Steel Tube and Pipe Manufacturing Processes

Contents

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1 Introduction

The advent of rolling mill technology and its development during the first half of the nineteenth century also heralded in the industrial manufacture of tube and pipe. Initially, rolled strips of sheet were formed into a circular cross section by funnel arrangements or rolls, and then butt or lap welded in the same heat (forge welding process). Toward the end of the century, various processes became available for the manufacture of seamless tube and pipe, with production volumes rapidly increasing over a relatively short period. In spite of the application of other welding processes, the ongoing development and further improvement of the seamless techniques led to welded tube being almost completely pushed out of the market, with the result that seamless tube and pipe dominated until the Second World War. During the subsequent period, the results of research into welding technology led to an upturn in the fortunes of the welded tube, with burgeoning development work ensuing and wide propagation of numerous tube welding processes. Currently, around two thirds of steel tube production in the world are accounted for by welding processes. Of this figure, however, about one quarter takes the form of so-called large-diameter line pipe in size ranges outside those which are economically viable in seamless tube and pipe manufacturing.

Chart I provides an overview of the size ranges for seamless (DIN 2448) and welded (DIN 2458) tube. As is evident, welded tube is predominantly manufactured in ranges characterized by small wall thicknesses and large outside diameters, while seamless tube is produced mainly in the range extending from normal to very large wall thicknesses in the diameter range up to approx. 660 mm. The process of selection of the manufacturing process – especially in the overlap regions where there is a real choice between seamless and welded tube – is essentially dictated by the application of the tube, i.e. the associated material requirements and the service conditions.
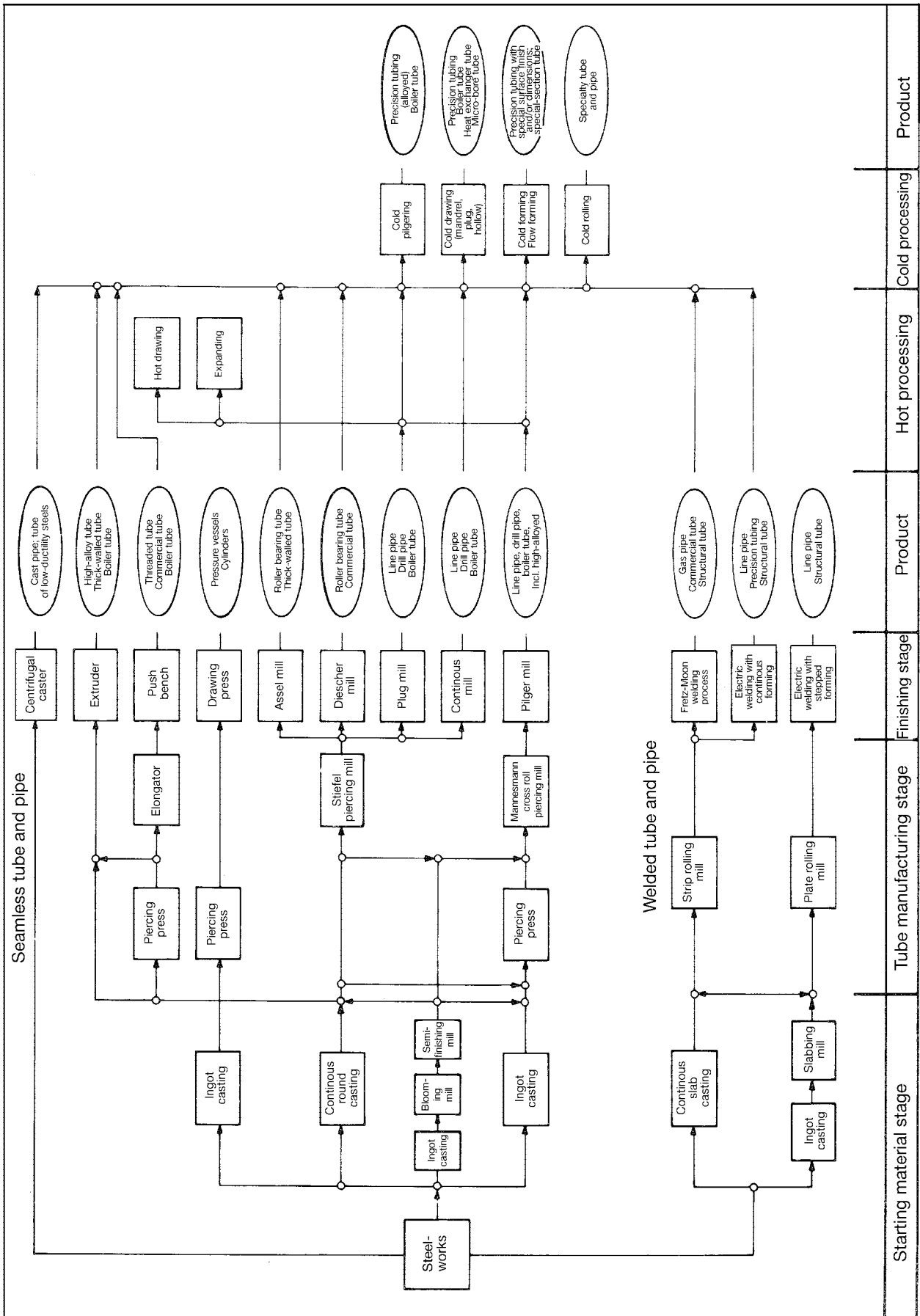
Chart II provides a summary of the main manufacturing processes applied nowadays in the production of seamless and welded steel tube. Also indicated are the upstream production stages, any downstream further processing operations, and the typical products of the individual technologies. This scheme has been applied in order to illustrate the fact that a varying number of production stages in the starting material preparation or roughing stage are required to serve the various facilities of the tube production stage.

In the case of seamless tube and also in the case of the Fretz-Moon welding process, the production stage invariably involves a heating operation, in which case the product may also be referred to as hot-formed tube or pipe. Downstream facilities for hot drawing or hot expanding occur relatively rarely; on the other hand, hot-formed tubes are extensively used as starting products for a downstream cold forming process. The latter is used in order to extend the product mix of a plant toward smaller diameters and wall thicknesses (DIN 2391), to reduce wall thickness and diameter tolerances, and to achieve special surface finishes or mechanical/thermo-mechanical properties in the tube.

The production of welded tube initially involves the continuous forming of strip, sheet or plate in roll stands (sometimes referred to as roller cages), or in presses (U-ing and O-ing; C-ing process). The strip may also be cold-formed on a three-roll bending machine and subsequently welded by pressure or fusion welding to produce the finished tube. Depending on the forming process, a distinction is made between longitudinally welded and spiral-welded tube; the latter may also be referred to as helical seam pipe.-

As the requirements imposed on tubular products continued to increase, not only were the associated manufacturing processes constantly improved, but also appropriate systems for effective production control and quality assurance were introduced. Nowadays, tube and pipe manufacturers of renown all have a system in place enabling the production process from the steelworks to the finished tube to be continuously monitored and documented for total traceability, and effectively controlled on the basis of quality criteria. The mechanical and nondestructive tests stipulated in the relevant technical specifications are carried out by personnel operating independently from the production control department so as to guarantee product of a constantly high quality.

Chart I: Standard dimensions for seamless and welded steel tube and pipe

Wall thickness [mm]

| Outside diameter [mm] | 1.4 | 1.6 | 1.8 | 2 | 2.3 | 2.6 | 2.9 | 3.2 | 3.6 | 4 | 4.5 | 5 | 5.6 | 6.3 | 7.1 | 8 | 8.8 | 10 | 11 | 12.5 | 14.2 | 16 | 17.5 | 20 | 22.2 | 25 | 28 | 30 | 32 | 36 | 40 | 45 | 50 | 55 | 60 | 65 |

Outside diameter [mm]: 10.2, 13.5, 16, 17.2, 19, 20, 21.3, 25, 25.4, 26.9, 30, 31.8, 33.7, 38, 42.4, 44.5, 48.3, 51, 54, 57, 60.3, 63.5, 70, 73, 76.1, 82.5, 88.9, 101.6, 108, 114.3, 127, 133, 139.7, 152.4, 159, 168.3, 177.8, 193.7, 219.1, 244.5, 273, 323.9, 355.6, 406.4, 457, 508, 559, 610, 660, 711, 762, 813, 864, 914, 1016, 1220, 1420, 1620, 1820, 2020, 2220

Seamless tube to DIN 2448

Welded tube to DIN 2458

● Standard wall thickness as per DIN 2448

○ Standard wall thickness as per DIN 2458

Chart II: Methods for the manufacture of seamless and welded steel tube and pipe, plus associated product applications

Seamless tube and pipe

Welded tube and pipe

Products (seamless):
- Precision tubing (alloyed); Boiler tube
- Precision tubing; Boiler tube; Heat exchanger tube; Micro-bore tube
- Precision tubing with special surface finish and/or dimensions; special-section tube
- Specialty tube and pipe

Cold processing:
- Cold pilgering
- Cold drawing (mandrel, plug, hollow)
- Cold forming / Flow forming
- Cold rolling

Hot processing:
- Hot drawing
- Expanding

Product (intermediate):
- Cast pipe; tube of low-ductility steels
- High-alloy tube; Thick-walled tube; Boiler tube
- Threaded tube; Commercial tube; Boiler tube
- Pressure vessels; Cylinders
- Roller bearing tube; Thick-walled tube
- Roller bearing tube; Commercial tube
- Line pipe; Drill pipe; Boiler tube
- Line pipe; Drill pipe; Boiler tube
- Line pipe, drill pipe, boiler tube; Incl. high-alloyed
- Gas pipe; Commercial tube; Structural tube
- Line pipe; Precision tubing; Structural tube
- Line pipe; Structural tube

Finishing stage:
- Centrifugal caster
- Extruder
- Push bench
- Drawing press
- Assel mill
- Diescher mill
- Plug mill
- Continous mill
- Pilger mill
- Fretz-Moon welding process
- Electric welding with continous forming
- Electric welding with stepped forming

Tube manufacturing stage:
- Elongator
- Stiefel piercing mill
- Mannesmann cross roll piercing mill
- Piercing press
- Strip rolling mill
- Plate rolling mill

Starting material stage:
- Ingot casting
- Continous round casting
- Bloom-ing mill
- Semi-finishing mill
- Ingot casting
- Continous slab casting
- Slabbing mill
- Steel-works

The following sections describe only those manufacturing processes which are widely employed today for the mass-production of tube and pipe.

2 Seamless tube and pipe

The main seamless tube manufacturing processes came into being toward the end of the nineteenth century. As patent and proprietary rights expired, the various parallel developments initially pursued became less distinct and their individual forming stages were merged into new processes. Today, the state of the art has developed to the point where preference is given to the following modern high-performance processes:

– The continuous mandrel rolling process and the push bench process in the size range from approx. 21 to 178 mm outside diameter

– The multi-stand plug mill (MPM) with controlled (constrained) floating mandrel bar and the plug mill process in the size range from approx. 140 to 406 mm outside diameter

– The cross roll piercing and pilger rolling process in the size range from approx. 250 to 660 mm outside diameter

Aside from these broadly defined size range limits, many facilities also operate in other dimensional ranges as described in the following sections and shown in Fig. 1.

In spite of many earlier tests, trials and technologies, the invention of the cross roll piercing process by the Mannesmann brothers toward the end of the 1880s is widely regarded as signalling the commencement of industrial-scale tube and pipe production.

This cross roll concept marked the first departure from the characteristic feature of all the rolling processes known until that time, i.e. the fact that the roll axes all lay in the same plane, the rolls rotated in opposite directions and the stock exit speed approximated to the roll circumferential speed (Fig. 2). In the cross roll piercing process, the roll axes were arranged parallel to the stock axis but at an angle to the stock plane. With the rolls rotating in the same direction, therefore, this arrangement produced a
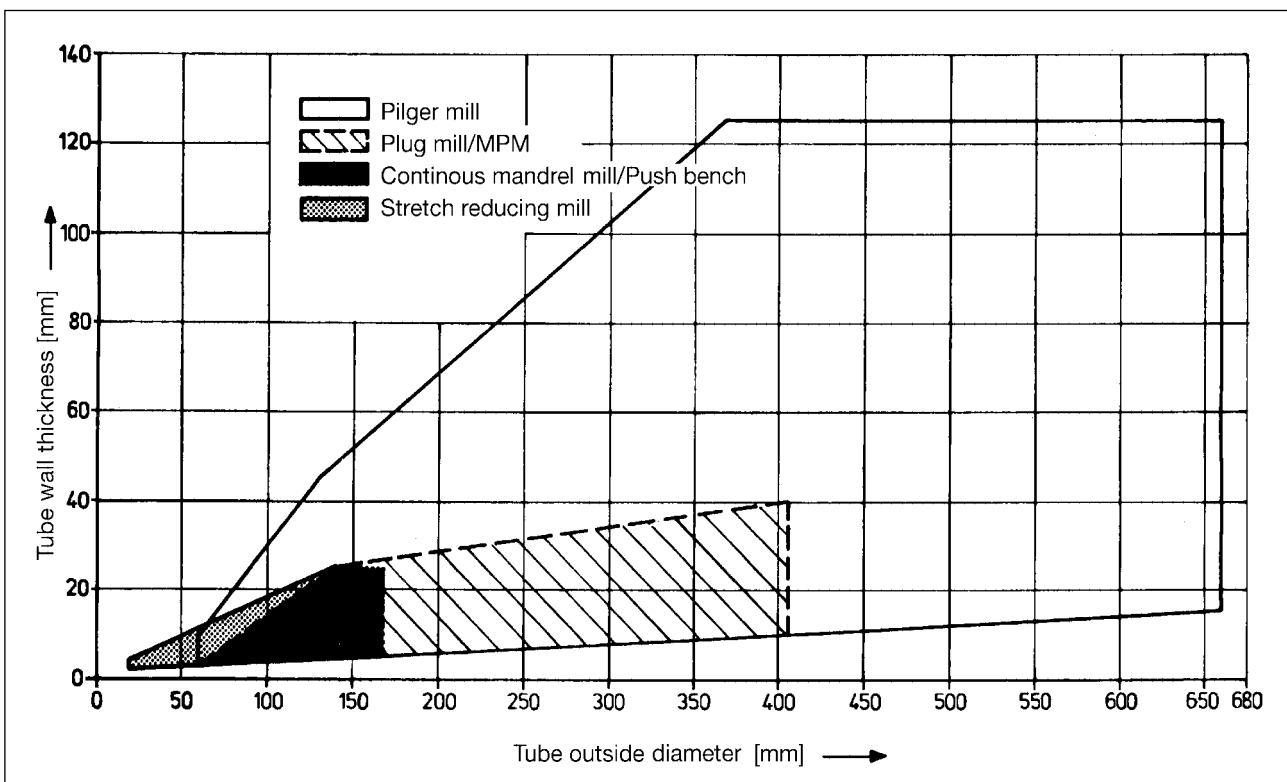

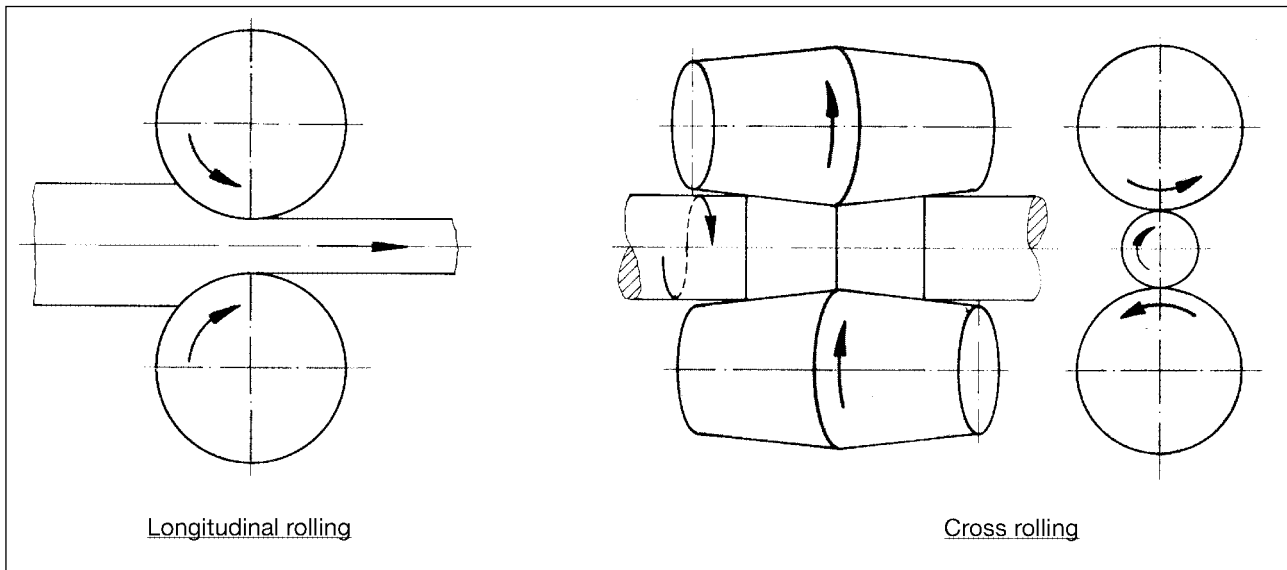Fig. 1: Production ranges for the manufacture of seamless tube by mill

Fig. 2: Comparison between longitudinal rolling and cross rolling

helical passage for the stock through the roll gap. Moreover, the exit speed was slower by about the power of 10 than the circumferential speed of the rolls.

By introducing a piercing mandrel arranged in the roll gap, solid round material could be pierced to produce a hollow shell in the rolling heat by the action of the cross rolls. However, it was not yet possible to produce tubes of normal wall thicknesses in useable lengths by the cross roll piercing process alone. It was only after development and introduction of a second forming stage – the pilger rolling process – again by the Mannesmann brothers, that it became practicable and economically viable to manufacture seamless steel tube. The pilgering process also constituted an unusual and innovative technology in that the thick-walled hollow shell was elongated to the finished tube dimensions by the discontinuous forging action of the pilger rolls – or "dies" – on a mandrel located inside the hollow shell.

Needless to say, this pioneering development encouraged many inventors at the time to submit a number of patent applications – in some cases merely to circumvent the proprietary rights of the Mannesmann brothers, but also to break completely new ground in the manufacture of seamless tube.

A member of the first group, R.C. Stiefel, a former Mannesmann employee, is worthy of particular mention. By further developing the cross roll piercing technique, he succeeded in the USA in producing thin-walled hollow shells which were subsequently rolled out to the finished tube on a two-high plug mill which had already become well known from the welding process for which it was used. This plug mill process was initially particularly successful in the USA, and is today employed throughout the world to roughly the same extent as the cross roll piercing and pilgering process.

The so-called continuous mandrel rolling mill is associated with the names Charles Kellog and, later, Aloys Fassl. This process initially involved several two-high stands arranged in tandem by means of which the thin-walled hollow bloom was rolled over a mandrel bar to produce the finished tube. Owing to difficult mechanical engineering and drive problems, however, the process was soon assigned to history. Fifty years later, with the advent of modern technology to solve, in particular, the open-loop and closed-loop control problems, it was reborn as one of the most efficient tube rolling mills ever invented.

Another possibility for the production of seamless tube was invented by H. Ehrhardt. By piercing a solid square ingot in a round die, he was able to produce a thick-walled hollow shell with a closed bottom. This shell was subsequently stretched on a mandrel bar through tandem-arranged ring dies to produce the final tube dimensions. This so-called push bench process in its modified form has remained viable to this very day.

Once the various patents expired, the following decades saw the original manufacturing processes modified to some extent, and the individual forming facilities combined in a wide range of different

constellations. Depending on the tube size and production mix, and also the availability of starting material, rolling mill facilities of comparatively disparate design were developed and built in the course of time.

Moreover, as a result of the further development of individual forming facilities, new processes were also invented, such as the cross roll piercing mill derivatives in the form of the Assel and Diescher processes, or the tube extrusion process derived from the Ehrhardt press.

