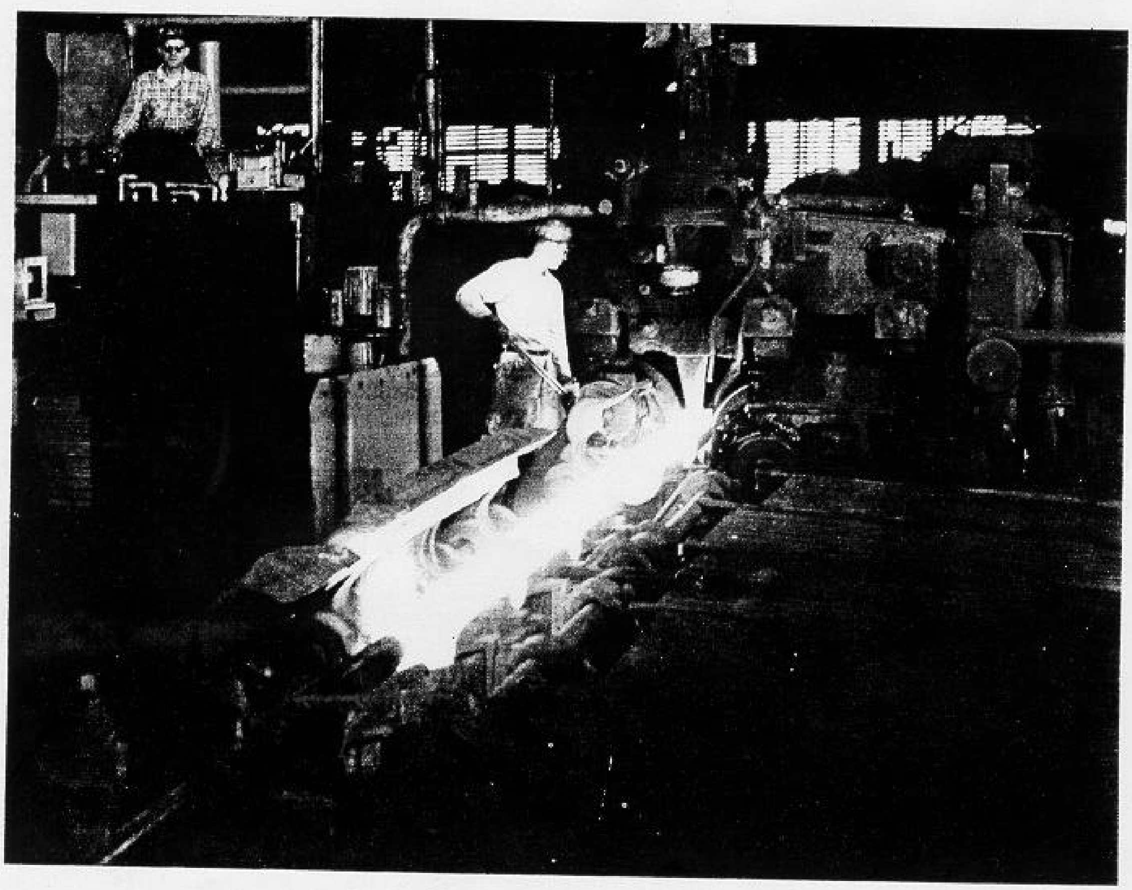

FIG. 32—22. Mannesmann piercer in operation.

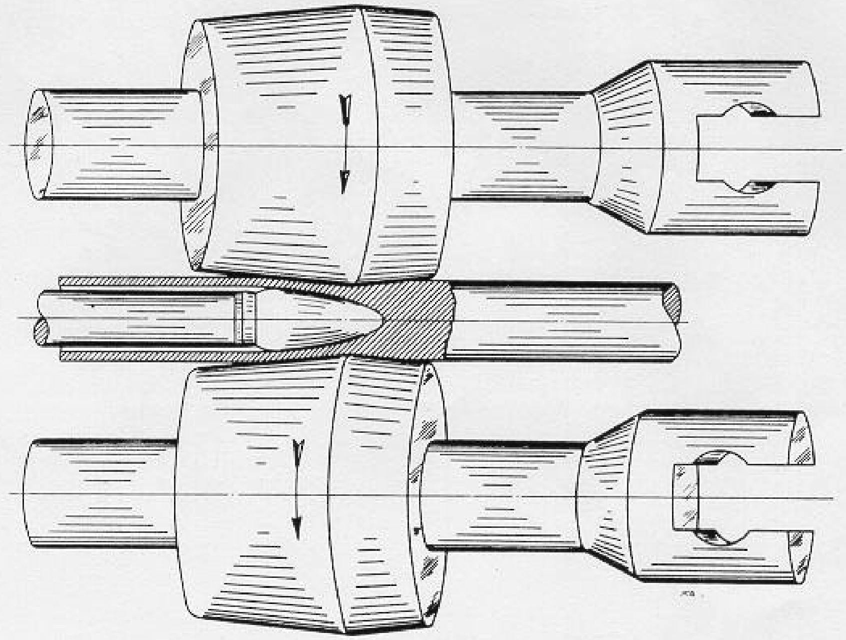

FIG. 32—23. Sketch illustrating action of different parts of Mannesmann piercer in the piercing of a solid billet.

The operation of each of the above units will be described in detail in the remainder of this section. In the overlapping sizes of the range NPS 14 to NPS 16, the lighter-wall pipe is rotary rolled, the heavier-wall pipe by-passing the second reheating operation and the rotary-rolling mill.

The Mannesmann Machine for piercing round billets for making seamless tubes (Figure 32—22) was patented in 1885. In this machine, the principle of helical rolling is employed. The two steel rolls, which bring into play the forces used to produce the cavity in the work piece, are positioned side by side and have their axes inclined at opposite angles 6 degrees to 12 degrees with the horizontal centerline of the mill (Figure 32—23). These rolls measure from 510 to 760 mm (20 to 30 inches) in length and from 810 to 1220 mm (32 to 48 inches) in diameter. The roll surfaces are contoured so that, in the horizontal plane through the centerline of the pass, the space between the rolls converges toward the delivery side for a length of from 130 mm to 380 mm (5 inches to 15 inches) to a minimum, called the gorge, and then diverges to form the pass outlet. The converging and diverging angles formed by the roll surfaces vary from 4 degrees to 12 degrees with 7 degrees as the usual standard. The shafts of these rolls are mounted in bearings which can be adjusted laterally in the housing to permit the space between the rolls to be properly set for the size of work piece being rolled. The inlet end of each roll shaft is fitted with a universal coupling which, through long spindles, connects with a common reduction gear powered by an electric motor. The size of this motor and reduction unit depends on the size range to be produced on the mill, varying between 559 and 3730 kilowatts (750 and 5000 horsepower). These motors are designed for a pullout torque of 300 per cent. The rolls are cooled by water sprays. The elevation of the centerline of the pass is determined by two guides, one of which is mounted above and the other below the center of the mill in the space between the rolls.