2.1 Pierce and pilger rolling process

The pierce and pilger method for the production of seamless pipe is also referred to as the Mannesmann process after its inventors, the Mannesmann brothers. Today it is employed for outside diameters from approx. 60 to 660 mm and wall thicknesses from 3 to 125 mm. Depending on the ratio of wall thickness to diameter and the weight of the starting ingot, pipe lengths of up to 28 m can be manufactured by this technique. Pipe diameters above the rolling range indicated can also be produced by expansion. To this end, the largest rolled pipes are reheated and then expanded either by pulling through a plug – a process often performed in several passes to gradually increase the outside diameter – or by rolling on a becking mill. Whichever of the two processes is employed, the wall thickness is, of course, also reduced.

With small pilger mills for manufacturing the lower size range, the two-stage rolling process is still employed today. The starting material takes the form of round rolled steel blooms, although round ingots are still frequently used. Round conticast billets measuring between 100 to approx. 300 mm in diameter are also being increasingly employed.

The input rounds are matched in terms of their diameter, length and weight to the required final pipe dimensions. Passing through various temperature zones in a rotary hearth furnace – usually gas or oil fired – the stock is heated to rolling temperature. This generally lies in the range 1250 to 1300 °C or, depending on the material composition, slightly lower. After removal from the rotary hearth furnace and subsequent descaling of the surface by high-pressure water jetting, the rounds are fed to the cross roll piercing mill where they are pierced to produce a thick-walled hollow shell. In this process, the material is elongated to between 1.5 and 2 times its original length, while the reduction in cross section lies between 33 and 50 %.

The piercing mill features two specially contoured work rolls which are driven in the same direction of rotation. Their axes are inclined by approx. 3 to 6° in relation to the horizontal stock plane. Generally, the roll gap is closed by a non-driven support roll at the top and a support shoe at the bottom. Located at the centre of the roll gap is a piercing point which functions as an internal tool and is held in position by an external thrust block via a mandrel.

Fig. 3 shows a schematic representation of the cross roll piercing process sequence. The round is thrust into the mill, "bitten" by the tapered inlet section of the rolls and formed in a spiral motion over the piercing mandrel to produce the thick-walled hollow shell. Initially, the stock is necked down in the horizontal plane while expanding in the vertical plane. Once the mandrel engages in the newly formed mouth of the workpiece, the material is continuously deformed as it passes between the rolls and over the mandrel (Section A-A). Fig. 4 shows a modern piercing mill viewed from the delivery end.

Following the cross roll piercing operation, the thick-walled hollow shell is rolled out in the same heat in the pilgering stand to produce the finished pipe. The elongation ratio during the pilgering process lies between 5 and 10, and is accompanied by a reduction in cross section of approx. 80 to 90 %.

The pilgering stand has two rolls, sometimes referred to as dies due to their forging action, with a tapered pass around their circumference. The rolls rotate counter to the ultimate direction of material flow. The pass design of the pilger rolls is shown in Fig. 5. The work pass encompasses between 200 and 220° of the "die" circumference and consists of the tapered inlet, an even, cylindrical polishing pass and a diverging pass which blends into a larger clearance for releasing the workpiece.

Fig. 6 shows a schematic representation of the pilger rolling sequence. The hollow shell is pushed over a lubricated cylindrical mandrel, the diameter of which roughly corresponds to the desired inside diameter of the finished tube. The shell-and-mandrel assembly is then fed into the pilger rolls by a feeder. As the hollow shell is "bitten" by the tapered inlet of the work pass, a small wave of material is
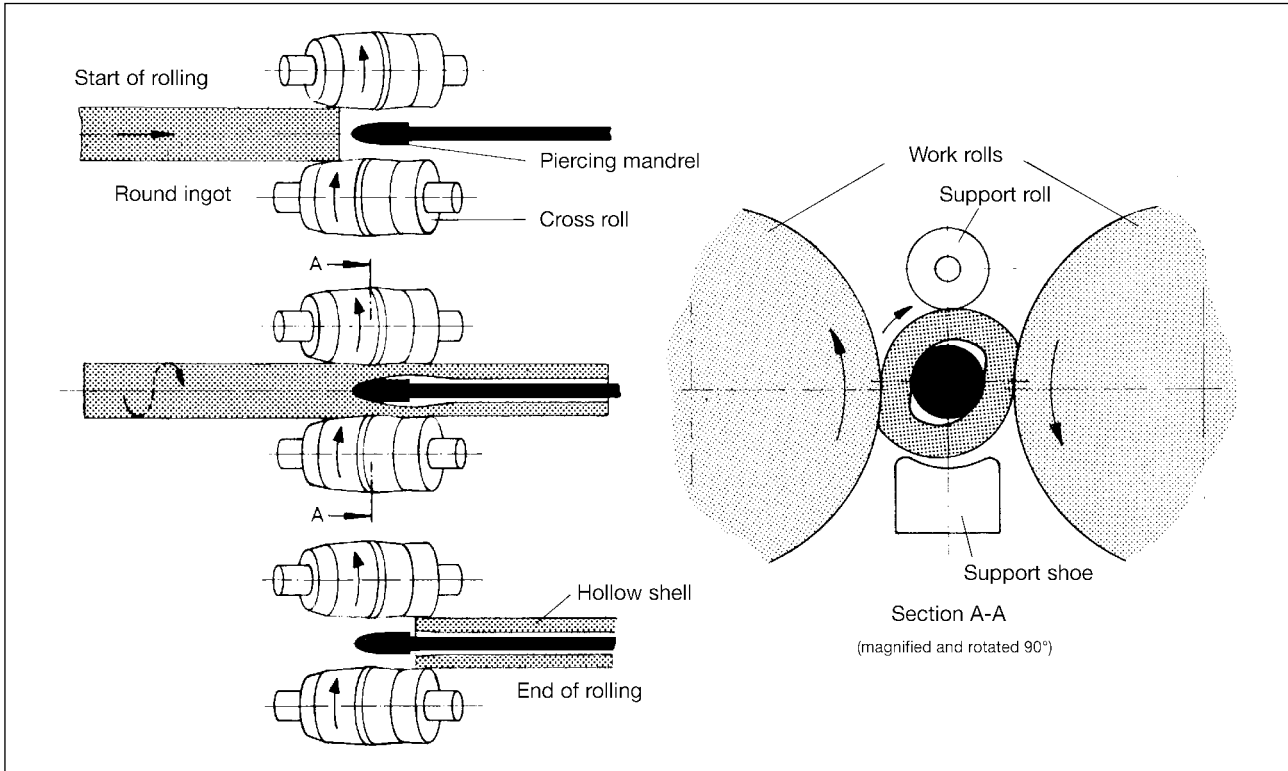
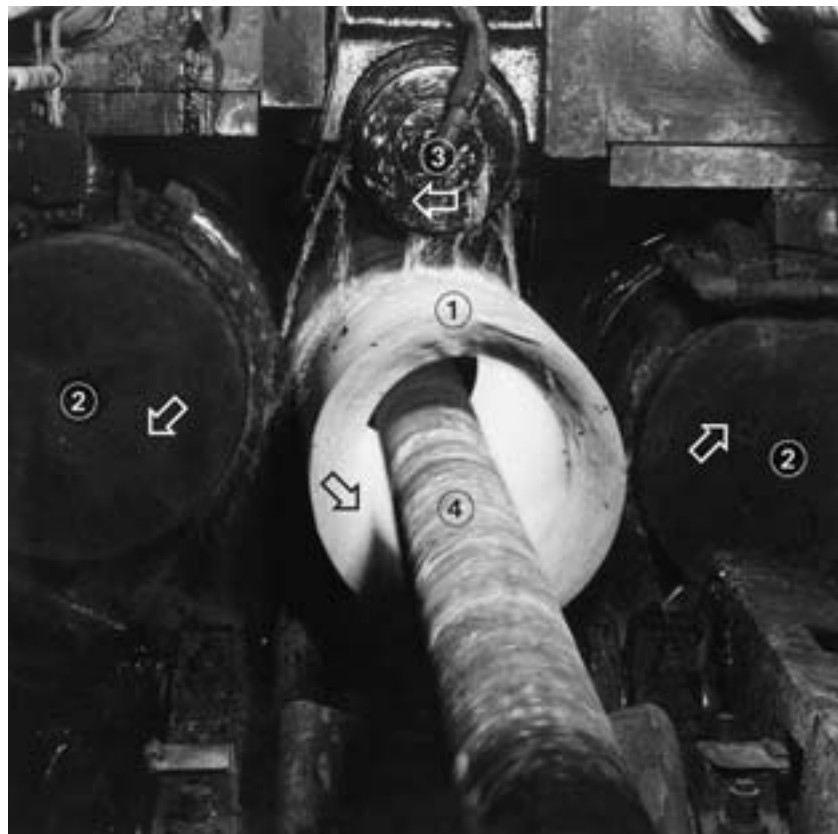Fig. 3: The piercing process as performed on a Mannesmann cross roll piercing mill

Fig. 4: Piercing of an ingot in the Mannesmann cross roll piercing mill (delivery end)
(Works photo: VALLOUREC & MANNESMANN TUBES)
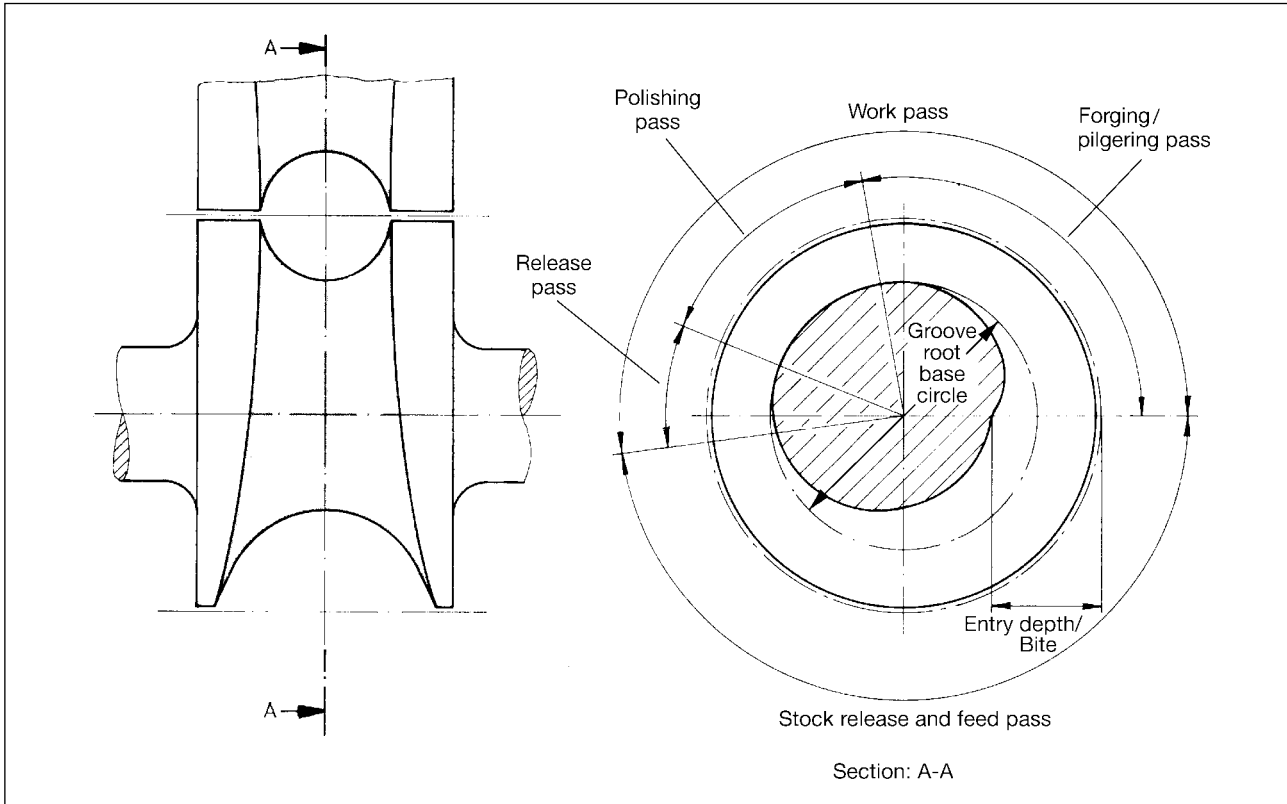1 Hollow shell; 2 Work rolls; 3 Support roll; 4 Mandrel bar with piercing mandrel

Fig. 5: Front and cross-sectional views of a pilger roll

pressed away from its external surface and then forged to the desired wall thickness by the smoothing portion of the work pass acting on the mandrel. Following the direction of rotation of the rolls, the mandrel together with hollow shell in which it is located is pushed backward, i.e. against the rolling direction, until the release pass comes into play, so releasing the stock. During this backward motion (rolling cycle), air compression energy is stored in the pneumatic cylinder of the feeder. As the hollow shell clears the release pass, the compression energy is utilized in order to feed the mandrel and hollow shell back to the original rolling position. A helical spindle simultaneously rotates the stock by 90° and a hydraulic system pushes the feeder forward by a length equivalent to the previously rolled hollow shell volume. Meanwhile, the rolls have rotated to the point where the stock is once again bitten by the inlet portion of the work pass, with a new wave of material being pushed over the shell surface in a repetition of the previous cycle. Because the stock has been rotated by 90°, any ridge of material produced by the roll gap is now located at the groove root for the next cycle, so that it too is then formed into the desired contour of the tube. Thanks to the fact that every area of the material is rolled at least twice in this way, the resulting tube exhibits both a uniform wall thickness and excellent concentricity.

This stepwise rolling-cum-forging process with its recurring backward and forward motion was given the name "pilger" (German for "pilgrim") owing to its similarity with a famous dancing procession associated with the town of Echternach in which participants take three steps forward and two steps back in their "pilgrims' progress".

Once the pilgering process is completed, the finished tube is stripped from the mandrel. The remaining unworked part of the hollow shell, the so-called pilger head, is cut off from the tube body by a hot saw, as is the leading end of the tube if this exhibits any unevenness or distortion. The tube is then fed into a sizing or a reducing mill, having first been reheated if necessary.

The sizing mill serves to produce a precise outside diameter and further improve concentricity. It usually consists of three stands with two-high or three-high roll arrangements. The work rolls form a closed pass, with – in multi-stand configurations – each stand pass being offset at an angle to the previous pass.
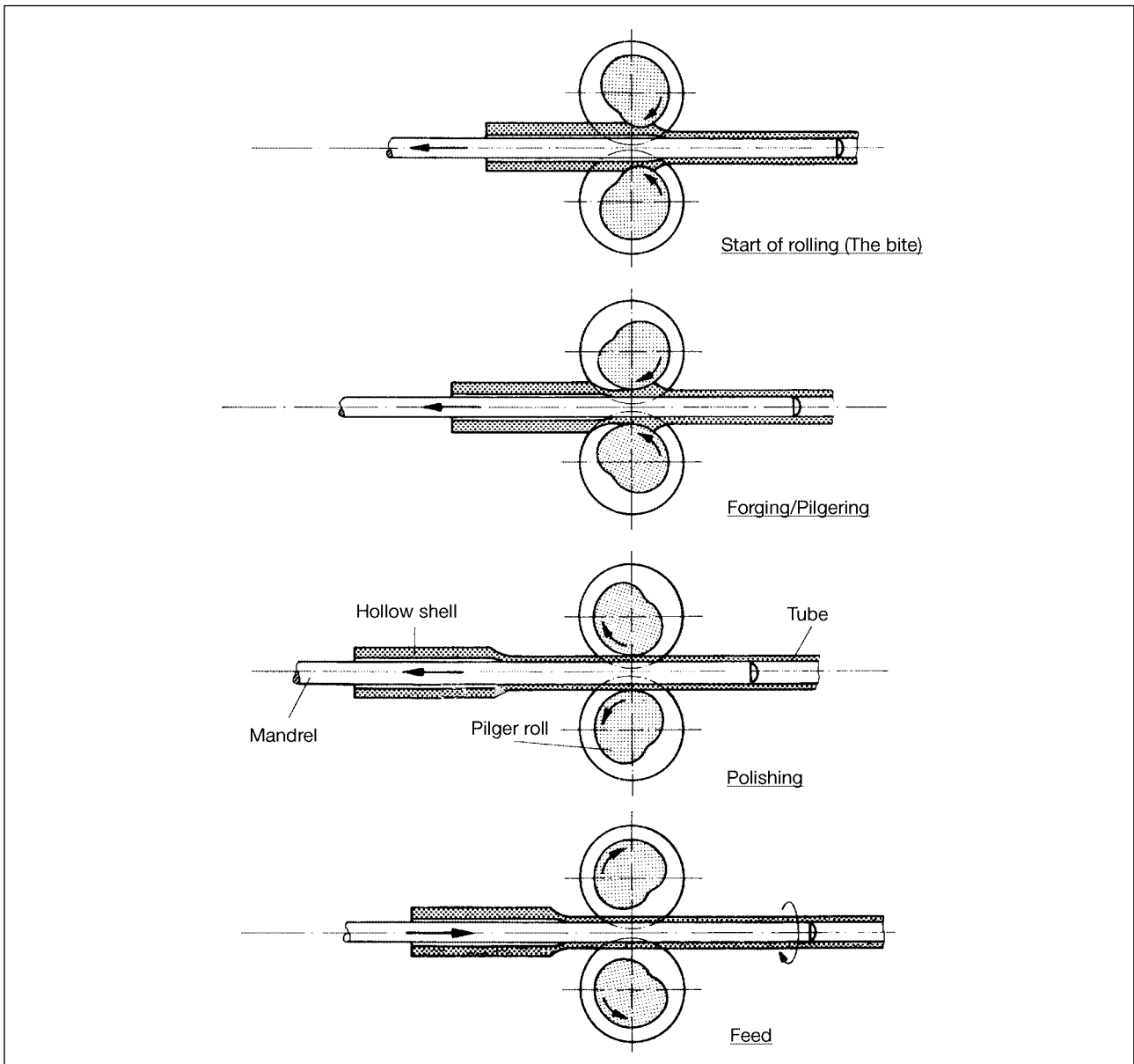
Fig. 6: The pilger rolling process

In the reducing or stretch-reducing mill, the outside diameter of the tube is substantially reduced with the wall thickness being slightly increased or decreased in the process. Depending on the product mix, mills with between 5 and 28 stands are used for this purpose.

Following the last forming operation, the finished tubes/pipes are cooled to ambient temperature on a cooling bed and, after a dimensional check, collected in cradles for transfer to the finishing department. The processes performed there include machining of the tube/pipe ends, straightening, and hydrostatic testing. Further tests and examinations may then follow in accordance with customer specifications.

Fig. 7 shows the principal arrangement and process sequence of a pierce and pilger rolling mill.