Between these guides in the pass outlet a projectile-shaped piercing mandrel is held in position on the end of a water-cooled mandrel-support bar, located on the delivery side of the mill. The opposite end of this bar is mounted in a thrust bearing which is carried in a reciprocating carriage that is latched stationary during the piercing operation. The pointed end of the piercing mandrel extends just beyond the gorge toward the entering side of the rolls.

The Operation of Piercing—A solid round bar or billet of the proper length and diameter to make the size and weight of tube desired, is heated uniformly to the usual temperature for rolling light sections, which is 1200° to 1260°C (2200° to 2300°F). With the rolls revolving at constant speed of 4.06 to 5.59 surface metres per second (800 to 1100 surface feet per minute), the heated billet is transferred to a horizontal trough, which positions the axis of the billet on the inlet side of the mill coincident with the centerline of the pass.

The heated billet is pushed forward into the space between the rolls, which has been adjusted so that the gorge is approximately 90 percent of the diameter of the billet. As soon as the leading end of the billet has contacted the rolls, the force of the pusher is removed. Because of the obliquity of the roll axes, the motion imparted to the billet between the rolls is one of rotation and axial advance. When the leading end of the billet has advanced to the gorge, it encounters the nose or pointed end of the piercing mandrel. The grip of the

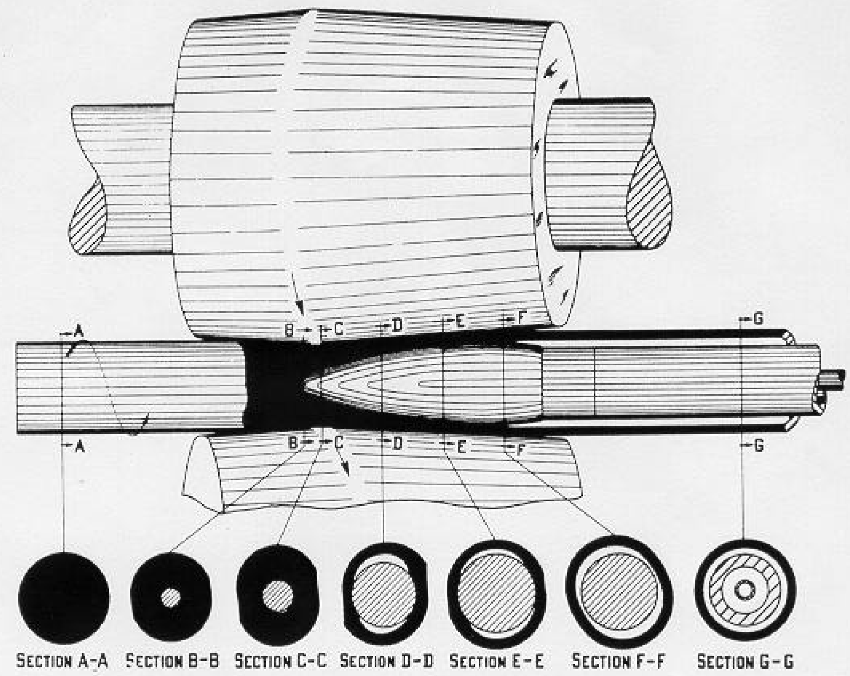

FIG. 32—24. Sketches illustrating action of rotary-piercing mill on the round billet.

rolls is sufficient to continue the advance of the work piece against the retarding effect imposed by the piercing mandrel. When the rearward end of the billet is rolled clear of the piercer mandrel, the thrust-bearing carriage is unlatched and the mandrel withdrawn from the billet, now a hollow shell, which is then conveyed to a reheating furnace in preparation for further fabrication into a finished tube. These shells are produced in lengths up to 8 metres (26 feet) in less than a minute.

The Action of the Rolls—It is evident that the forward motion of the billet is caused by the inclination of the axes of the rolls. How these two rolls, by exerting pressure only on a surface of the billet, are able to force the metal over the mandrel to form a tube from a solid billet is not so readily grasped. It is to be especially noted that the mandrel is not forced through the metal, but that the rolls cause the metal to flow over and about the mandrel. To bring about this result, the rolls must first draw metal away from the center of the billet, which action tends to form a central hole, or cavity, for the entrance of the piercer point. The truth of this statement is evident from the fact that a small, but somewhat irregular, hole may be formed in a billet without the use of the piercer point. In practice, the end of the piercer mandrel is placed sufficiently forward to prevent the formation of a cavity ahead of the point. Advantage is taken only of the tendency of the rolls to form this cavity.

Principle Involved in Forming the Cavity—Indeed, such a hole can be opened up in the center of any solid cylindrically shaped plastic body by rolling it between, even, two flat surfaces. Steel workers, particularly hammermen, are familiar with the fact that, if a piece of steel in the form of a round be pressed or hammered into an oval form several times in succession, a rupture will occur in the center that will extend longitudinally through the middle of the bar. The reason for the formation of this rupture is plainly due to the fact that when pressure is applied to the round bar at diametrically opposite points sufficient to deform it, making one diameter shorter and that at right angles to it longer, the spreading of the metal, which takes place along the long diameter and in opposite directions, sets up a lateral tension that may cause its particles to be drawn away from the center (Figure 32—24).

Flow of the Metal in Piercing—As the billet, which is in a plastic state, enters the mill, the rolls grasp it at diametrically opposite points on its circumference. As they draw the billet forward in the converging portion of the pass, they continue to compress it at these opposite points and, since the billet is being revolved rapidly, these points are continually changing. As the compressive rolling or cross-rolling proceeds from the point of initial contact of the piercer rolls to the gorge, the diameter of the billet is reduced and the section is changed from a circle to an oval with the long diameter in a vertical position. Since the billet is rotating, the central portion is acted on by all of the forces which are applied around its circumference during successive contacts between the billet and rolls. If a sufficient reduction is effected in this manner, a cavity will be formed in the center of the billet even without the presence of a piercer mandrel. In practice, this cavity is not permitted to form in advance of the nose of the mandrel, since the rough surface of the self-formed cavity might not permit the inner surface of the shell to be subsequently rolled smooth by the action of the mandrel. It is for this reason that the end of the piercer