The design of heavy pilger mills for the production of large pipe diameters is also essentially as indicated above. However, the starting material takes the form of a polygonal ingot with edge dimensions ranging from 300 to 750 mm and weights often in excess of 5 tonnes. Following heating to rolling temperature in a rotary hearth furnace, the ingot is initially inserted in a round die on a usually vertical piercing press. The solid ingot is then pierced by a cylindrical punch of approx. half the diameter of the die, to produce a hollow shell with a closed base. The next operation involves reducing the wall
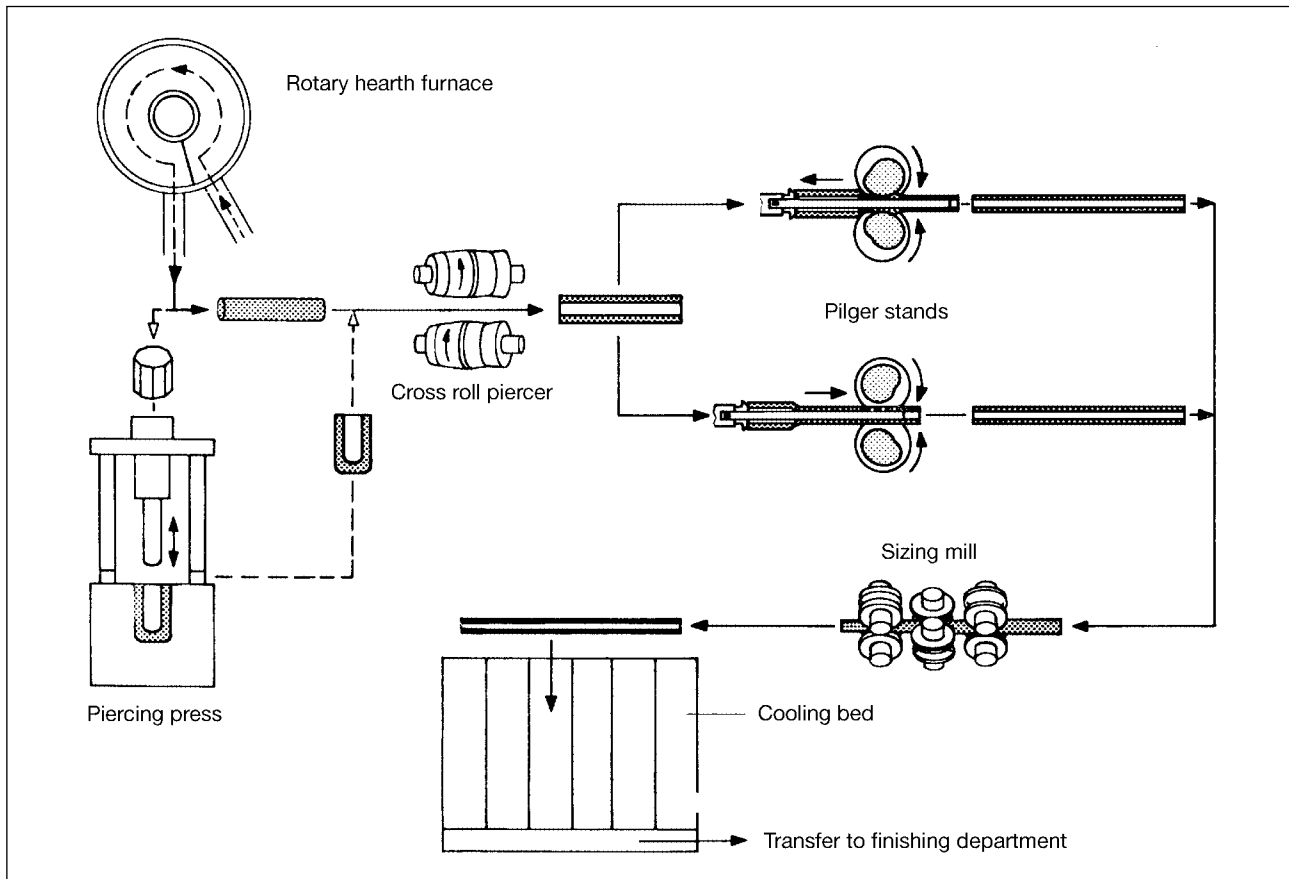
Fig. 7: Basic arrangement of a pierce and pilger mill

thickness, accompanied by a small degree of elongation, in the cross roll mill. During this process the closed end is also pierced. In the same heat, the hollow shell is then elongated in the pilger mill, followed by sizing on a single-stand or multi-stand sizing mill.

2.2 Plug rolling process

The plug rolling process is also known as the Stiefel process – particularly in German speaking countries – after its inventor, and by the name "automatic mill" in English-speaking countries. Seamless tubes in the diameter range from approx. 60 to 406 mm with wall thicknesses from approx. 3 to 40 mm are produced nowadays on plug mills. The usual wall thickness range lies between the limits of normal wall thickness to DIN 2448 up to four times normal wall thickness as a function of outside diameter. The largest mill lengths of the finished tube range between 12 and 16 m.

On small and medium mills, the forming process from the solid material to the tube is again performed in two stages, with rolled rounds or, more recently, continuously cast round billets/blooms with diameters between 100 and 300 mm as the starting material. In contrast to the pilgering process, the bloom diameter corresponds roughly to the tube diameter to be manufactured from it, and consequently the bloom lengths are larger at between 1000 and 5000 mm.

The blooms are heated in a rotary hearth furnace to a forming temperature of approx. 1280 °C. Following high-pressure water jet descaling, the bloom is pierced in the cross roll piercing mill to produce a thin-walled hollow shell which is elongated to between 3 and 4.5 times its original length, corresponding to a deformation level of between 65 % and 75 %.

The cross roll piercing mill type – also known as a barrel piercer (Fig. 8) – used in the plug mill differs considerably in design and function from the cross roll piercing mill used in conjunction with pilger mills. The two driven work rolls feature a biconical pass, and their axes which are likewise arranged parallel to the stock, are inclined to the horizontal by between 6 and 12°. The gap between the work rolls is
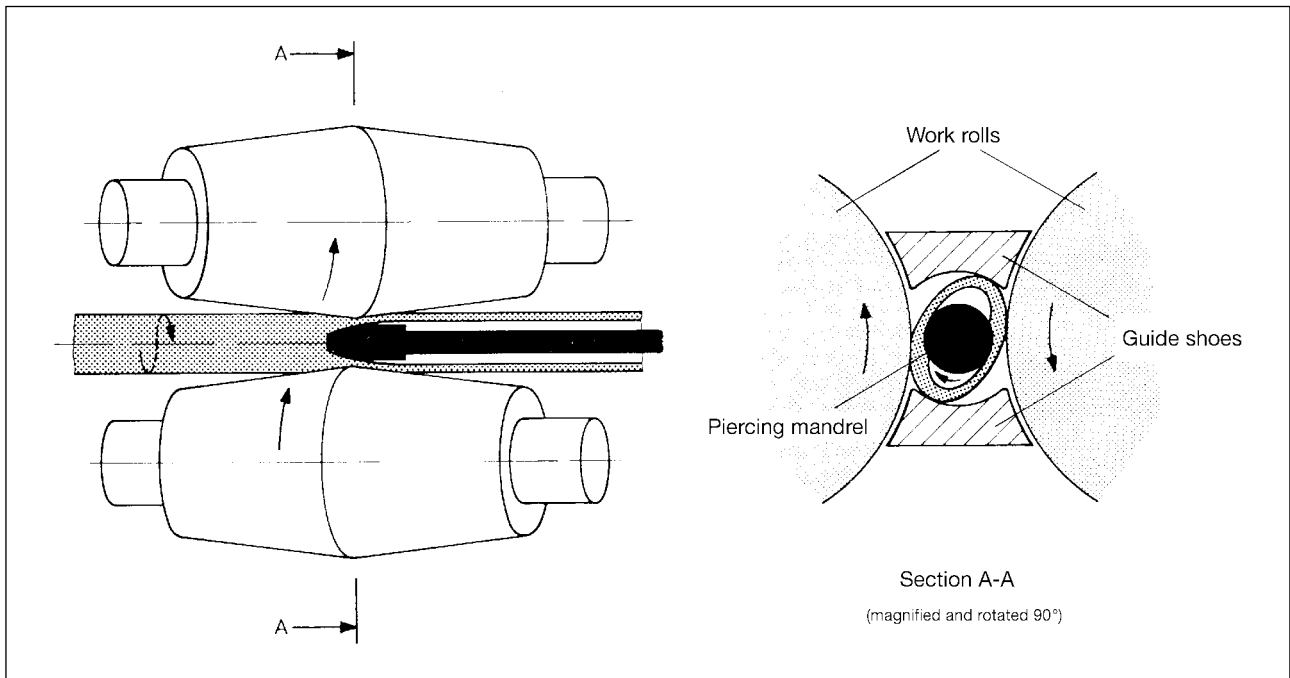
Fig. 8: Method of operation of the cross roll piercer (barrel-type)
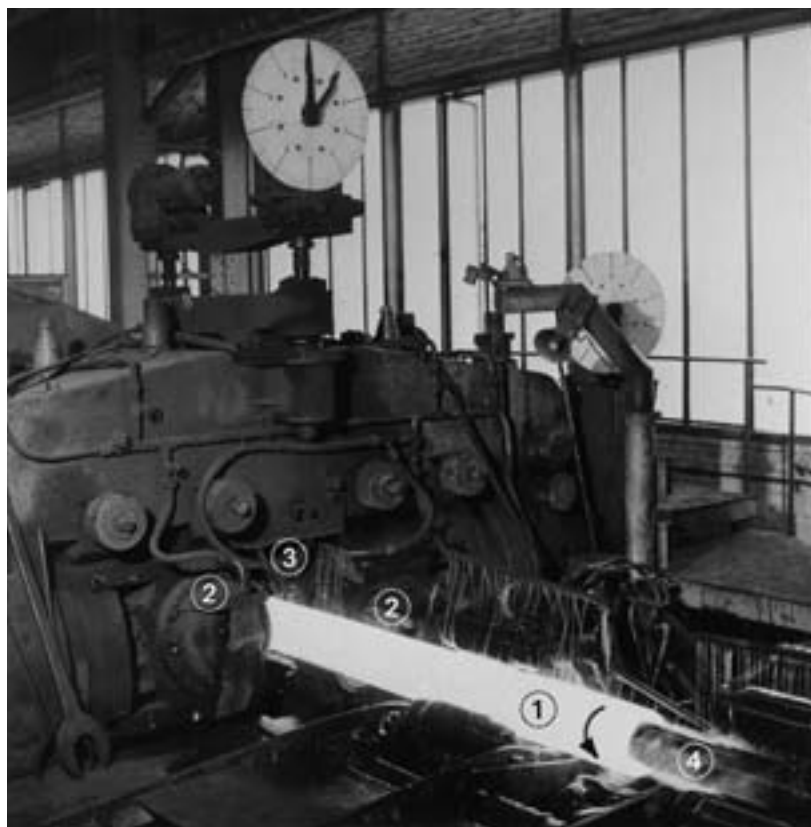

Fig. 9: Bloom piercing in the barrel-type cross roll piercer (viewed from the delivery end)
(Works photo: VALLOUREC & MANNESMANN TUBES)
1 Hollow bloom; 2 Work rolls; 3 Guide shoe; 4 Mandrel bar with piercing mandrel

extensively closed by a top and a bottom guide shoe. These guide shoes introduced by R.C. Stiefel contribute to the elongation process by acting as stationary rolls, so enabling the production of a relatively thin-walled hollow bloom. Again, the stock follows a helical line as it passes through the roll gap, so enabling the piercing mandrel, acting as an internal tool, to displace the material more effectively. Owing to the relatively large angle of roll inclination, and higher rolling speeds, stock exit speed in the case of barrel-type piercers is considerably faster than in Mannesmann piercing mills. This is necessary owing to the cycle time of the downstream plug stand.

Fig. 9 shows the exit end of a barrel-type cross roll piercer.

In plug mills employed for the manufacture of large tube diameters, arranged between the barrel-type piercer and the plug stand is frequently a second piercing mill of the same design. This is often described as an "elongator", the purpose of which is, in particular, to extend the inside and outside diameters and to further elongate the hollow shell.

In recent times, however, these two piercing mills have been replaced by heavy-duty plug mills featuring just one cone piercing unit (Fig. 10). Here again, the work rolls feature a biconical design. They are each angled at approx. 30° to the hollow bloom axis and inclined at approx. 10 to 12° to the horizontal. The roll gap is closed by means of two side discs which are also driven. This arrangement results in higher degrees of elongation (up to 6-fold), increased diameter expansion, and also faster hollow shell exit speeds (up to 1.5 m/s). Fig. 11 shows a modern cone piercing mill viewed from the inlet end with the one drive unit visible on the top right side of the photo.

The process of forming the hollow shell into the finished tube is performed in the same heat in the downstream plug stand with an approximately two-fold elongation (50 % cross sectional reduction), with two rolling passes normally being applied.
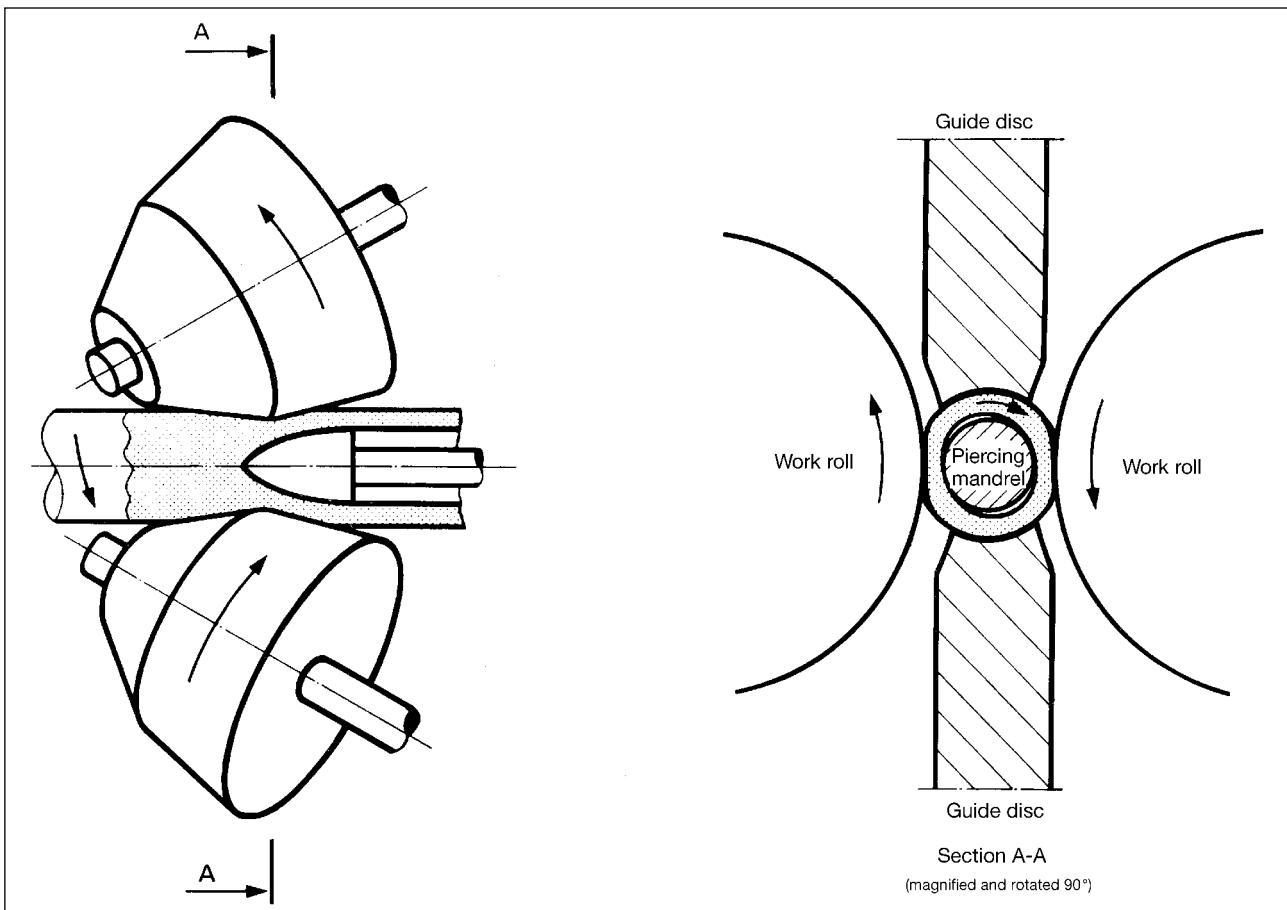

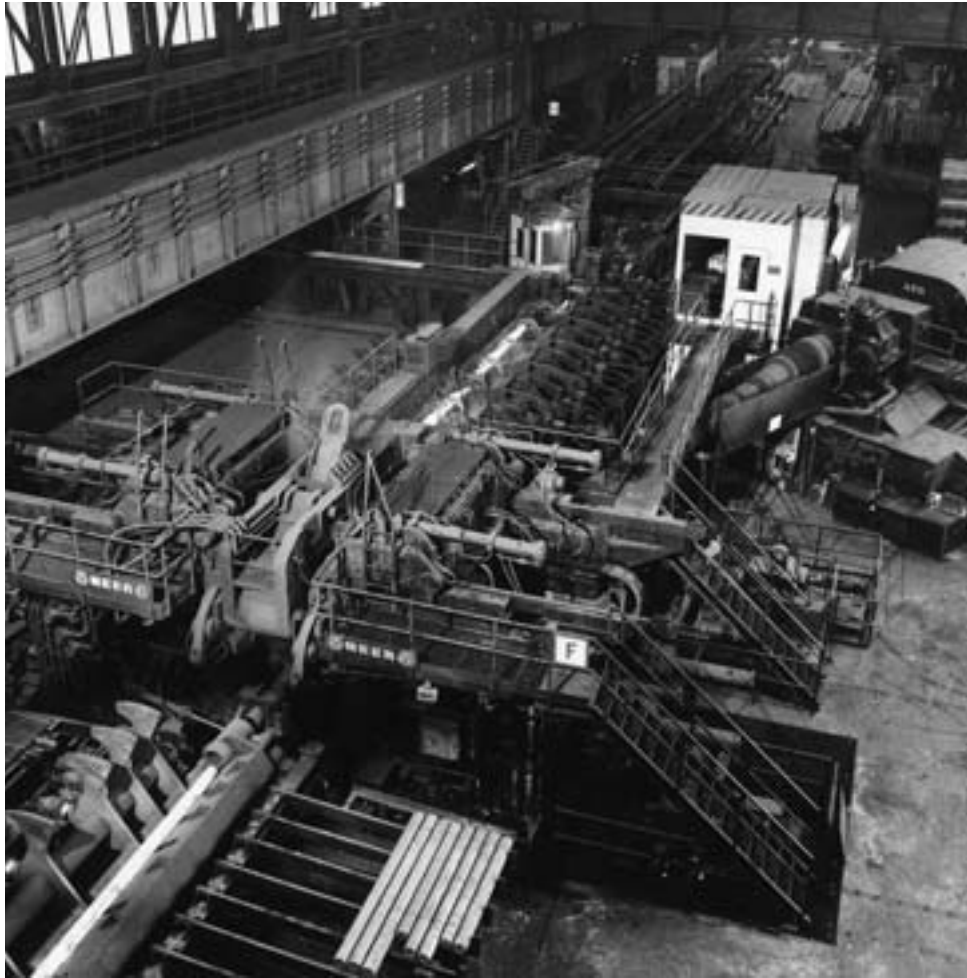Fig. 10: Diagrammatic representation of a cone piercing mill

Fig. 11: Modern cone piercing mill (viewed from the inlet end)
(Works photo: VALLOUREC & MANNESMANN TUBES)

In the plug stand are mounted the two cylindrical work rolls which are provided with approximately circular grooves, and also the two separately driven stripper rolls. A plug, which is located at the roll pass centre, is held in position by a mandrel supported by a thrust block located downstream of the rolling stand. The resultant annular gap between the rolls and plug corresponds to the finished tube wall thickness.

Fig. 12 shows a diagrammatic representation of the rolling process. The hollow shell is thrust into the mill by means of a pneumatic pusher. It is then gripped by the rolls and rolled over the plug causing a reduction in both outside diameter and wall thickness. On completion of the rolling operation, the mandrel remains inserted in the pipe while the plug falls through the gap into a tooling and changing device. In order to return the tube to the pass entry side, the upper work roll is raised and, at the same time, the stripper rolls are set in rotation. After the tube has turned through 90°, a second roll pass is initiated using a plug with an approx. 1 to 3 mm larger diameter, and the tube is returned to the front end of the rolling stand.

Figures 13 and 14 show the plug stand in a large plug rolling mill.

With the tube wall now having been rolled to the desired thickness, the tube is transferred without reheating to a reeler. There, between two barrel-shaped cross rolls with a plug working as an internal tool, it is rounded and smoothed in a process which leads to a further slight diameter increase. Subsequently, the tube is passed through a multi-stand sizing mill where the outside diameter is rolled to a defined dimension. The finished tubes are then placed on the cooling bed. After a subsequent straightening operation, the tube is transferred to the finishing department for further processing and testing.

Fig. 15 shows a diagrammatic representation of the structure and operating sequence of a plug mill.
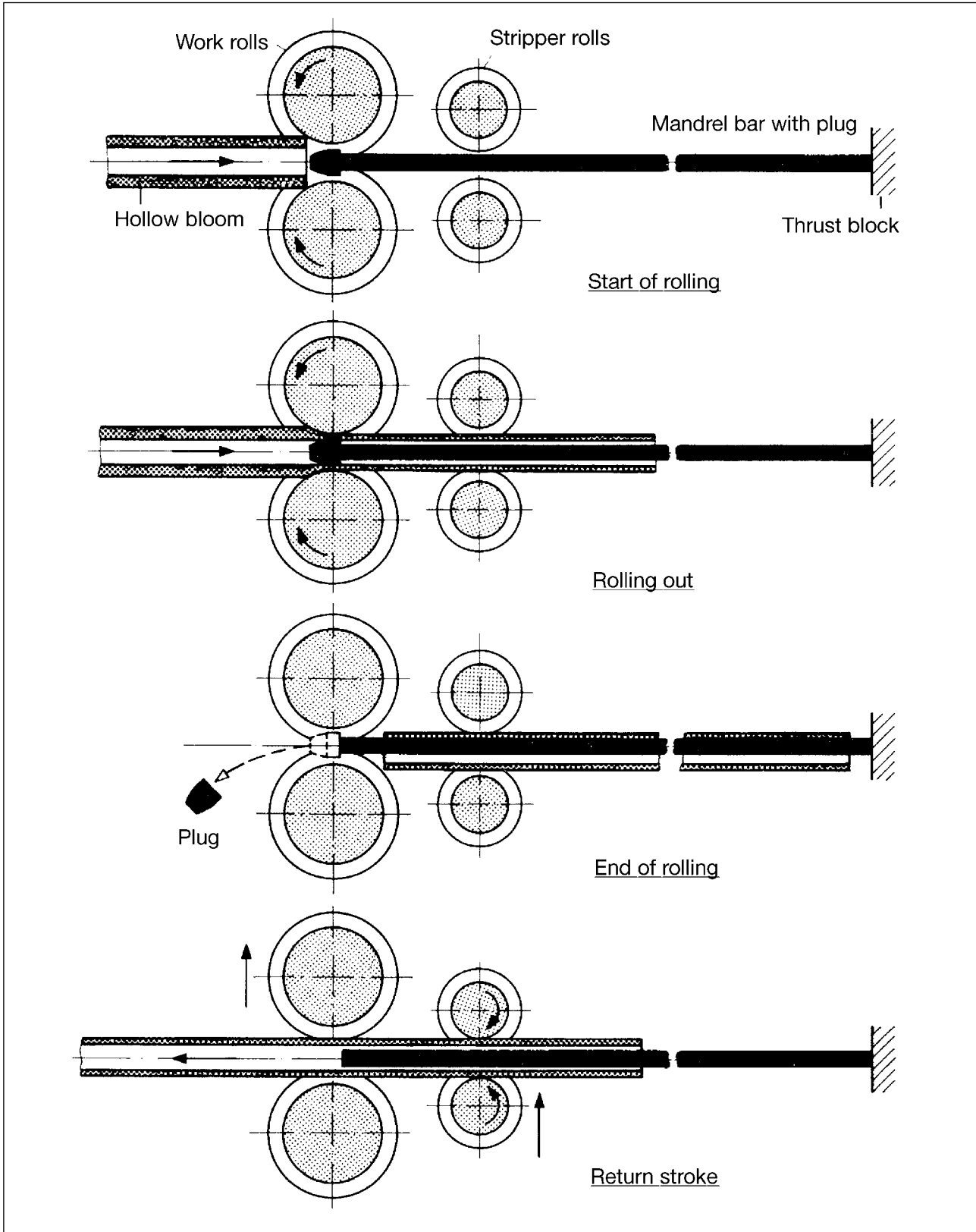
Fig. 12: Operating sequence in the plug rolling process

In some cases – and particularly for tube in the mid-dimensional range – the facility downstream of the plug mill proper may take the form of a reducing or stretch-reducing mill with reheating furnace, instead of the sizing mill, to enable better program mix adaptation (see also sections dealing with the pilger mill and continuous mandrel rolling mill).
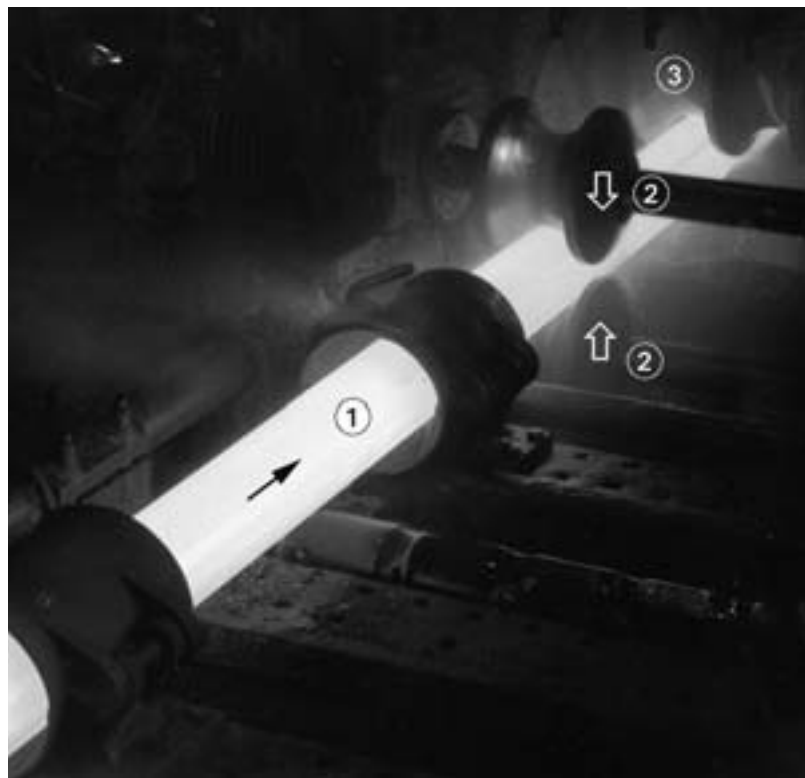
Fig. 13: Two-high plug mill (inlet end)
(Works photo: VALLOUREC & MANNESMANN TUBES)

Fig. 14: Two-high plug mill (delivery end - stripper rolls engaged)
(Works photo: VALLOUREC & MANNESMANN TUBES)
1 Hollow bloom; 2 Stripper rolls; 3 Work rolls
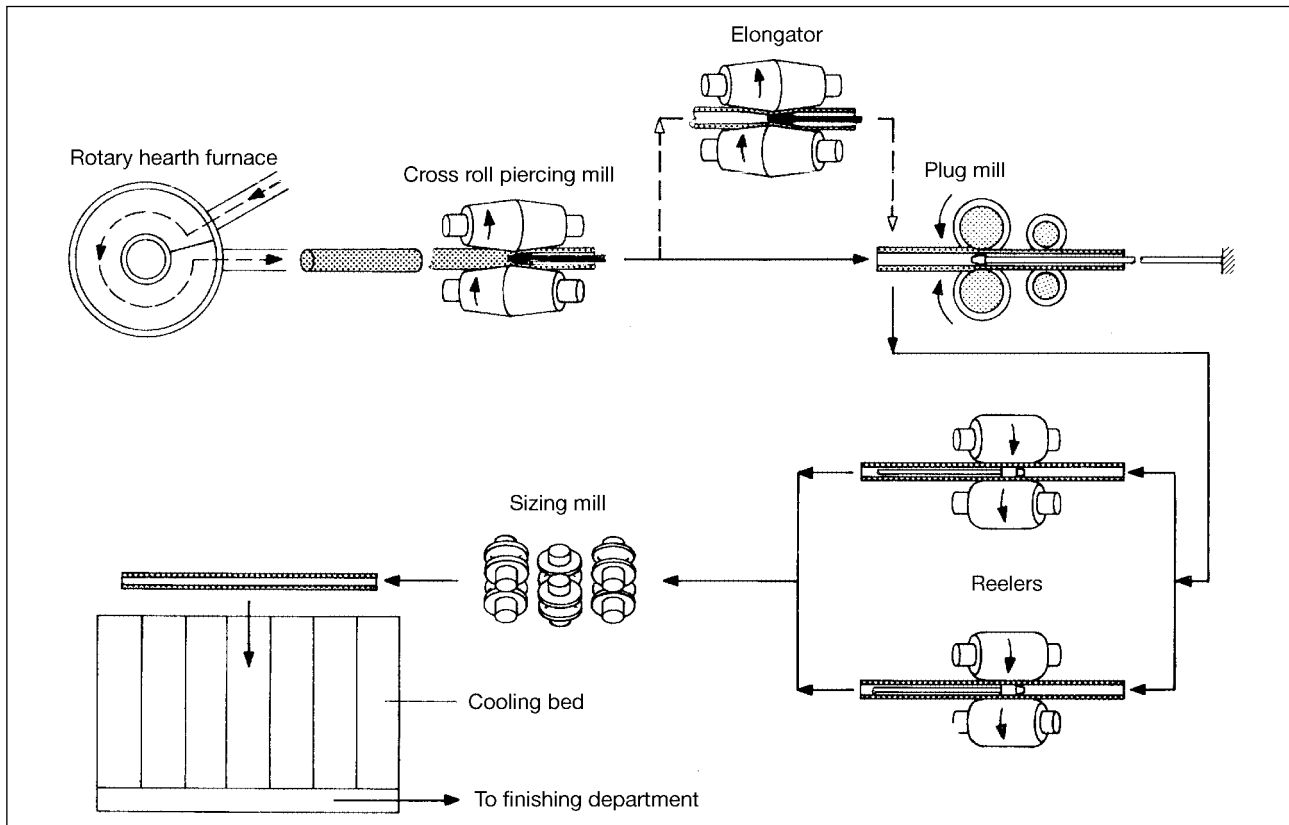
Fig. 15: Diagrammatic representation of a plug mill

2.3 Continuous mandrel rolling process

The continuous mandrel rolling process also came into being around the turn of the century – this time as a result of arranging in tandem several graduated rolling passes in a series of rolling stands to form a rolling line. This mill type elongated the hollow shell pierced in the piercing mill over a floating mandrel bar acting as the internal tool to produce the finished tube.

During the early period of development of this process, problems of material flow coordination tended to occur between the various stands, with the different rates of roll wear arising from stand to stand further exacerbating the situation. Only with the advent of modern drive and control technology has the continuous mandrel rolling mill been able to develop over the last few decades into today's high-performance production process, one that is widely applied for seamless tube in the size range from 60 to 178 mm outside diameter. In the more modern mills of this type, the practice has been adopted whereby only one or two hollow shell/tube blank sizes are produced in the continuous rolling train, with the downstream stretch-reducing mill finish-rolling them down – sometimes to sizes as low as 21 mm OD. The wall thicknesses produced in this process range from 2 to 25 mm, depending on the outside diameter.

The starting material used takes the form of round billets, either rolled or, more likely nowadays, continuously cast down to diameters of 200 mm. These are charged in lengths of up to 5 m into the rotary hearth furnace where they are heated to the rolling temperature of approx. 1280 °C. Following high-pressure water descaling, the solid billet is pierced to produce a thin-walled hollow shell in a Stiefel-type cross roll piercing mill (automatic mill). In this process, the stock is elongated to between 2 and 4 times its original length, corresponding to a reduction in area of 50 to 75 %.

Owing to the high throughput rates required, the work rolls are inclined to the stock axis by between 10 and 12°. Nowadays, driven guide discs – so-called Diescher discs – are employed in place of the previously used guide shoes in order to prevent frictional losses and thus to give a further increase in capacity.

Fig. 16: Continuous mandrel mill (delivery end)
(Works photo: VALLOUREC & MANNESMANN TUBES)
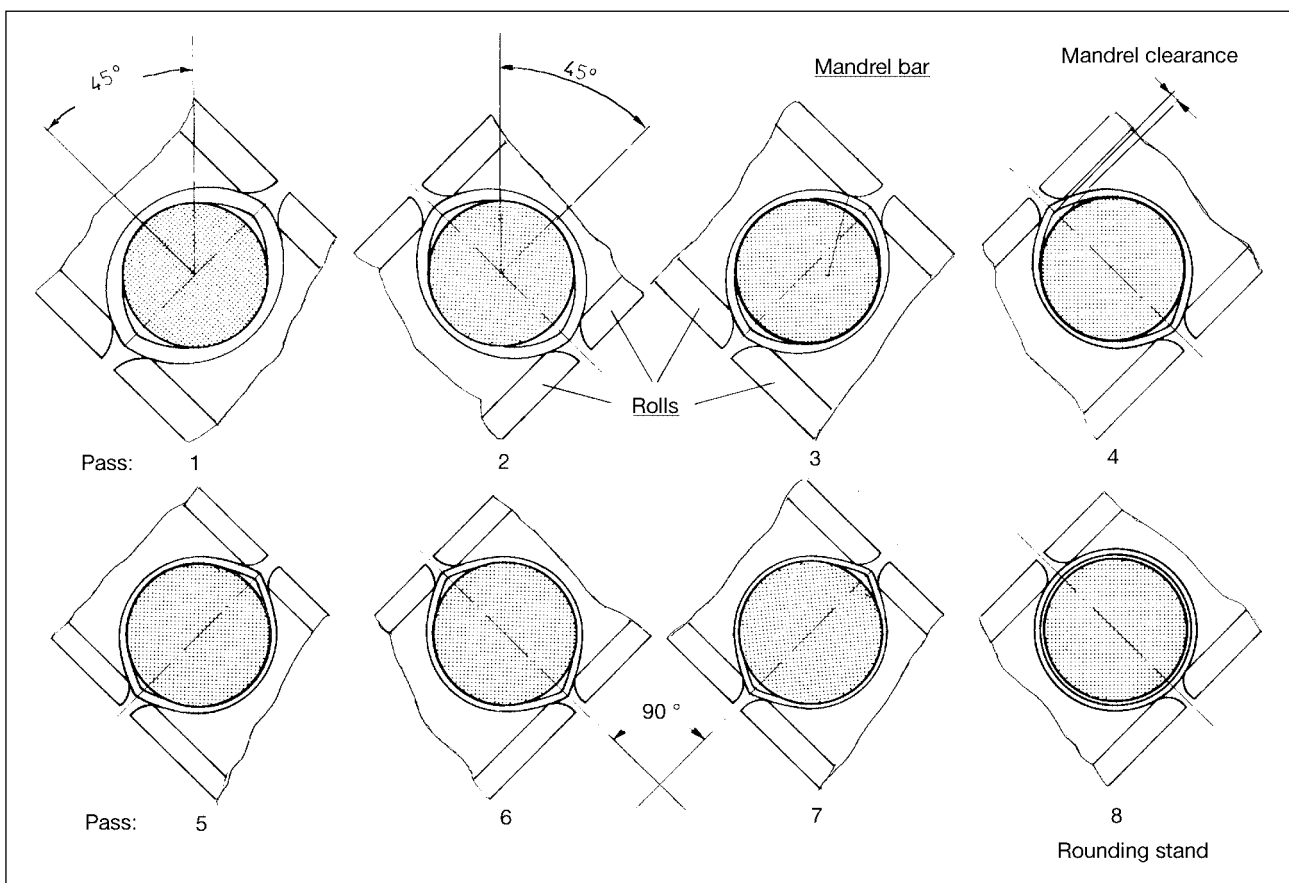1 Pipe; 2 Stand changer; 3 Rolling stand

Fig. 17: Roll arrangement and pass schedule of a continuous mandrel mill

The hollow shell produced in the cross roll piercer is subsequently rolled out in the continuous rolling mill over a mandrel bar without reheating to produce the continuous tube. In this process, a maximum elongation of 400 % is achieved, corresponding to a reduction in area of 75 %.

Continuous mandrel rolling mills consist of between 7 and 9 closely arranged in-line rolling stands which are offset by 90° to their adjacent neighbours and inclined at 45° to the horizontal (Fig. 16). Each stand features its own variable-speed drive motor. The circumferential speeds of the rolls are adjusted to one another in accordance with the reductions in cross-sectional area, so as to ensure that there are no appreciable tensile or compression forces acting on the stock between the stands. There is a certain clearance between the mandrel bar and the pipe material in the region of the flanks of the oval pass formed by the two-high rolls (Fig. 17). In the last round pass, this clearance is evenly distributed around the entire circumference in order to enable the tube to be stripped from the mandrel bar.

Prior to commencement of the rolling operation, the mandrel bar is inserted into the hollow shell; then, once it has reached a certain position, the shell/mandrel bar assembly is inserted into the continuous mandrel rolling mill. The stock is gripped by the rolls and elongated from stand to stand as the ever-smaller roll passes act on the mandrel bar. As the speed with which the stock travels through the rolling stands increases, so does that of the mandrel bar.

Finally, at a point adjacent to the rolling line, the mandrel bar is removed from the tube, cooled and prepared for the next rolling operation. As a rule, between 8 and 10 mandrel bars of the same size are in circulation at any one time.

Tubes of up to 30 m in length can be manufactured in continuous rolling mills of this type, in which case the requisite mandrel bar length is approx. 25 m.

Fig. 18 shows the structure and process sequence encountered in a continuous mandrel rolling mill.

In more recent times, rolling practice in mills of this type has reverted to the use of controlled, i.e. constrained, instead of freely floating mandrel bars. The advantage of this process variant lies in the fact that substantially shorter and fewer mandrel bars are required, and the tube is rolled from the bar; owing to favourable forming conditions, larger tube outside diameters (up to a maximum of 406 mm) can be produced in tube lengths up to 30 m.