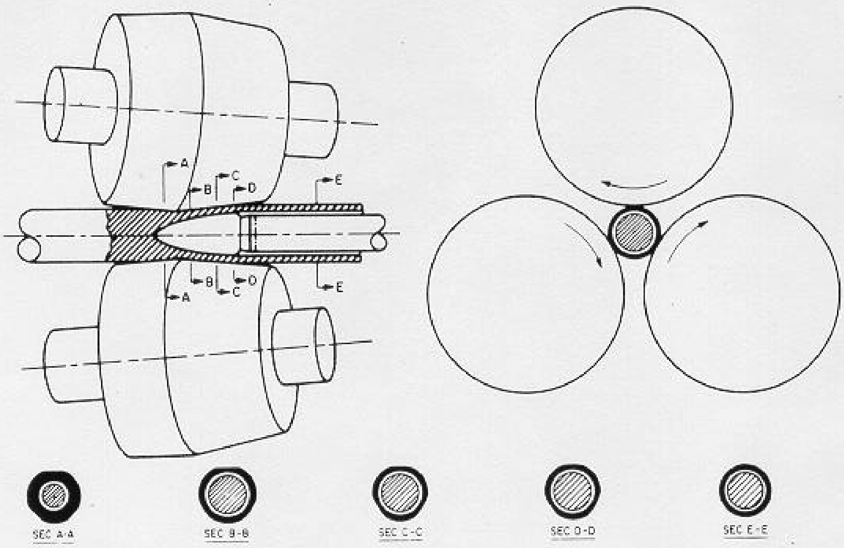

FIG. 32—25. Schematic diagram showing principle of operation of a three-roll piercing machine.

mandrel is positioned in advance of the gorge so that it will actually effect the opening in the billet, being assisted in its function by the cross-rolling action. To avoid the difficulty of accurately centering the mandrel, the forward end of the billet is centered to ensure that the point of the mandrel will penetrate the billet at or very near its axis. Centering is not absolutely necessary; however, it assists in starting the end of the mandrel in the center of the billet and reduces wear on the mandrel. If the end of the piercer mandrel is positioned too far in advance of the gorge, the cross-roll action on the center of the billet will not be great enough to reduce the resistance sufficiently to permit the grip of the rolls to advance the billet over the mandrel.

Once the end of the mandrel has penetrated the axial center of the billet, the piercer mandrel serves as a third roll so that, with the properly designed pass, the metal of the work piece is helically rolled over the piercing mandrel (rather than extruded) to produce the hollow shell. The grip of the rolls on the hollow in the diverging portion of the pass, due to the obliquity of the roll axes, tends to draw the billet forward as the reduction in wall thickness is being made, and, as a consequence, tends to increase the length of the pierced hollow shell at the expense of diameter.

Double Piercing—It is to be especially noted that the amount of metal displaced in piercing increases considerably as the OD size (outside diameter) is increased. In 1925, United States Steel Corporation developed the process known as double piercing. In this process the solid billet is first pierced to a comparatively heavy-walled shell, after which, without reheating, it is put through a second piercing mill. The second mill further reduces the wall thickness and increases the diameter and length of the piece. This practice has extended the permissible diameter range of the automatic-mill method of producing seamless tubes by dividing the requisite work of piercing in the two stages.

Three-Roll Piercing—The three-roll piercing process (Figure 32—25) differs from the Mannesmann process in that three (instead of two) contoured rolls are triangularly disposed around the centerline of the pass and angularly disposed longitudinally. The use of three rolls, rather than two rolls and two shoes which constitute the closed pass on the Mannesmann piercer, provides a more concentric tube with improved inside surface and freedom from stationary guides or shoes.

The Plug Rolling Mill is a motor-driven, nonreversing, single two-high stand, which resembles a reversing bar mill (Figures 32—26 and 32—27). There are, however, several differences between the two. Instead of roll tables, the mill is equipped on the entering side with a movable trough and pusher and on the delivery side with a stationary guide table, and mandrel-bar support. The guides on the latter table, two or more in number, are of the double-bell type and are mounted on cross beams and lined up one behind the other directly in back of the grooves in the rolls. The water-cooled mandrel bar, which is anchored in the support at the rear of the table, projects through a series of these guides with its opposite end terminating about 6.4 mm (¼ inch) short of the vertical centerline of the rolls. The free end of the mandrel bar provides support for the mandrel or plug during the working cycle. The work rolls, which are from 560 to 965 mm (22 to 38 inches) in diameter, depending upon the size of the mill, have several semi-circular grooves machined in their surface. With the rolls in position one above the other, the opening formed by the groove is not a true circle but is slightly oval with the long axis in a horizontal plane. This flare of the groove at the roll surface is provided to prevent the edge of the groove from shearing the work piece. In general, only one mandrel bar and one groove are used in the rolling of a given size tube. The tube is passed through this roll

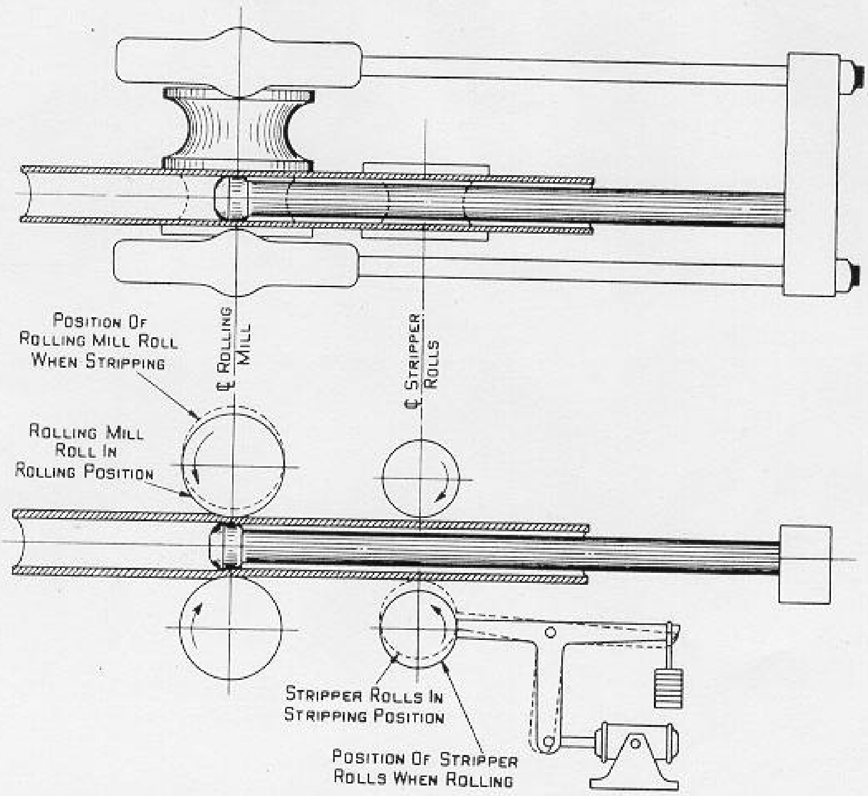

FIG. 32—26. Schematic plan view (above) and elevation (below) of a plug rolling mill.

FIG. 32—27. Plug rolling mill.