This version of the continuous mandrel rolling process is also referred to as simply the MPM (multi-stand plug mill) and is becoming increasingly popular for new plant investment throughout the world in place of larger plug mills.
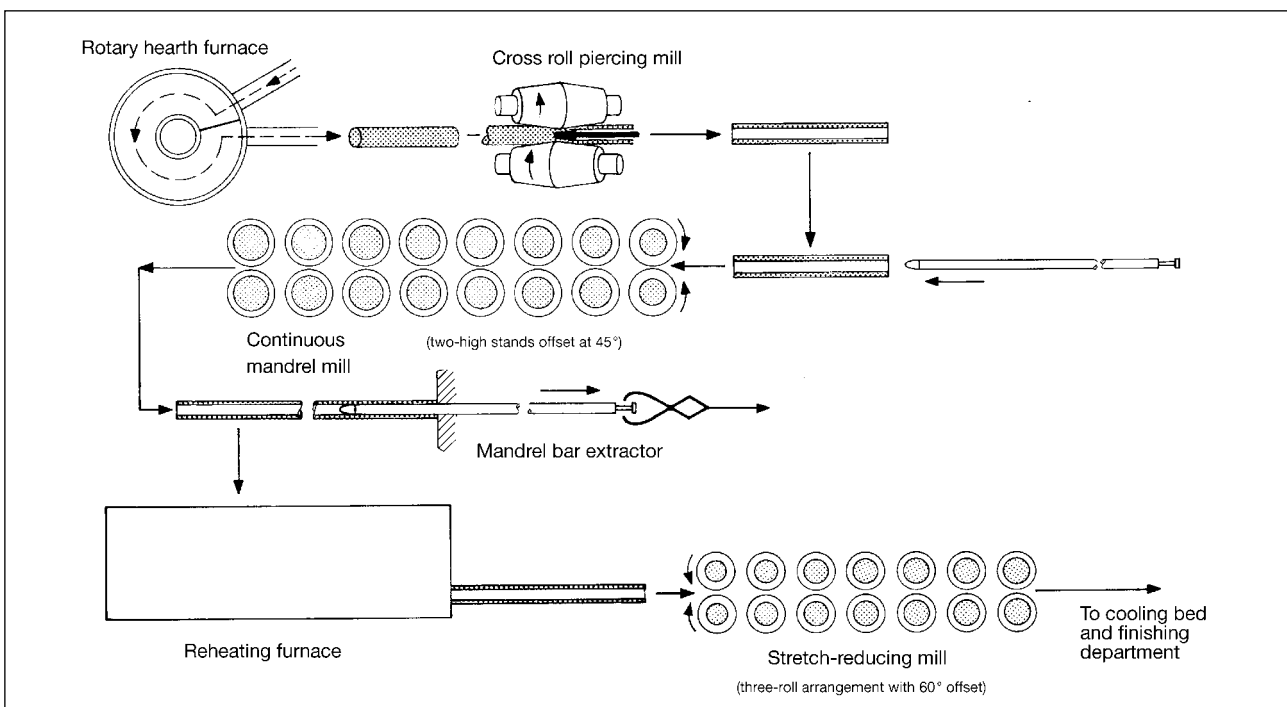

Fig. 18: Diagrammatic representation of a continuous mandrel mill
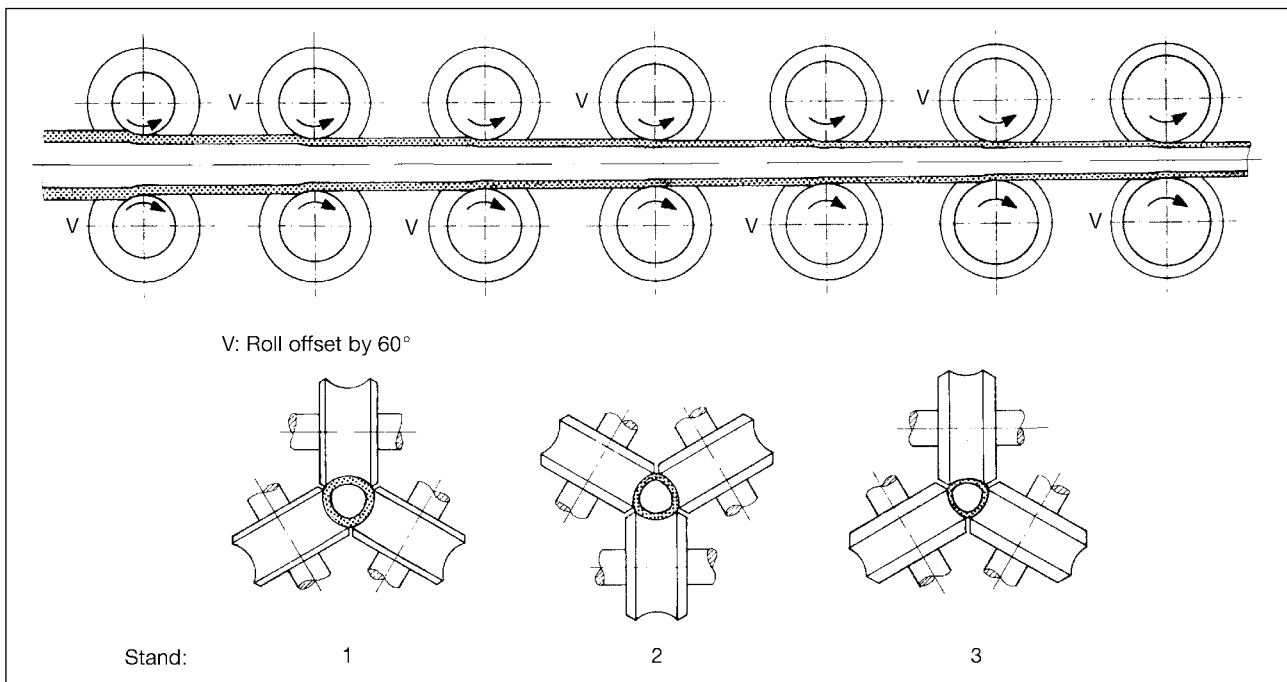
V: Roll offset by 60°

Stand: 1 2 3

Fig. 19: Diagrammatic representation of the stretch-reducing process

In the course of this continuous rolling process up to extraction of the mandrel bar, the tube temperature falls to approx. 500 °C. Consequently, it is fed to a reheating furnace where it is held for between 10 and 15 minutes in order to enable it to regain a forming temperature of between 950 and 980 °C. As a rule, natural gas or oil-fired walking beam furnaces are used in order to ensure uniform temperature distribution.

On exit from the reheating furnace, the tube is subjected to high-pressure water descaling and rolled to its finished dimensions in the downstream stretch-reducing mill where no internal tool is used. This can involve further elongation up to ten times the incoming length, depending on the final dimensions required.

Stretch-reducing mills can contain anything between 24 and 28 stands or more, all arranged in a close in-line formation. Each stand nowadays usually has its own variable-speed drive and is fitted with three rolls of the smallest possible diameter. The three rolls together form a pass which is offset and becomes progressively smaller from stand to stand (Fig. 19).

In accordance with the ever increasing tube length and accompanying reduction in the outside diameter and wall thickness of the tube, the circumferential speed of the rolls continually increases from the inlet to the exit end of the rolling train.

Depending on the number of stands installed, various diameters of finished tube can be produced by such an arrangement. By altering the longitudinal tension between the individual stands, it is possible not only to reduce the diameter but also achieve a specific level of wall thickness reduction. This longitudinal tension is achieved by disproportionately increasing the roll circumferential speed from one stand to the next to a value in excess of that normally required to compensate for the reduction in area. With each stand equipped with its own drive and the wide control range available in today's modern motors, it has become possible to manufacture finished tubes of various wall thicknesses from a single ingoing tube blank size.

In the smaller size range, tube lengths of up to 150 m in length can be manufactured, with exit speeds at up to 15 m/s.

Special devices enable modern stretch-reducing rolling mills to undergo a stand change, and thus conversion to another tube diameter, in just a few minutes. For this reason, the more time-consuming size change required in the case of modern continuous mandrel rolling mills can be eliminated and
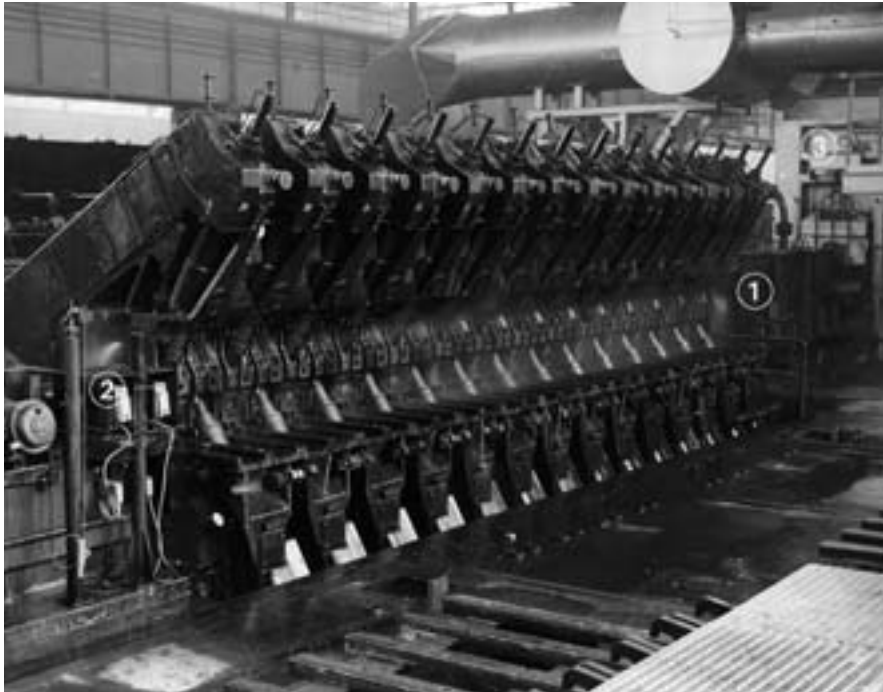
Fig. 20: 28-stand stretch-reducing mill
        (Works photo: VALLOUREC & MANNESMANN TUBES)
        1 Inlet; 2 Delivery end; 3 Reheating furnace

production limited to just one tube blank diameter. The stretch-reducing mill then performs all the size changes.

Fig. 20 shows a modern stretch-reducing mill.

2.4 Push bench process

This process is also known as the rotary forge process, and – in Germany – after the name of its inventor, as the Ehrhardt process. It is employed for the manufacture of tube in the diameter range from approx. 50 to 170 mm with wall thicknesses from 3 to 18 mm and lengths up to 18 m. Modern push bench plants usually only produce one (large) hollow bloom size, leaving a downstream stretch-reducing mill to convert this into all the usual tube dimensions down to a smallest outside diameter of approx. 20 mm.

The starting material used may be square, octagonal or round blooms or billets, either rolled or of continuously cast material. Following heating to forming temperature in a rotary hearth furnace, these are placed in the cylindrical die of a piercing press. A piercing mandrel then forms them into a thick-

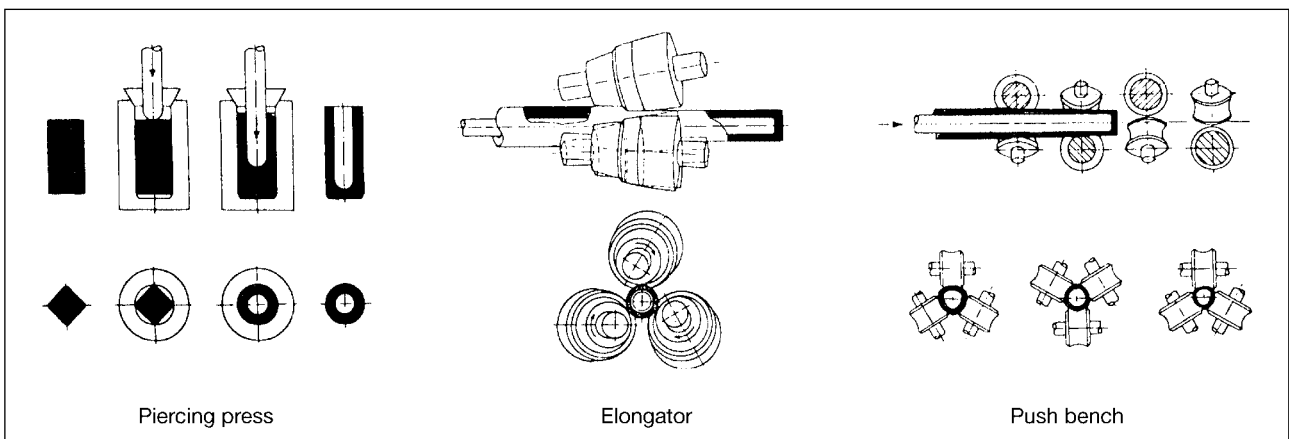Piercing press   Elongator   Push bench

Fig. 21: Forming operations incorporated in the push bench process
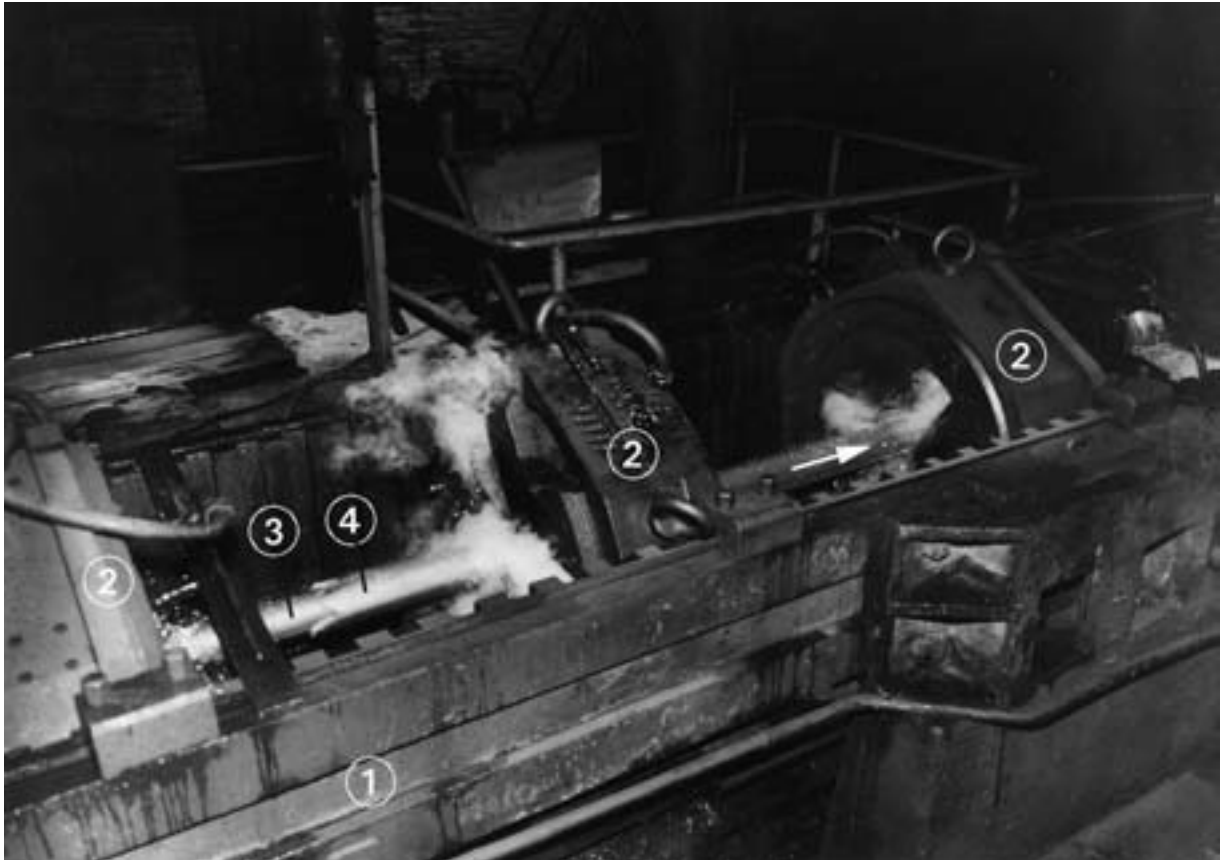
Fig. 22: Push bench with roll stands
      (Works photo: VALLOUREC & MANNESMANN TUBES)
      1 Push bench bed; 2 Roll stands; 3 Mandrel bar; 4 Tube

walled hollow shell with a closed bottom (Fig. 21). The hollow shell passes to an elongator, usually equipped with three rolls, where it is forged over a mandrel bar to approx. 1.8 times its original length. This reduction process also produces greater wall thickness evenness. The hollow bloom is then elongated on the push bench, without reheating, to between 10 and 15 times its incoming length, using a mandrel bar as the internal tool.

Arranged in the foundation bed of the push bench are up to 15 roll stands (Fig. 22). The roll stands usually comprise three (sometimes four) circumferentially distributed, non-driven grooved rollers. The gradually decreasing cross sections of the roller passes produce reductions which, in the main work passes, can amount to up to 25 %. During this process, between 6 and 7 roll stands are simultaneously in operation at any one time. The push force is applied to the mandrel bar by a rack-and-pinion arrangement, and operating speeds can be up to 6 m/s.

Following this elongation process, the tube rolled onto the mandrel bar enters a detaching mill or reeler to enable the mandrel bar to be extracted. Following the removal of the mandrel bar, the closed bottom and also the open tube end are cropped off by a hot saw. In a downstream stretch-reducing mill, the tube, reheated to forming temperature, is then rolled to its final size (see section dealing with the continuous mandrel rolling process).

Fig. 23 shows a diagrammatic representation of a push bench plant with stretch-reducing mill.

A modern derivative of the Ehrhardt process is the CPE process (cross-roll piercing elongation) in which the piercing press and elongator are replaced by a rotary piercing mill. In this operation it is not possible to leave an end of the pierced billet closed, so that therefore one end has to be crimped. The hollow cylinder is then elongated on the push bench to produce the shell. The largest size which can be manufactured lies in the region of approx. 245 mm outside diameter, and again the finished tube is manufactured by a downstream stretch-reducing mill.
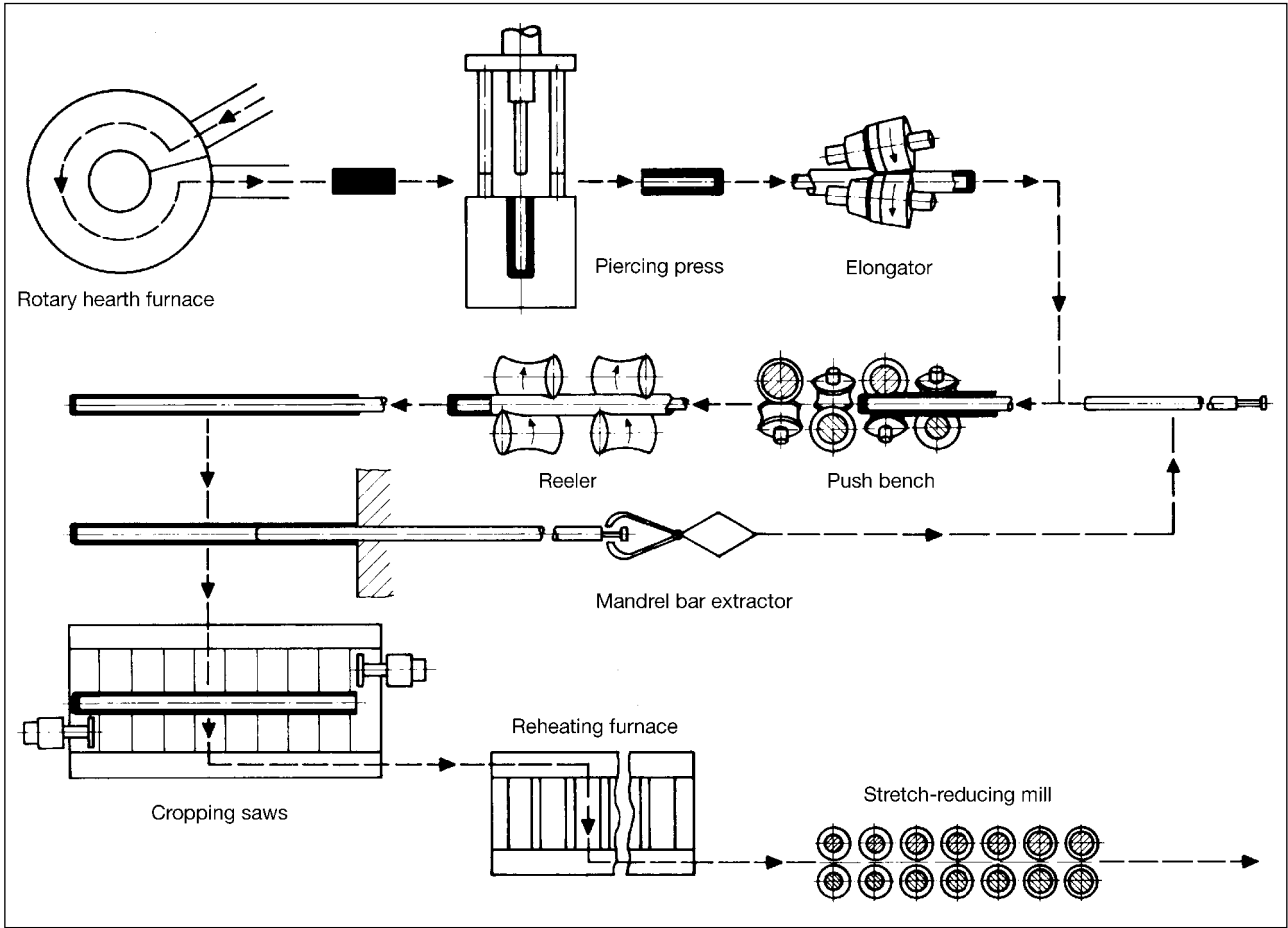
Rotary hearth furnace