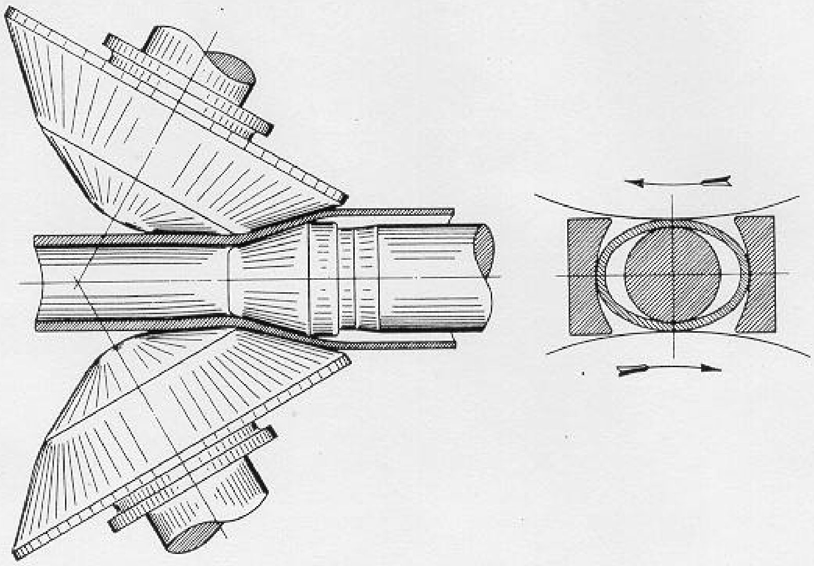

FIG. 32—28. Rotary-rolling mill.

stand twice, being rotated through 90 degrees between the passes so that the entire surface receives an equal and similar treatment in the slightly ovalled groove. To permit the tube to be stripped rapidly from the mandrel bar, the top roll is supported by counterweights and arranged to be elevated mechanically for a rapid opening of the pass. Stripper rolls, located just to the rear of the main rolls, are grooved to correspond with the main rolls. The lower stripper roll is also arranged for mechanical movement for rapid closing of the pass. These stripper rolls rotate in a direction opposite to that of the main rolls and function only when the top main roll is in its elevated or open pass position.

The Operation of Plug Rolling—The pierced shell, except for the smaller pipe sizes, is reheated after the piercing operations. With the pierced shell lying in the feed or delivery trough, an alloy-steel mandrel or plug is attached to the end of the bar, the bar holding the plug at the correct position in the roll groove. The plug is somewhat larger in diameter than the support bar in order to provide clearance between the inside of the tube and the support bar. In order to start the shell over the plug and permit the rolls to secure a good bite upon it, the shell is shoved into the pass with considerable force by a compressed-air-operated ram or pusher. Once started, the force of friction due to the pressure exerted by the revolving rolls is sufficient to draw the shell rapidly over the plug, slightly reducing its diameter and wall thickness and increasing its length. As soon as the shell has passed through the groove, the mandrel is removed from the bar. The top work roll is elevated approximately 38 mm (1½ inches). The lower stripper roll is then elevated to raise the tube clear of the bottom work roll and to grip it in the grooves of the stripper rolls, which return it to the entering side of the mill. Another mandrel is then placed on the bar, and the tube is rotated through an angle of 90 degrees. The top work roll and the lower stripper roll are returned to their original position, and the pusher again enters the tube in the pass. As soon as the tube has passed through the groove for the second working pass, it is returned again to the entering side of the mill, from which it is discharged for further fabrication. In this way the wall of the tube, supported by the plug on the inside and subjected to the action of the rolls on the outside, is reduced in thickness to the gage desired. The pierced billet is proportionately lengthened and slightly reduced in outside diameter. The wall reduction normally made in the plug mill is approximately 3.2 to 6.4 mm (⅛ to ¼ inch). After plug rolling, the tube has a uniform wall of the desired thickness throughout but is slightly out of round or oval shaped, not perfectly straight, and still at a bright-red heat.

Rotary Rolling—The large demand for pipe between 405 and 915 mm (16 and 36 inches) in outside diameter for the transportation of natural gas for long distances raised a serious question as to the best manner of manufacturing such pipe. The lap-weld processes then used for making such pipe sizes were both costly and slow and also unsuited for the manufacture of lengths over 12.2 metres (40 feet). It is also not feasible to roll pipe over 405 mm (16 inches) in diameter on the automatic rolling mill, and this feature made it questionable whether seamless pipe in these sizes could be economically made. The rotary-rolling mill was developed by United States Steel Corporation, which has made possible the production of pipe as large as 660 mm (26 inches) in outside diameter in lengths up to 13.7 metres (45 feet) and with wall thicknesses as light as 7.1 mm (0.281 inch). Other large sizes are produced with wall thicknesses as light as 6.4 mm (0.250 inches).

The rotary-rolling mill is a modification and enlargement of the cone-type piercing mill. The shafts of this mill, which drive the 1880-mm or 74-inch (diameter) conical rolls, are in separated horizontal planes and are at an angle of 60 degrees with the axis of the pipe being rolled. A diagram of this mill is shown in Figure 32—28; an actual mill in operation is shown in Figure 32—29.

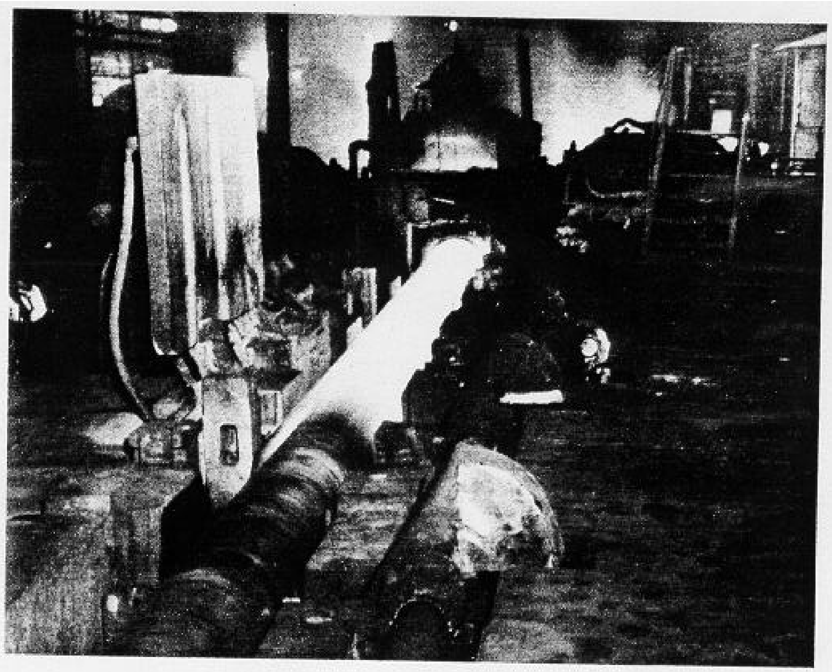

FIG. 32—29. Rotary-rolling mill in operation.

Each shaft is powered with a 1120-kilowatt (1500-horsepower), 200-500-rpm, d-c motor, which provides peripheral roll speeds of 4.06 to 12.19 metres per second (800 to 2400 feet per minute). In operation, the conical rolls grip and spin the pipe, feeding it forward over a large tapered mandrel, thereby effecting a decrease in the wall thickness of the pipe and an increase in the diameter. The length of the tube is substantially unchanged by the operation. The rolling action is similar to that which takes place in a tire- or ring-rolling machine, except that in the rotary-rolling mill a forward helical advance is imparted to the tube, which is supported on the inside by the tapered mandrel.

The Reeling Machine (Figure 32—30) is similar in construction and operation to the Mannesmann piercer except that the rolls, which are about 760 mm (30 inches) long and 865 mm (34 inches) in diameter, are almost cylindrical in form. The rolls are adjusted later-

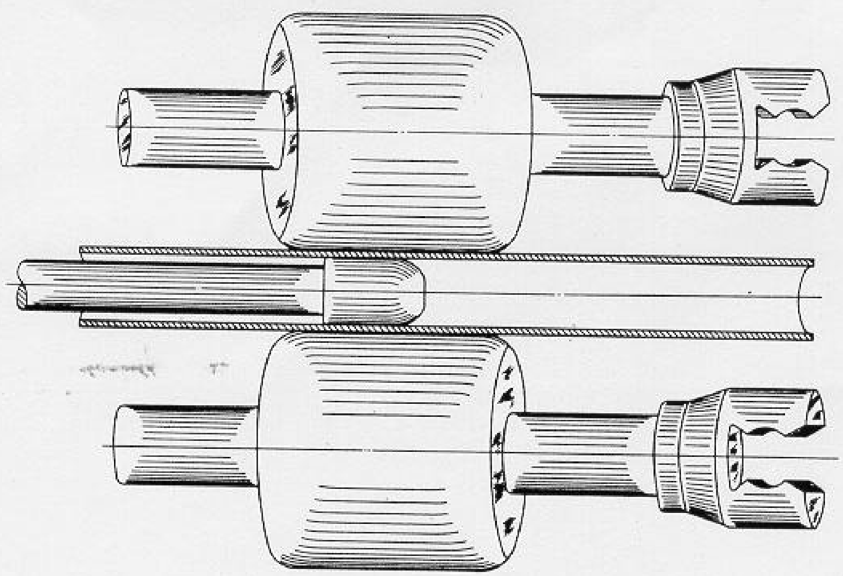

FIG. 32—30. Reeling machine.

ally in the same manner as that described for the Mannesmann piercer and are separated by a space a little less than the diameter of the tube to be reeled. The rolls are motor-driven and are geared together to revolve in the same direction at a surface speed of approximately 4.57 metres per second (900 feet per minute). In operation, a cylindrical mandrel, which is placed between the rolls, is supported on the delivery end by a water-cooled mandrel-support bar. Like the piercing mill, the opposite end of this bar is connected to a thrust bearing carried in a reciprocating carriage, locked stationary during the reeling operation. On the inlet side of the mill a conveyor carries the tube through stationary guides to contact with the rolls. Since the rolls are revolving in the same direction and with axes oppositely inclined, they cause the tube to revolve and helically advance over the mandrel. The elevation of the mandrel and tube during reeling is maintained in the proper horizontal position by stationary guides mounted between the reeler rolls above and below the pass. Owing to the fact that the total space between the reeler rolls and the mandrel is a few hundredths of a millimeter (thousandths of an inch) less than twice the wall thickness of the entering tube, a slight reduction in the thickness of the wall is effected during the reeling operation. This slight reduction made in the reeling operation has the effect of burnishing the inside and outside surfaces of the tube and slightly increasing its diameter. The function of the reeler is, therefore, to round up and to burnish the inside and outside surfaces of the tube delivered from previous fabricating operations.

Sizing the Tube—The manner of sizing the reeled tube depends upon the diameter of the pipe that is being produced. For sizes from approximately 140 mm (5½ inches) and over, the sizing process consists merely of passing the tube, reheated in some cases, through two or three stands of sizing rolls the grooves of which are slightly smaller than the reeled tube. The diameter reduction effected is to ensure uniform size and roundness throughout the length of the tube.

Seamless mills producing pipe from 90 mm to 180 mm (3½ to approximately 7 inches) outside diameter usually are equipped with a seven-stand gear-driven reducing mill where reductions up to 12.7 mm (½ inch) in diameter can be made. Such a reduction in diameter provides greater flexibility in operation and minimizes the change time of the mill by lessening the number of steel sizes and high-mill roll changes required for the size range of the mill.

Since it is not economical to pierce, roll and reel tubes of small diameter, the production of hot-finished tubes less than about 75 mm (3 inches) in diameter requires a reducing and sizing process for which a special machine is employed. This machine is similar to a continuous rolling mill. It consists of 8 to 16 stands of two-high grooved rolls about 305 mm (12 inches) in diameter, arranged on the continuous plan and set about 610 mm (24 inches) apart, center to center. Instead of standing vertically, the housings for these rolls are inclined 45 degrees, so the adjacent stands lie at right angles to each other and the loci of the centers of the pass openings formed by the grooves, which gradually decrease in size from the first to the last, are in the same straight line. The grooves in the initial stands are slightly oval in shape. However, the grooves in the last two stands on the delivery end of the mill are preferably round. As the tube from the reeling machine is too cold to be reduced in diameter, it is passed endwise into a long reheating furnace located at the entering end of the reducing mill where it is heated to a uniform temperature just below the scale-forming point. It is then pushed by a mechanical pusher directly into the first stand of the reducing mill, being drawn continuously through the successive stands in which it is elongated and reduced to the outside diameter desired. The smallest size to which tubes generally are reduced by this process is 38 mm (1½ inches). The preferred maximum diameter reduction per stand in this type of reducing mill is 3 per cent. Since the relationship of wall change and elongation varies with the ratio of diameter to wall thickness (D/T), a medium condition is assured and the diameter of the rolls in successive stands is chosen to provide a linear speed as close as possible to the natural flow of the metal.

An improvement to the reducing mill is the stretch-reducing mill described later in connection with the continuous seamless process.

Spray-Quenched Deep Well Casing—When higher strength casing than that produced by low alloy additions or by normalizing is desired for deep oil wells, carbon-manganese steel pipe is heat treated by a special process. In this process, the hot-rolled pipe is heat treated in a continuous unit by water quenching from temperatures of approximately 845°C (1550°F) and tempering at 480° to 705°C (900° to 1300°F). A suitable furnace is used for heating the pipe. During heating and quenching, the pipe is rotated. The furnace is normally gas-fired, but could take the form of a continuous induction heating unit. After heating to 845°C (1550°F), the pipe is quenched as it passes through a specially designed water-spray ring containing nozzles which spray water on the complete periphery of the pipe.