Piercing press

Elongator

Reeler

Push bench

Mandrel bar extractor

Cropping saws

Reheating furnace

Stretch-reducing mill

Fig. 23: Diagrammatic representation of a push bench facility

Piercing mandrel

Pierced ingot

Die block
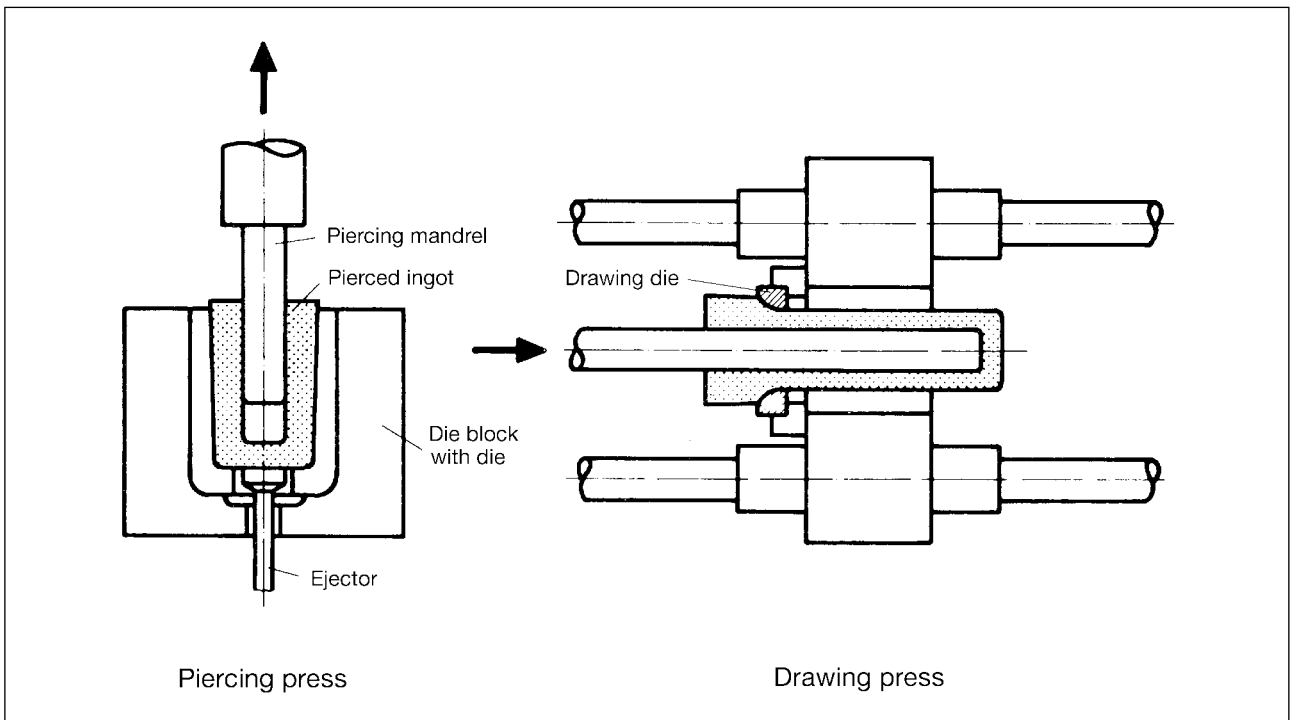with die

Ejector

Drawing die

Piercing press

Drawing press

Fig. 24: Pierce and draw process

Fig. 25: Inserting the pierced ingot in the drawing press
        (Works photo: VALLOUREC & MANNESMANN TUBES)
        1 Pierced ingot; 2 Mandrel; 3 Drawing die

2.5 Pierce and draw process

This process, also developed by H. Ehrhardt, is similar to the push bench variant but, unlike the technologies described so far, is not suitable for mass production. Consequently, therefore, the number of plants employing this process is quite small. These, however, are specially designed for the manufacture of seamless hollow components combining large diameters with large wall thicknesses.

The production range of such facilities lies between approx. 200 and 1450 mm in outside diameter, with wall thicknesses ranging from approx. 20 to 270 mm. This therefore provides an effective complement to the product mix available in large pilger mills. With a maximum length of around 10 m, tube blanks and hollow sections can be manufactured (in all steel grades), by this process for items such as power plant components, hydraulic cylinders, high-pressure gas cylinders and pressure vessels, as can products such as thick-walled square section tubes.

The usual starting material takes the form of mould-cast polygonal ingots with diameters from 500 to 1400 mm and weights up to 26 t. These are heated to forming temperature in a soaking pit and then formed into a cylinder with integral bottom on a vertical, hydraulic piercing press (Fig. 24). This is then elongated to its final size on a horizontal hydraulic drawing press using a mandrel which corresponds to the requisite inside diameter of the hollow component. Together with the mandrel, the hollow shell is sequentially pushed through a series of drawing dies of decreasing diameter until the requisite outside diameter has been attained (Fig. 25). Up to five passes can be performed in one heat, depending on the cooling rate of the workpiece and the specified temperature range for the forming process. If necessary, the material is then reheated. Once the forming work has been completed, the finished component is removed from the mandrel by means of a stripping device. Depending on the application, the integral bottom may either be left on the hollow component (e.g. for vessels), or it may be cut off once the item has cooled to ambient temperature.
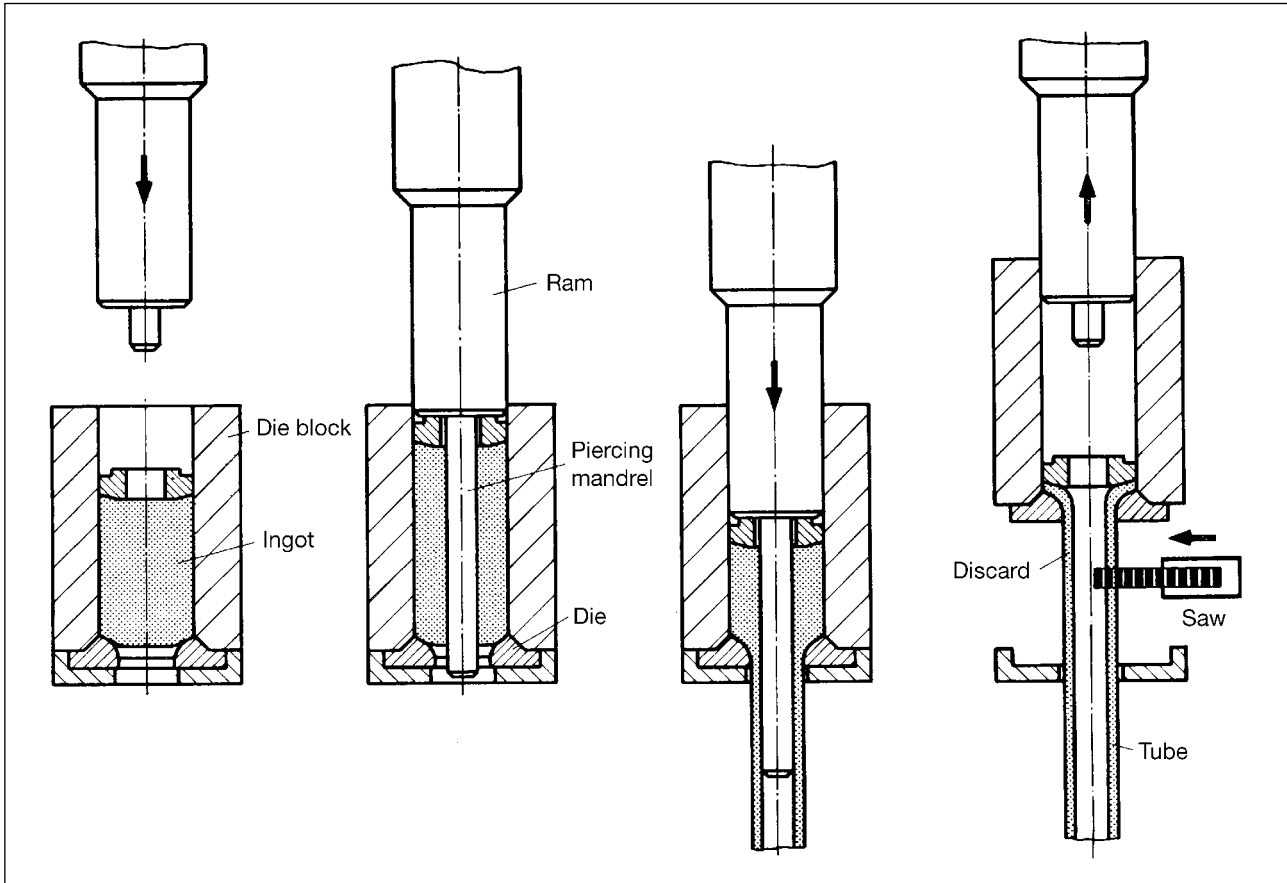
Fig. 26: Diagrammatic illustration of the extrusion process

2.6 Tube extrusion process

This process is employed for manufacturing tubes up to approx. 230 mm outside diameter. The usual starting material takes the form of round steel billets/blooms, either rolled, forged or continuously cast, with diameters up to 300 mm.

Following heating to forming temperature, the starting material is inserted in the cylindrical recipient of the extruder, which features a round-bored die in its bottom. The bloom is initially pierced through the centre by a mandrel driven by a hydraulic ram. As the piercing mandrel passes through the die, it forms an annular gap through which the material is extruded under the pressure exerted by the ram to form the tube (Fig. 26). The material remaining in the extruder is subsequently cut from the tube as recyclable discard.

Mechanical (crank-type) extruders of vertical design are capable of producing steel tubes from various materials, including high-alloy steels, in the OD range from 60 to 120 mm, with wall thicknesses from 3 to 15 mm. The extrusion process is often followed by a stretch-reducing mill, enabling the manufacturing range to be extended down to approx. 20 mm OD in one heat. Mechanical extruders can handle billet dimensions up to approx. 200 mm dia. with an input weight of approx. 100 kg, and are capable of capacities up to max. 15 MN.

Hydraulic presses of horizontal design are predominantly used in the manufacture of high-alloy steel tube up to outside diameters of approx. 230 mm. Consequently, the maximum extruder capacities lie in the region of 30 MN.

When manufacturing high-alloy tube, the starting material is normally drilled, re-heated and the bore is then expanded to the required inside diameter – usually by means of an upstream press. Following temperature equalization, this tube blank is then inserted in the extruder to produce the final tube dimensions.

2.7 Cross rolling processes

As an extension to the original idea propagated by the Mannesmann brothers, i.e. manufacturing tubes by application of a cross rolling concept, two further processes came on to the scene in the 1930s which became known by the names of their respective inventors, W.J. Assel and S.E. Diescher. Both systems utilize the Stiefel piercing press for producing the hollow shell from the round bloom, and apply a further cross rolling operation in order to roll the material to the finished tube dimensions. However, while the Assel process quickly became widely accepted, the Diescher method was only employed in a few plants.

2.7.1 Assel rolling process

Assel mills are used nowadays to produce stainless tube with outside diameters ranging from 60 to 250 mm and lengths of up to 12 m. The ratio of outside diameter to wall thickness tends to lie in the region 4 to 15. The smallest inside diameter of the tubes is approx. 40 mm. The tubes manufactured
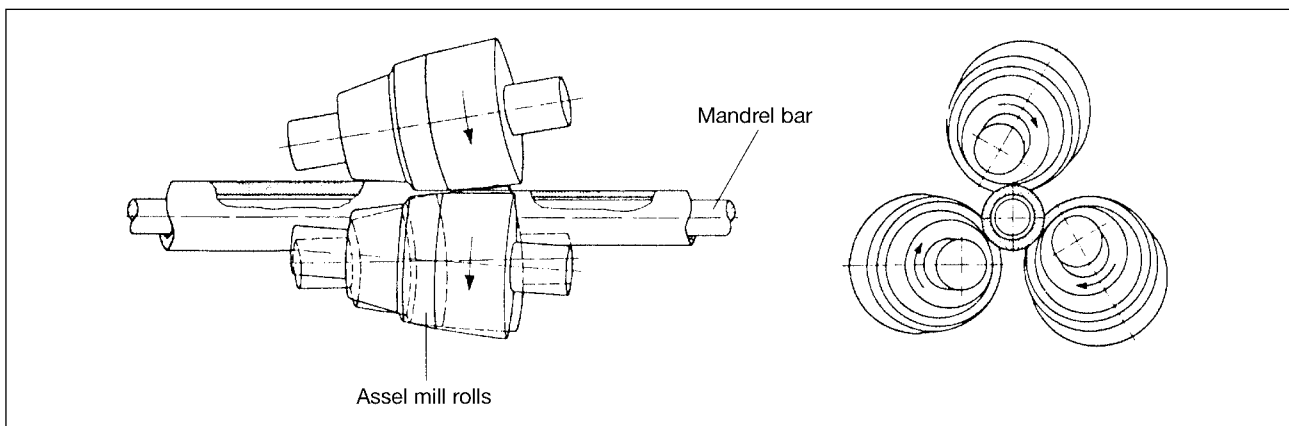

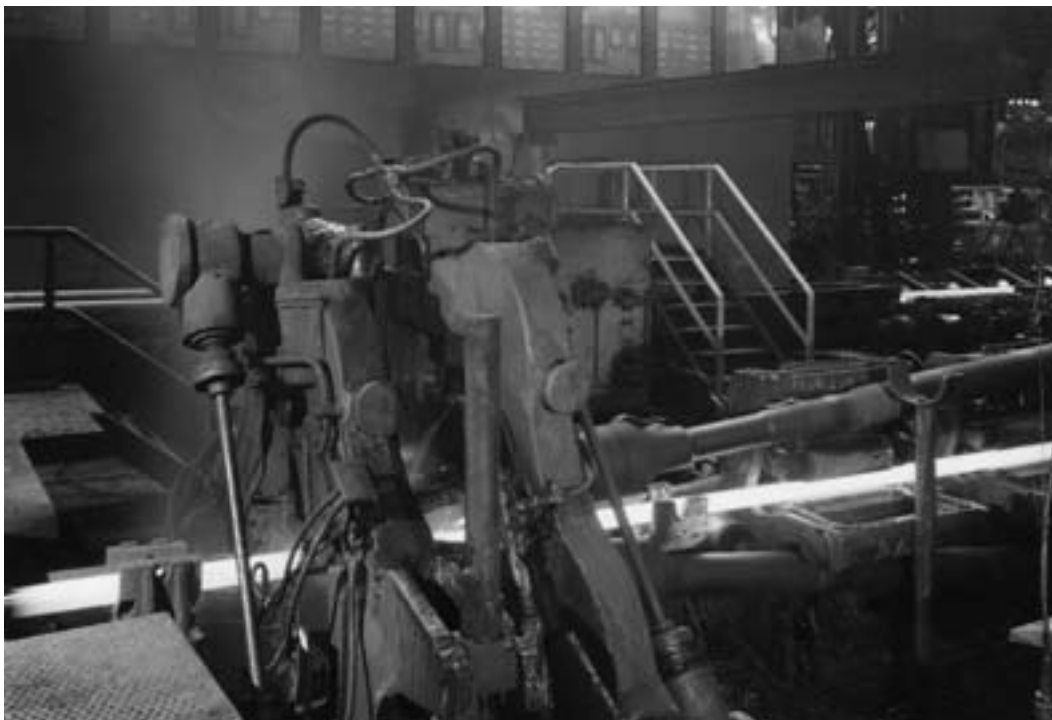Fig. 27: Diagrammatic representation of the Assel process

Fig. 28: Assel mill
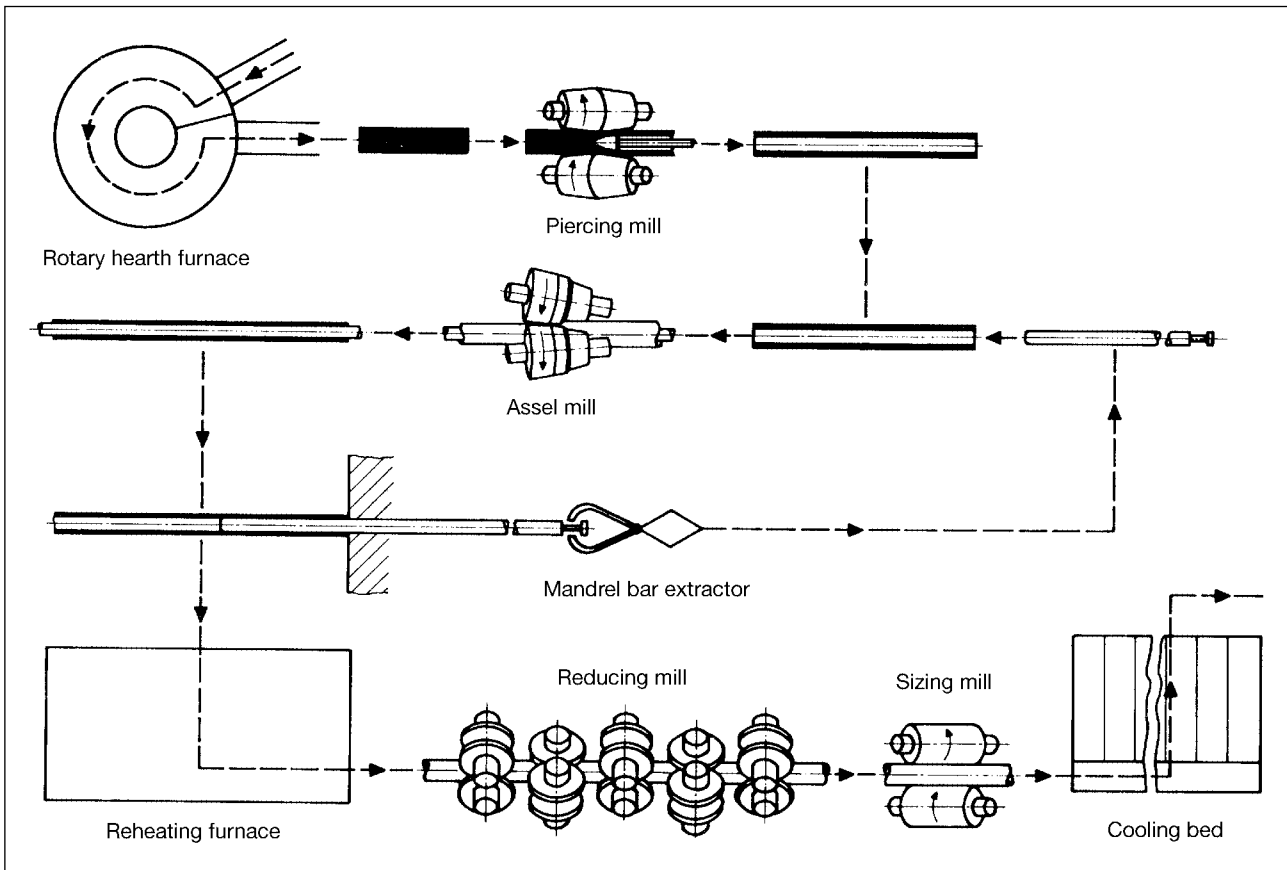(Works photo: Mannesmannröhren-Werke AG)

Fig. 29: Diagrammatic illustration of an Assel facility

by this method are characterized by their excellent concentricity and are extensively employed in the production of turned components (shafts, axles) and also for medium-alloy steel roller bearing production (general product name: mechanical tube).

The starting material predominantly takes the form of round steel blooms of the appropriate length which are heated to forming temperature in a rotary hearth furnace. Following descaling and end face centering, the bloom is formed into a hollow shell in the cross roll piercing mill and then fed into the Assel mill.

The Assel mill features three tapered rolls arranged symmetrically at an offset of 120° around the rolling centerline. In this secondary cross rolling mill, the rolls are again inclined to the stock plane (Figs. 27 and 28). The main feature of the roll pass is the so-called shoulder or "hump", the height of which determines the degree of wall thickness reduction. The release pass is designed to detach the tube from the mandrel and to smooth, round and polish the external tube surface. The internal tool is usually a floating mandrel bar which is extracted from the tube at the end of the rolling operation. A downstream sizing mill (rotary sizer) or a reducing mill then serves to size the tubes or produce intermediate dimensions (Fig. 29).

2.7.2 Diescher rolling process

In the Diescher process, the hollow shell produced in the cross roll piercer is again elongated in the Diescher mill on a mandrel bar serving as the inner tool to produce the finished tube dimensions.