After quenching, the steel pipe is placed in a tempering furnace and heated to 480° to 705°C (900° to 1300°F) depending upon the final properties desired. The pipe is rotated during heating in the tempering furnace to maintain straightness and uniformity of heating. The continuous tempering furnace is fired with gas and the pipe temperature is checked with a radiation-type pyrometer as it leaves the furnace.

When the pipe leaves the tempering furnace, it immediately passes through a set of five stands of sizing rolls. Due to the formation of martensite during quenching, an increase in volume of the steel occurs which increases the outside diameter of the pipe, and introduces a limited amount of ovality and out-of-straightness. The sizing operation ensures uniform size in the quenched and tempered product; however, the severity of the sizing pass must be limited.

Test results show that a carbon-manganese steel with average hot-rolled mechanical properties of 441 MPa (64 000 psi) yield strength, 689 MPa (100 000 psi) ultimate strength and 30 per cent elongation will, after spray quenching and tempering, exhibit average mechanical properties of 848 MPa (123 000 psi) yield strength, 938 MPa (136 000 psi) inch ultimate strength and 23 per cent elongation. A marked increase in collapse resistance also results from this heat-treating process. For example, 178 mm (7 inch) OD casing with a wall thickness of 10.4 mm (0.408 inch) will have its collapse resistance increased from 44 MPa (6400 psi) in hot-rolled pipe to 85 MPa (12 290 psi) after heat treating—an increase of 92 per cent.

Experimentation has shown that cold rotary straightening can have a deleterious effect on mechanical properties, which is caused by the Dauschinger effect. If the cold work associated with cold straightening is great enough, the yield strength of a pipe or tube can be reduced. Furthermore, casing pipe will also suffer a reduction in collapsing resistance because of this effect. As a consequence, many seamless mills are now using hot rotary straightening, which is done at temperatures of about 700°F (330°C) and higher, but in the case of quench and temper product does not exceed the tempering temperature. Tubular products processed in this manner do not exhibit any reduction in mechanical properties.

The Continuous Seamless Process—Some seamless mills utilize equipment entirely different than that used in the conventional seamless process. The rolling mill and reelers of the conventional mill are replaced by a continuous rolling mill (Figure 32—31) with nine tandem individually powered stands of two-high grooved rolls. Figure 32—32 illustrates the method of reduction employed by this continuous rolling mill. The rolls in the consecutive stands have their axes at 90 degrees to each other and are driven by motors which provide a total of 6340 kilowatts (8500 horsepower). The pipe mill requires an internal mandrel against which the work piece is rolled to reduce wall thickness. This cylindrical mandrel extends entirely through the pierced billet and passes through the mill with the work piece. In the first two roll stands, the diameter of the pierced billet is reduced so that the inner surface is in substantial contact with the mandrel bar. Each of the next two stands makes a reduction in wall over a portion of the circumference, the two jointly completing the first increment of reduction. The next two stands, the fifth and sixth in this mill, make a similar complete reduction but of somewhat less magnitude. The next two succeeding stands (7 and 8) are designed to effect a very slight reduction, the purpose of which is to planish the tube surface. The shape of the tube which has been oval in the preceding stands is changed to approximately circular section in the ninth stand. The rounding up operation effected by this stand frees the inner surface of the tube from the mandrel bar to facilitate withdrawal of the mandrel.

In the operation of the mill, after a billet has been pierced by a conventional Mannesmann piercing mill, a lubricated mandrel, considerably longer than the pierced shell, is inserted and both pass through the rolling mill. The tube and mandrel are then kicked out of the pass line to a stripper which mechanically removes the mandrel. The rolled tube is then further processed by one of two methods depending on the desired product.

After withdrawal of the mandrel, the rolled tubes are reheated before being processed in either a sizing mill or a tension reducing or "stretch" mill. The stretch mill (Figure 32—33) which is similar in construction to the continuous rolling mill, consists of twelve two-high roll stands with the individual stands powered by 150 kilowatt (200 horsepower) variable-speed motors. Tension reducing is unique in that without the use of a supporting mandrel the wall thickness is diminished while the

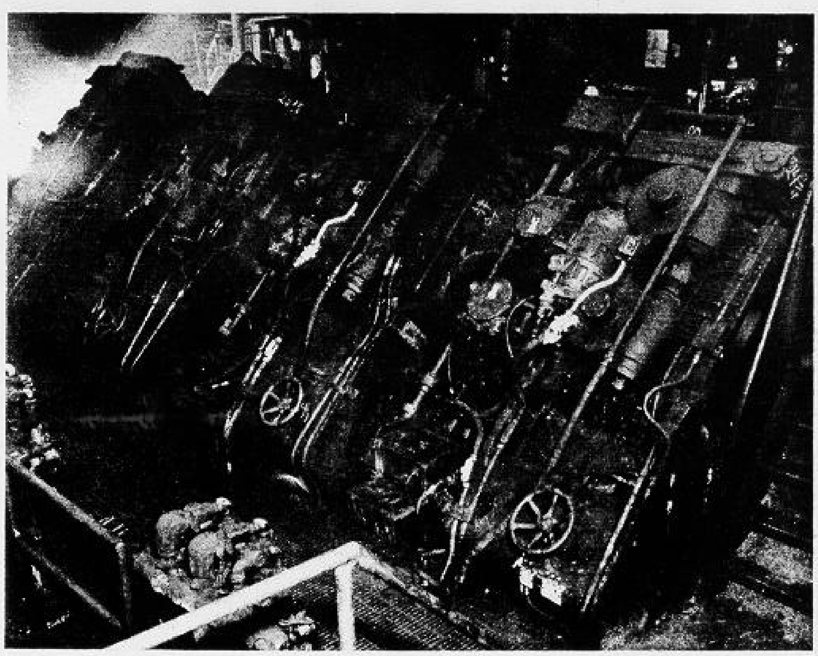

FIG. 32—31. Over-all view of a continuous seamless-pipe mill, known as a mandrel mill.