The gap between the two barrel-shaped work rolls is closed off by so-called Diescher discs instead of the fixed guide shoes normally found in the Stiefel (automatic) mill. The pass formed by the Diescher discs corresponds to the roll pass formed by the barrel-shaped work rolls (Fig. 30). The Diescher discs are driven at a speed which is higher than the exit speed of the tubular stock. This promotes favourable material flow and facilitates the manufacture of thin-walled tubes. In the Diescher mills still being
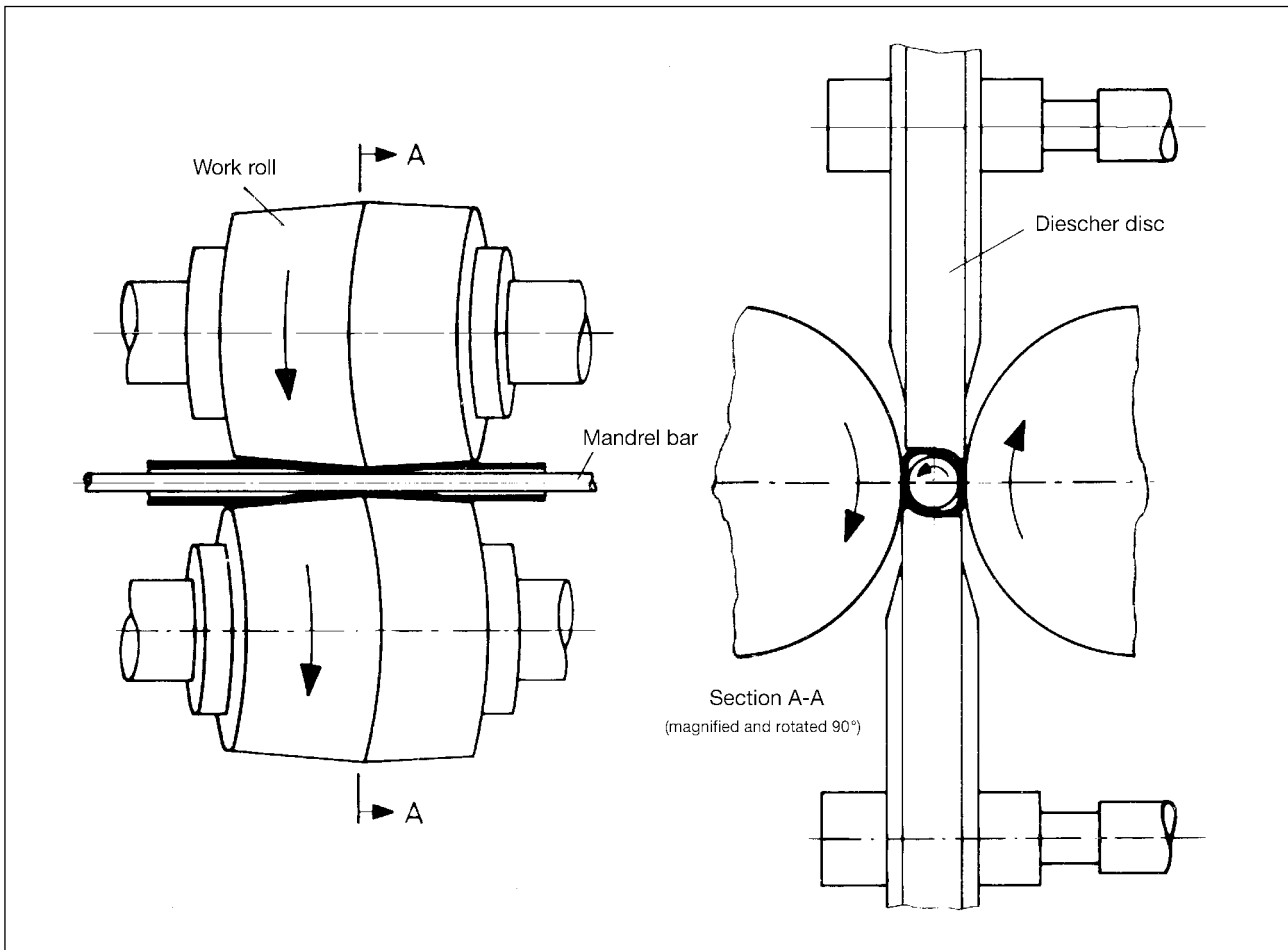
Fig. 30: Diagrammatic illustration of the elongation process performed in the Diescher mill

operated in the USA, Britain and China, tubes are manufactured in the size range 60 to 168 mm OD, with an OD to wall thickness ratio of between 4 and 30 and a maximum tube length of approx. 12 m.

Although Diescher mills have not enjoyed wide market penetration as elongating or finish-rolling facilities, modern cross roll piercing mills are nowadays being equipped more and more with Diescher discs (see continuous mandrel process and plug rolling/MPM process).

3 Downstream tube cold forming

A considerable proportion of the seamless tube and pipe manufactured using the above-described processes, and also longitudinally welded tube, undergo subsequent cold forming (see Chart II). The main purpose of these cold working processes is to achieve closer wall thickness and diameter tolerances, an improvement in surface finish and specific mechanical properties in the tube. Cold forming also serves to expand the product mix toward the lower end of the OD and wall thickness scales.

The processes which predominate in this respect are cold drawing and cold pilgering. Cold forging, flow forming, cold rolling and other processes involving machining operations (e.g. honing) are less important in terms of the quantities produced and tend to be reserved for the manufacture of tube and pipe for special applications (e.g. cylinder barrels).

3.1 Cold drawing

Seamless precision steel tube has been standardized in DIN 2391 for the diameter range from 4 to 120 mm and wall thicknesses from 0.5 to 10 mm. In addition, however, non-standardized intermediate
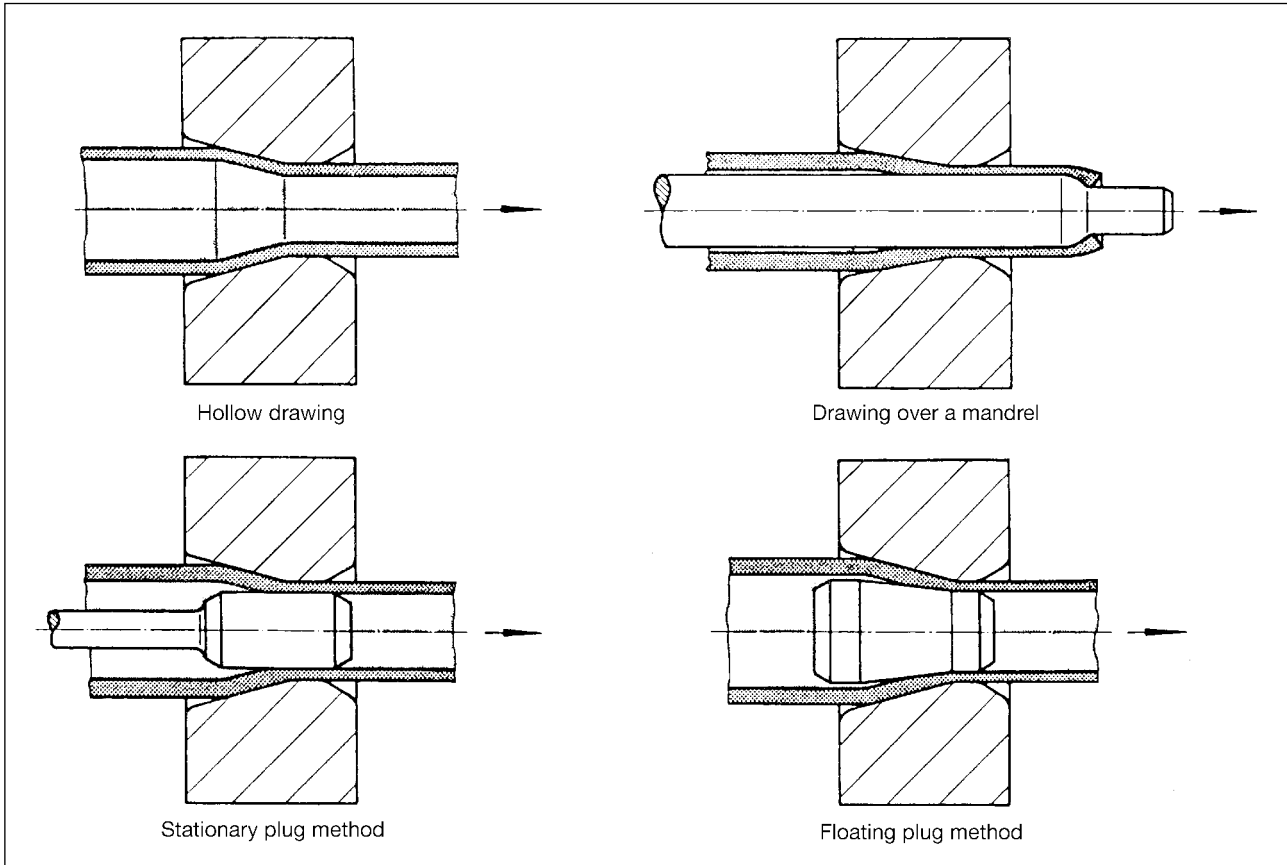
Fig. 31: Diagrammatic illustration of the four main tube drawing processes

sizes, and tube up to 380 mm outside diameter with wall thicknesses up to 35 mm, can also be manufactured by cold drawing.

There are three processes employed for the cold drawing of tube: hollow drawing, stationary or floating plug drawing, and drawing over a mandrel (also known as drawing on-the-bar) (Fig. 31).

Because of the lack of an internal tool, in hollow drawing only the outside diameter of the tube is reduced and the outside surface polished in the die, with the wall thickness undergoing no more than negligible change in both absolute terms and in respect of its tolerances.

In plug drawing, a plug which is either fixed to a mandrel bar, or a so-called floating plug (this lodges in the forming zone as a result of its particular shape and the forming pass it produces) forms an annular gap with the block die through which the tube is drawn. This reduces within close tolerances both the outside and inside diameters, and thus also the wall thickness, as well as smoothing and polishing both the outside and inside surfaces. In general, a fixed, stationary plug is used to produce reductions in area of up to 45 % per draw. Drawing over a floating plug is predominantly employed for small-diameter tubes and greater lengths, and particularly when the stock is taken from a coil and, following drawing, re-coiled on a capstan.

In drawing over a mandrel, the tube is pulled through the die with the aid of an inserted mandrel bar, with the outside and inside diameters, and also the wall thickness, again undergoing reduction. The possible reductions in area per draw are higher than in the case of plug drawing, but the length of tube is limited by the length of the mandrel bar. Moreover, the tube has to be slightly expanded in a reeling mill following drawing in order to enable the mandrel to be extracted. Drawing over a mandrel is therefore applied predominantly for standard sizes and as a so-called preliminary draw where the final dimensions are only produced in several sequential drawing operations with intermediate heat treatment. Prior to cold drawing, the scale adhering to the tube following the heating process or an intermediate annealing operation is removed and the surface is provided with a lubricant carrier; drawing is then performed with the addition of lubricants.
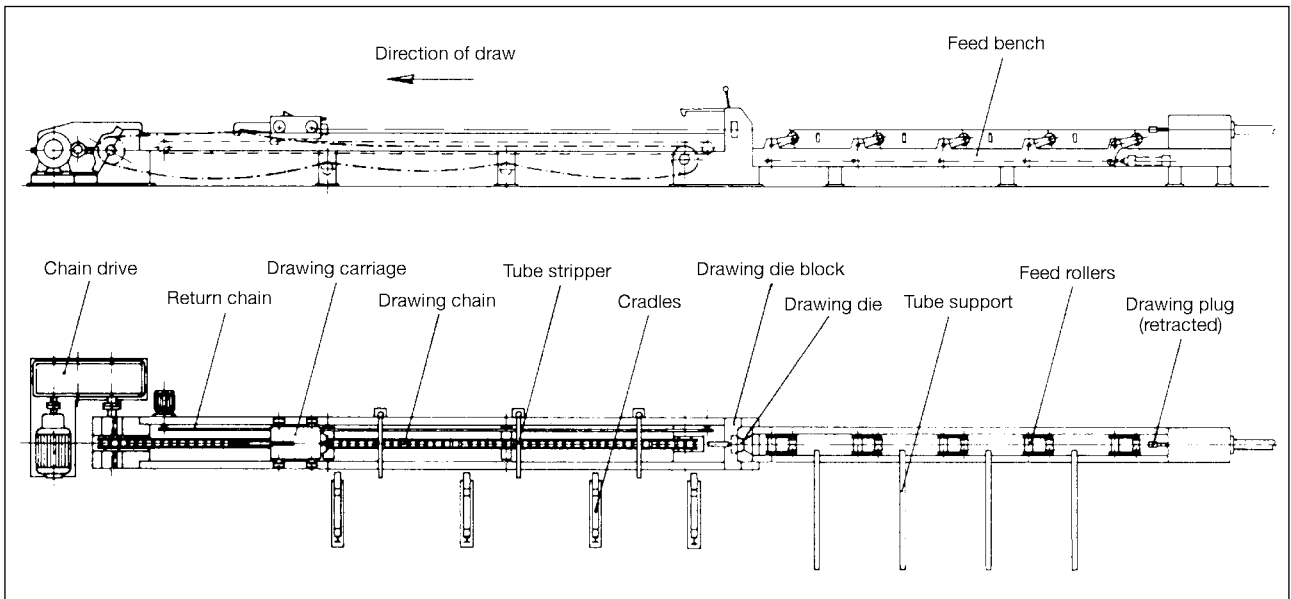
Fig. 32: Chain-type draw bench with continuous chain

Fig. 33: Draw bench
       (Works photo: Dahlhaus Iserlohn)
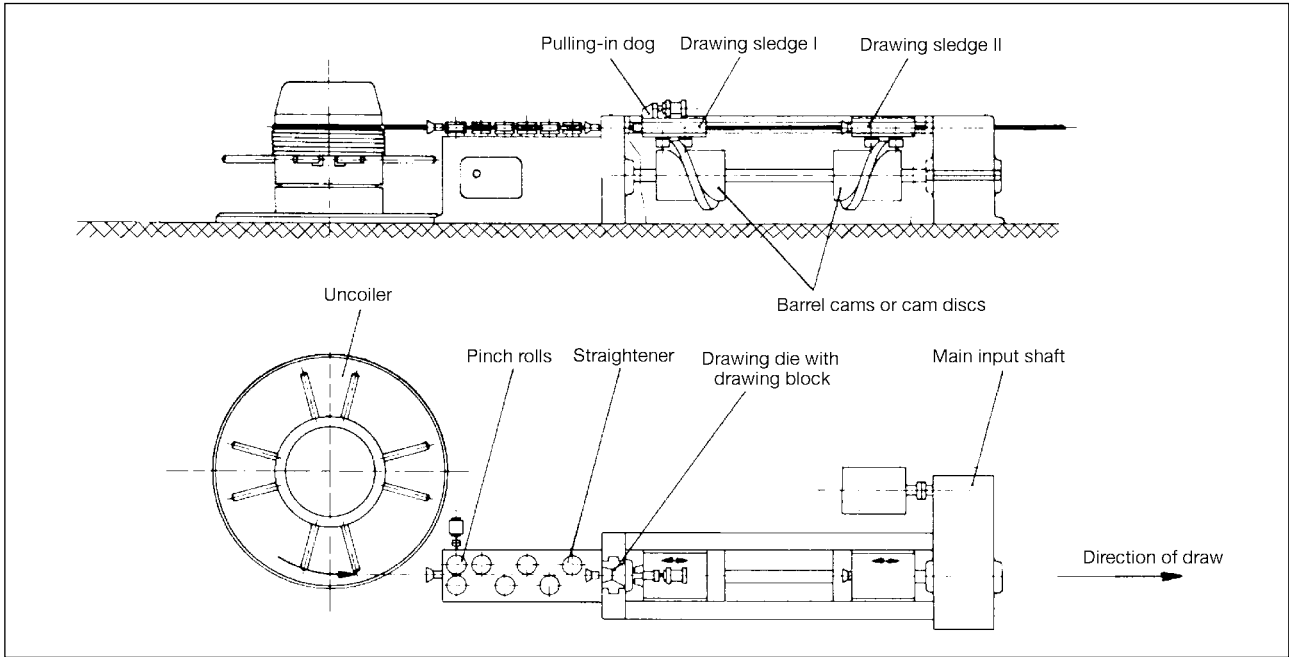   1 Drawing chain; 2 Drawing carriage; 3 Drawing die

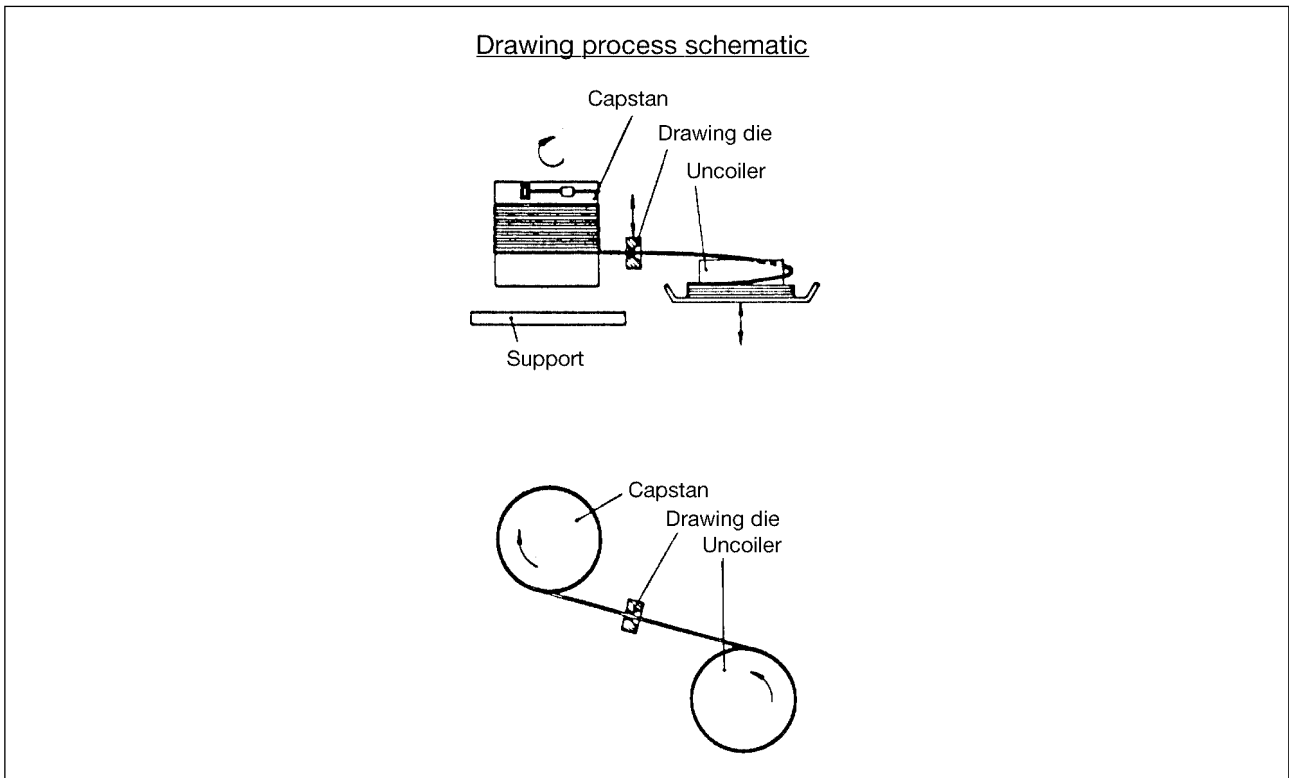Fig. 34: Continuous straight-line drawing machine

Fig. 35: Bull block drawing process

The cold forming process causes the material to undergo strain hardening, i.e. the yield strength and tensile strength values of the material are increased while its elongation and toughness values decrease. This is desirable for many applications. However, owing to the associated reduction in ductility, a heat treatment has to be applied prior to any further forming operation. The drawing of tube over a mandrel or a stationary plug as the internal tool requires machines which are configured for a straight-line, finite motion. These predominantly take the form of draw benches equipped with a continuous chain (engaged in this is the drawing carriage which serves to grip the stock – Figs. 32

and 33); or draw benches with reversible finite drawing and return chains attached to the drawing carriage. Other designs include rope-type draw benches, rack and pinion draw benches and also draw benches with a hydraulic drive system.