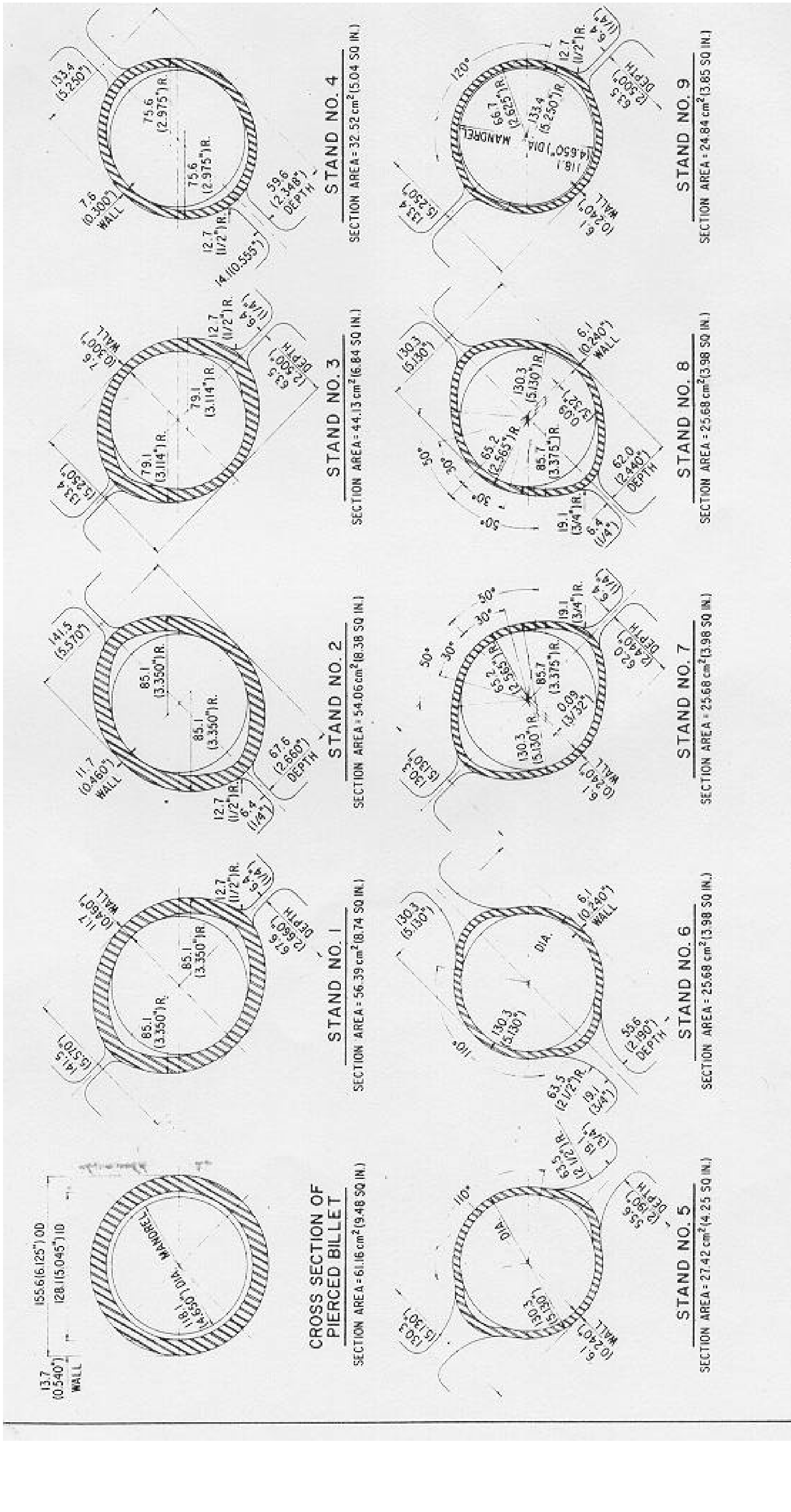

FIG. 32—32. Pass design for a nine-stand continuous tube-rolling mill when rolling 1334 mm (5.250-inch) OD by 6.1 mm (0.240-inch) wall pipe shell.

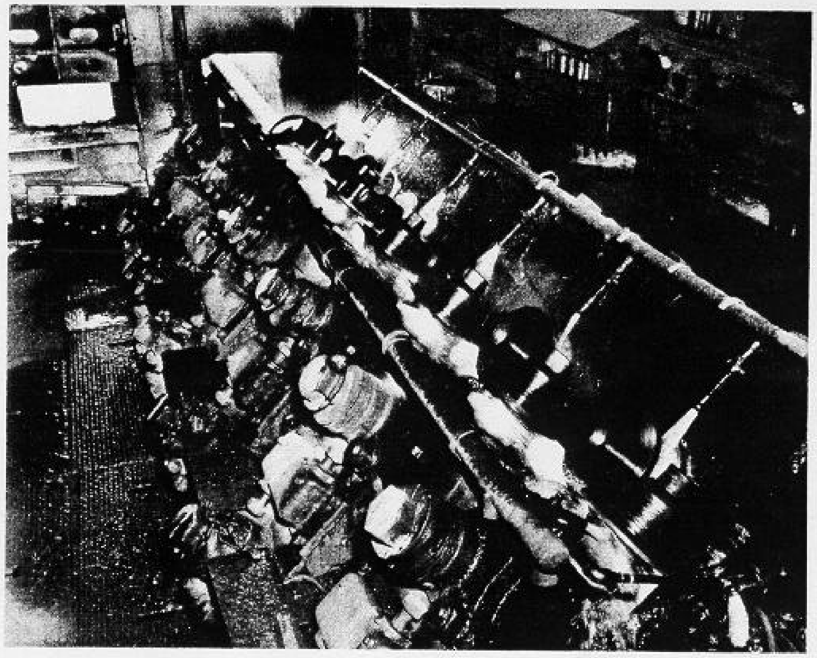

FIG. 32—33. Over-all view of 12-stand stretch-reducing mill, with tube emerging from tube-reheating furnace in the background.

diameter is reduced. This operation differs from the conventional reducing mill in which the wall thickness is increased as the diameter is reduced. In the tension reducing mill, the tension forces to which the tube is subjected between roll stands are not only effective in reducing wall thickness of the tube but the reduction in diameter performed in each stand can be tripled over conventional practice.

A typical schedule of roll-pass design for making 60.3 mm (2⅜ inch) outside diameter by 4.8 mm (0.190 inch) wall thickness by 42.7 metre (140 foot) length from a shell size of 131.0 mm (5.156 inch) outside diameter by 5.7 mm (0.225 inch) wall thickness by 16.5 metre (54 foot) length is shown in Table 32—IV for 356 mm (14 inch) diameter rolls.

Having both a sizing and stretch mill permits continuous production since it is possible to divert tubes to either unit, depending upon the desired size.

The pierced billet which is 149.2 mm (5⅞ inches) in outside diameter by 11.4 mm (0.450 inch) wall thickness and 6.7 metres (22 feet) long, pierced from a solid round that is 139.7 mm (5½ inches) in diameter and 2.44 metres (8 feet) long, will emerge from the continuous reducing mill as a tube with 127 mm (5 inches)

Table 32—IV. Schedule of Roll-Pass Design for A Tension Reducing Mill with 356-mm (14-Inch) Diameter Rolls.

Stand	Height of Groove		Cutter Diameter		Mean Diameter		Groove Depth		Reduction per Pass (%)	Roll Speed (rpm)
	mm	in.	mm	in.	mm	in.	mm	in.		
1	117.6	4.630	141.2	5.560	126.2	4.970	58.4	2.300	3.5	115
2	109.5	4.310	131.3	5.170	117.4	4.620	54.4	2.140	7.0	123
3	101.9	4.010	120.1	4.730	108.5	4.270	50.6	1.990	7.5	132
4	93.8	3.692	109.7	4.320	99.6	3.920	46.5	1.831	8.1	154
5	85.4	3.362	90.1	3.900	90.4	3.560	42.3	1.666	9.1	167
6	77.8	3.062	89.4	3.520	82.0	3.230	38.5	1.516	9.1	181
7	71.1	2.798	81.0	3.190	74.7	2.940	35.2	1.384	9.0	204
8	64.6	2.542	73.7	2.900	67.9	2.672	31.9	1.256	9.0	240
9	62.1	2.445	67.1	2.640	63.9	2.514	30.7	1.208	6.0	265
10	61.3	2.414	63.5	2.500	62.2	2.447	30.3	1.192	2.7	275
11	61.3	2.414	61.3	2.414	61.3	2.414	30.3	1.192	1.3	275
12	61.3	2.414	61.3	2.414	61.3	2.414	30.3	1.192	0	275

outside diameter with 5.7 mm (0.225 inch) wall and 16.5 metres (54 feet) long. This tube, after passing through the stretch-reducing mill, if rolled into 60.3 mm (2⅜ inch) outside diameter tubing with 4.8 mm (0.190 inch) wall, will be 42.7 metres (140 feet) long.

The long tubes are cut into two sections by a rotary saw on the cooling table. The half sections then are cut into predetermined lengths by high-speed rotary-blade cutters before going to the finishing floors.

Seamless Fabricating Practices—In the discussion of the various phases of seamless-tube manufacture in this section, the role of each unit was described. It was also indicated that the number of operations is dependent upon the size of the tube to be produced. To further clarify these discussions, the following examples, which typify the variations employed in the manufacture of seamless tubes, are given to develop the operations step by step.

In producing a 60.3 mm (2⅜ inch) OD by 3.9 mm (0.154 inch) wall single-length hot-rolled tube, a solid billet 83 mm (3¼ inches) in diameter and weighing approximately 37 kilograms (82 pounds) is pierced to a shell 87 mm (3⁷⁄₁₆ inches) OD with 5.5 mm (0.215 inch) wall, about 3.4 metres (11 feet) long. This pierced shell is passed, without reheating, to the plug rolling mill where it is plug-rolled in an 82.6 mm (3¼ inch) groove to produce a tube 82.6 mm (3¼ inches) OD with a 3.6 mm (0.140 inch) wall and 5.3 metres (17 feet, 6 inches) long. The plug-rolled shell is then reeled to approximately 87 mm (3⁷⁄₁₆ inches) OD, 3.6 mm (0.140 inch) wall and about 5 metres (16 feet, 6 inches) in length. After reeling, the tube is passed through a reheating furnace and into the reducing-sizing mill from which it emerges 60.3 mm (2⅜ inch) OD with 3.9 mm (0.154 inch) wall and approximately 6.8 metres (22 feet, 3 inches) long. From this tube, the crop-ends, and any test pieces that may be required, are cut in the finishing operations described in a later section.

In producing a double-length hot-rolled tube 219 mm (8⅝ inch) OD with 7 mm (0.277 inch) wall, a solid billet 210 mm (8¼ inches) in diameter, 2 metres (6 feet, 5 inches) long, weighing 529 kilograms (1166 pounds), is pierced in the first piercer to a shell 203 mm (8 inches) OD, wall thickness of 32 mm (1¼ inches) and 3.9 metres (12 feet, 10 inches) long. Without reheating, this shell is further processed in the second piercer to a shell 219 mm (8⅝ inches) OD, with an 11.9 mm (0.470 inch) wall, and approximately 8.5 metres (28 feet) long. The shell from the second piercer, after reheating, is plug-rolled in a 214 mm (8⁷⁄₁₆ inch) groove to 214 mm (8⁷⁄₁₆ inches) OD, 5.8 mm (0.227 inch) wall and 14.3 metres (46 feet, 9 inches) long. The plug-rolled tube is transferred directly to the reeling machine which produces a tube 222.3 mm (8¾ inches) OD, 7 mm (0.277 inch) wall, and 13.3 metres (45 feet, 5 inches) long. The tube then receives two or more passes in the two-high sizing mill from which it emerges 219 mm (8⅝ inch) OD, with a 7 mm (0.277 inch) wall and about 14 metres (46 feet) long, ready for end cropping and the other finishing operations.

To produce 660 mm (26 inch) OD, 7.7 mm (0.303 inch) wall double-length hot-rolled tubes, a solid billet 311 mm (12¼ inches) in diameter, 3 metres (10 feet) long and weighing 1818 kilograms (4007 pounds) is pierced to a shell 355 mm (14 inches) in outside diameter, 41.7 mm (1.640 inch) wall, and 5.6 metres (18 feet, 3 inches) long in the first piercer. This shell, on the same heat, is entered in the second piercer where it is rolled to 430 mm (17 inches) OD, 19 mm (0.750 inch) wall, and 9.2 metres (30 feet, 2 inches) long. After reheating, the shell is plug-rolled to form a tube 426 mm (16¾ inches) OD, 12.7 mm (0.500 inch) wall, and 13.6 metres (14 feet, 9 inches) long. The plug-rolled shell is reheated a second time, after which it is rotary rolled to 667 mm (26¼ inches) OD, 7.7 mm (0.303 inch) wall, and 13.9 metres (45 feet, 8 inches) long. Without reheating, it is then reeled to 673 mm (26½ inches) OD, 7.7 mm (0.303 inch) wall, 13.8 metres (45 feet, 3 inches) long. The tube, after reeling, is again reheated in the tunnel-type reheating furnace, after which it passes through two stands of two-high sizing-mill rolls, forming a hot-rolled tube 660 mm (26 inches) OD, 7.7 mm (0.303 inch) wall, and 14 metres (46 feet) long, ready for the finishing operations.

SECTION 6

PRODUCTION OF SEAMLESS PIPE BY PRESS-PIERCING MILL

The press-piercing mill (PPM) is composed of three basic elements: a roll stand with a round pass between a pair of driven rolls; a billet pusher; and a fixed plug located between the two rolls. The billet, enveloped in a 4-sided guide, is forced against the plug by the combined action of the pusher and the driven rolls. The material deformation by this process is mainly compressive with low elongation (maximum 1.2) which avoids subjecting the cast material to high tensile stresses.

The advantages of this process include:

- The use of continuous-cast square billets.
- Elimination of internal porosity and segregation common to continuous-cast blooms. This is the result of the combined action of the three elements of the PPM which, together, cause radial displacement and heavy internal surface compaction by the plug. It is made possible by the opposing external surface compaction of the wall by the mill rolls while under the heavy longitudinal compressive force exerted by the pusher.
- Transformation from solid to hollow under compression. This method improves the physical quality of the cast material, thereby rendering harm-