Large tube lengths are generally drawn using a floating plug on continuous-type straight-line machines in which two reciprocating sledges alternate in the performance of the drawing operation (Fig. 34). Tube of small diameter is usually cold-drawn by the bull block process in which the stock is taken from a coil and the drawing power is applied by a capstan (Fig. 35).
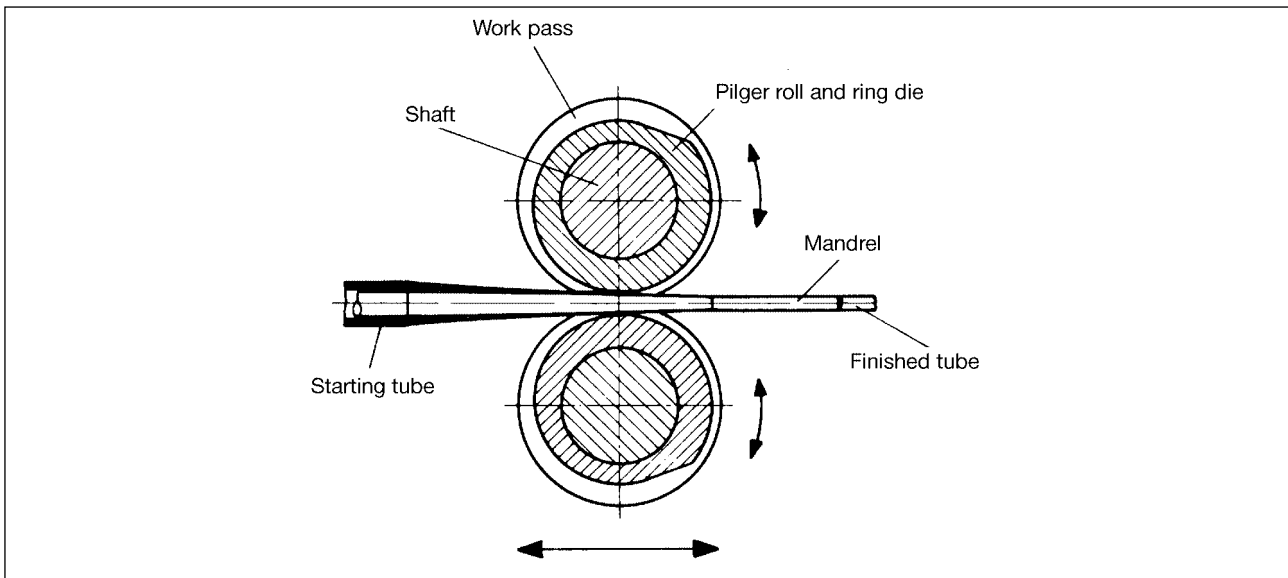

Fig. 36: Cold pilgering (schematic)

3.2 Cold pilgering

The cold pilgering process is employed for the working of hot-formed hollow blanks in the manufacture of tubes measuring 8 to 230 mm OD and 0.5 to 25 mm wall thickness. The reductions in area attained are a multiple of those achievable in cold drawing. As a result of the heavy, simultaneous reduction in diameter and wall thickness in the rolling-cum-forging process, eccentricities and wall
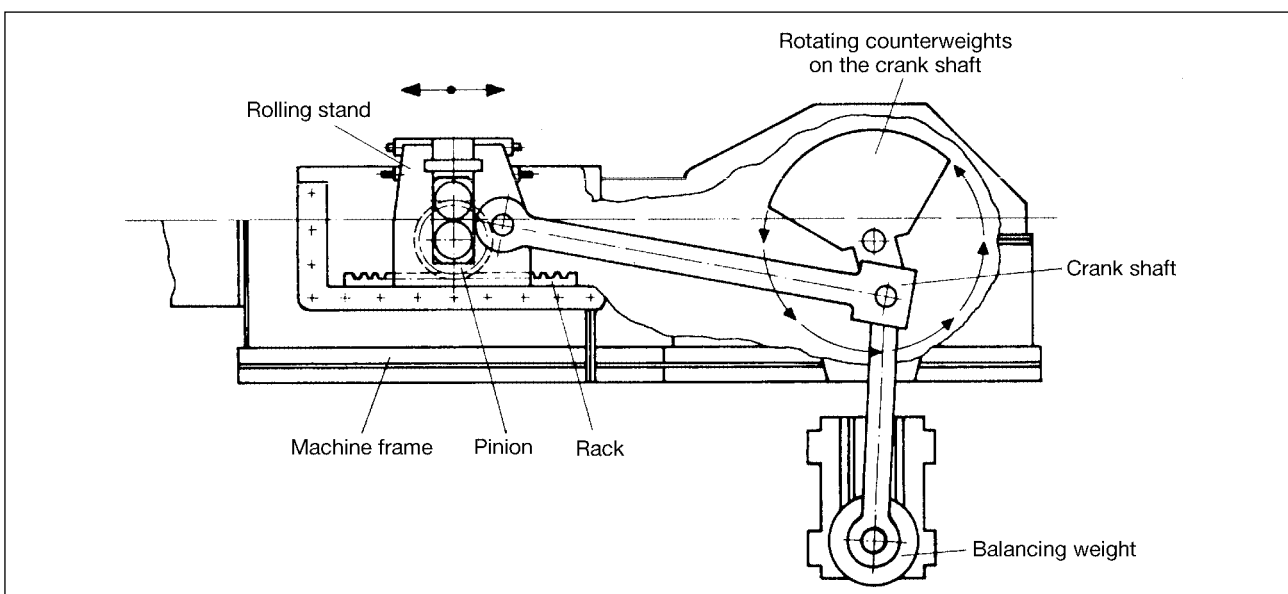

Fig. 37: Cold pilgering machine (drive system schematic)

thickness differences in the input blank become substantially reduced: The cold-pilgered tube is a product exhibiting very small dimensional variations and a very high level of surface quality.

Owing to the favourable stress pattern applied to the stock in the forming zone, the cold pilgering process is also a preferred option in the manufacture of tube and pipe of non-ductile materials.

The cold pilgering process is characterized by the fact that the hollow blank is forged and elongated over a stationary, tapered mandrel by two rolls with ring dies of a corresponding pass design which reciprocate back and forth over the stock (Fig. 36). This rolling action is imparted by a rack and pinion arrangement in which the pinions are rigidly connected to the pilger rolls, so causing them to rotate as the rolling stand traverses to and fro. The rolling stand motion, and thus the longitudinal travel and rotation of the rolls, is powered by a crank drive (Fig. 37).

The pass design of the two rolls consists of a circular recess, corresponding to the cross section of the hollow blank, which tapers over a certain portion of the roll circumference to provide an ideal, continuous transition to the finished tube diameter. Consequently, as the rolls move forward and backward, the hollow blank is formed in the desired manner. An essential aspect of the process lies in the fact that elongation of the hollow blank to produce the finished tube is performed by simultaneous reduction of the diameter and the wall thickness. This is aided by the shape of the mandrel which tapers from the hollow blank inside diameter to the finished tube inside diameter. Following a forward and backward rolling cycle, the rolls release the blank which is then advanced by a certain, infinitely variable feed value. The corresponding material volume is then elongated with the subsequent forward and backward rolling cycle executed by the stand.

As the hollow blank is advanced, it is also rotated by a certain angle in order to achieve a perfectly circular cross section as the material is forged to the finished tube dimensions.

The pass length determines the length of hollow blank which is rolled with each forward stroke of the stand. The portion of the roll containing the pass may take the form of either a half-round die or a ring die. The half-round die with its approx. semi-cylindrical design and short pass (arc length up to 180°) is a characteristic feature of short-stroke mills. Nowadays, however, it is the long-stroke mills which dominate, and these with their ring dies offer longer working passes (arc length up to 300°) while operating at the same high rotational speeds. As a result, they attain higher levels of productivity, more favourable deformation results, improved surface quality and a higher degree of dimensional precision in the finished tube.

Fig. 38 shows a tube being rolled in a short-stroke cold pilgering machine.
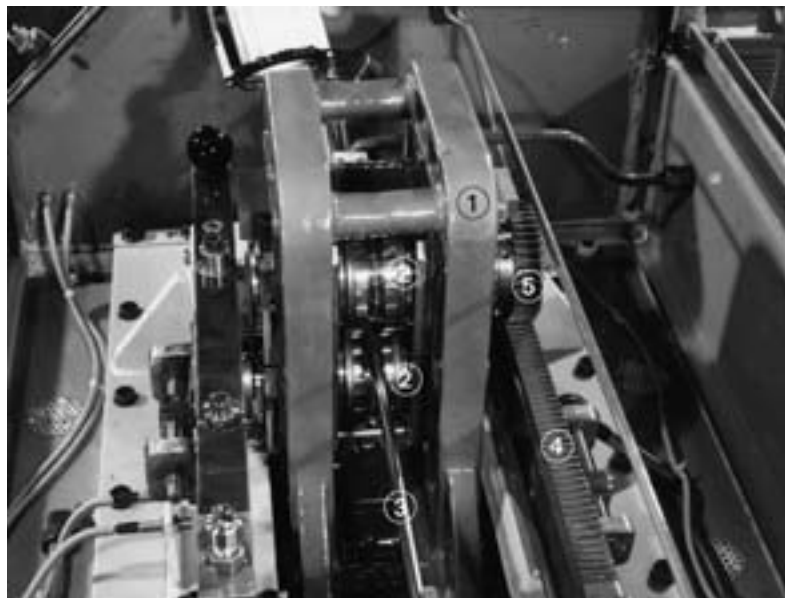

Fig. 38: Tube production on a cold pilgering machine
        (Works photo: Mannesmannröhren-Werke AG)
        1 Rolling stand; 2 Pilger rolls; 3 Tube; 4 Rack; 5 Pinion

4 Welded tube and pipe

Ever since it became possible to manufacture strip and plate, people have constantly tried to bend the material and connect its edges in order to manufacture tube and pipe.

This led to the development of the oldest welding process, that of forge-welding, which goes back over 150 years.

In 1825, the British ironware merchant James Whitehouse was granted a patent for the manufacture of welded pipe.

The process consisted of forging individual metal plates over a mandrel to produce an open-seam pipe, and then heating the mating edges of the open seam and welding them by pressing them together mechanically in a draw bench.

The technology evolved to the point where strip could be formed and welded in one pass in a welding furnace. The development of this butt-welding concept culminated in 1931 in the Fretz-Moon process devised by J. Moon, an American, and his German colleague Fretz.

Welding lines employing this process are still operating successfully today in the manufacture of tube up to outside diameters of approx. 114 mm.

Aside from this hot pressure welding technique, in which the strip is heated in a furnace to welding temperature, several other processes were devised by the American E. Thomson between the years 1886 and 1890 enabling metals to be electrically welded. The basis for this was the property discovered by James P. Joule whereby passing an electric current through a conductor causes it to heat up due to its electrical resistance. In 1898, the Standard Tool Company, USA, was granted a patent covering the application of electric resistance welding for tube and pipe manufacture. The production of electric resistance welded tube and pipe received a considerable boost in the United States, and much later in Germany, following the establishment of continuous hot strip rolling mills for the production of the bulk starting material necessary for large-scale manufacture. During the Second World War, an argon arc welding process was invented – again in the United States – which enabled the efficient welding of magnesium in aircraft construction.

As a consequence of this development, various gas-shielded welding processes were developed, predominantly for the production of stainless steel tube.

Following the far-reaching developments which have occurred in the energy sector in the last 30 years, and the resultant construction of large-capacity long-distance pipelines, the submerged-arc welding process has gained a position of pre-eminence for the welding of line pipe of diameters upward of approx. 500 mm.

Chart III: Welded tube and pipe production processes

Forming process	Welding process	Nomenclature	Weld	Size range (OD)
Continuous	Hot pressure welding	Fretz-Moon	longitudinal	13 ... 114
	Electric resistance welding (ERW)	Direct current Low-frequency High-frequency (e.g. HFI)	longitudinal	10 ... 20 (30) 10 ... 114 20 ... 600
		Submerged-arc (SAW) Gas metal arc (MAG) (tack welding only) Gas metal arc (TIG, MIG, ERW)*	spiral spiral/ longitudinal	168 ... 2500 406 ... 2032 30 ... 500/10 ...420
Single forming operation 3-roll bending machine C-ing press	Electric arc welding (Fusion welding)	Submerged-arc (SAW) Gas metal arc (TIG, MIG, ERW)*	longitudinal	≥ 500 200 ... 600
Single forming operation U/O-ing press		Submerged-arc (SAW) Gas metal arc (MAG) (tack welding only)	longitudinal	457 ... 1626

* Stainless steel tube

Welded steel tubes and pipes are manufactured with either a longitudinal or a spiral (helical) seam. The diameters of these products range from approx. 6 to 2500 mm, with wall thicknesses from 0.5 to approx. 40 mm.

The starting material in all cases is rolled flat product which, depending on the manufacturing process, tube or pipe dimension and application, may take the form of hot or cold rolled steel strip/skelp, hot rolled wide strip or plate.

The physical properties and surface finishes required of the tube or pipe are, in many cases, already provided in the rolled flat product. If this is not the case, a downstream heat treatment or strain hardening/cold working process may be applied to the tubular product in order to attain the required values.

The starting material can be formed into its tubular shape in either the hot or cold condition. A distinction is made in this respect between continuous tube forming and the single tube forming process.

In continuous tube forming, uncoiled strip material is taken from an accumulator, with the leading end and trailing end of the consecutive coils being welded together.

In single pipe production, the tube forming and welding process is not performed over endless lengths, but rather (as the name suggests) in single pipe lengths.

The welding processes employed fall into two main categories:

– Pressure welding processes

– Fusion welding processes

The better known pressure welding processes are the Fretz-Moon method, DC electric resistance welding, low-frequency electric resistance welding, high-frequency induction (HFI) welding and high-frequency conduction welding. Fusion welding processes include the submerged-arc and gas-shielded methods.

Chart III shows an overview of the main generic welding processes.

The main methods used for the production of welded tube and pipe are the Fretz-Moon, high-frequency induction, submerged-arc and combination gas-shielded submerged-arc processes, plus the various gas-shielded welding methods for the production of stainless steel tube and pipe.

4.1 Pressure welding processes

4.1.1 Fretz-Moon process

In this process, named after its inventors, steel strip in the form of a continuous skelp is heated to welding temperature in a forming and welding line (Fig. 39). The stock is continuously formed by rollers into an open-seam tube and then the mating edges are pressed together and welded by a process related to the forge-welding technique of old. Tube and pipe from 40 to 114 mm outside diameter can be manufactured in this way, with welding speeds ranging from 200 to 100 m/min respectively.
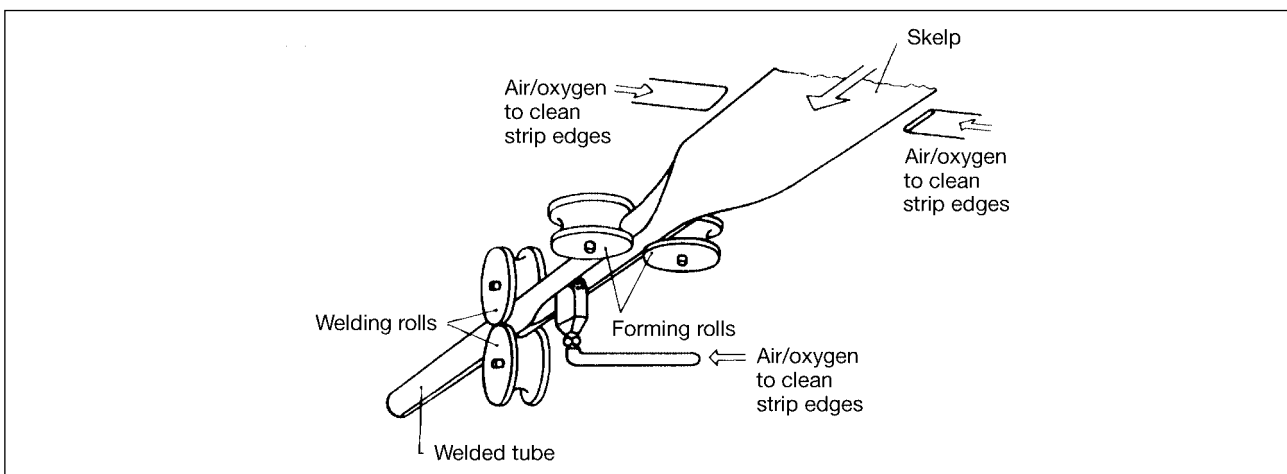

Fig. 39: Fretz-Moon welding line viewed from below

The hot-rolled steel strip coils used as the starting material are uncoiled at high speed and stored in loop accumulators. These serve as a buffer during the continuous production process, enabling the trailing end to be butt-welded to the leading end of the strip provided by the next coil. This continuous strip or "skelp" is taken through a tunnel furnace where it is heated to a high temperature. Laterally arranged burners increase the temperature at the skelp edges to a welding heat approx. 100 to 150 °C higher than the temperature prevailing at the skelp centre. The forming roll stand shapes the continuously incoming skelp into an open-seam pipe, the circumference of which is slightly reduced (by approx. 3 %) in the downstream squeeze roll welding stand, which is offset at 90° to the preceding stand. The upsetting pressure which this welding stand produces causes the edges to be pressed together and welded. The weld structure is further compressed in the following, again 90° offset, reducing roller stands which serve to size the tube. A flying hot saw located downstream of the welding line cuts the endless tube into individual lengths which are then conveyed via cooling beds to the tube finishing department.

In modern Fretz-Moon facilities, the endless tube is directly charged to a stretch-reducing mill. This is provided in the runout line for rolling the stock in the same heat to various diameters down to approx. 13 mm. The tube string is then cut into individual lengths for placement on the cooling beds. This combination of facilities has the advantage that the Fretz-Moon plant can be used for a single, constant tube diameter, so eliminating costly roll changing and resetting work.

4.1.2 Electric resistance welding

4.1.2.1 DC processes

The processes which operate with direct current (for example the DC system from Newcor) or employ the quasi-direct current effect (square wave system from Yoder) were developed for the longitudinal welding of small tube up to 20 mm, and in special cases up to 30 mm OD, with small wall thicknesses from 0.5 to approx. 2.0 mm.

The advantages of DC welding compared with low-frequency and high-frequency methods are derived in particular from the relatively smooth finish of the inside pass with no more than minimal ridging (reinforcement). This advantage is important in tubes in which a smooth inside weld is required and where inside flash removal is not possible, such as in the case of tubes for heat exchangers or for subsequent drawing.

The range of applications of the DC process is limited by the electrical power which can be transmitted by the disc electrodes employed. The welding speeds attained range from 50 to 100 m/min. The tubes produced are, without exception, subsequently cold stretch-reduced, in which process the thickness of the main body is increased slightly more than that of the weld zone, as a result of which these tubes exhibit virtually no internal weld protrusion at all. For tolerance reasons, cold-rolled strip is employed as the starting material.

4.1.2.2 Low-frequency process

In this process, welding is performed with alternating current frequencies from 50 to 400 Hz. An electrode comprising two insulated discs of a copper alloy serves not only as the power supply but also as the forming tool and the element which generates the necessary welding pressure (Fig. 40).

The electrodes constitute the critical components of the plant, because not only must they be provided with a groove which matches the diameter of the tube being manufactured, but also this radius has to be constantly monitored for wear during production operations.

The material extruded during the pressure welding process forms an inner and outer flash along the weld zone which has to be removed inline just downstream of the welding point by internal and external trimmers.

Provided that the process is carefully monitored in line with these various requirements, the low-frequency welding method can produce welds of a high degree of perfection.

This process is used to manufacture longitudinally welded tube from 10 to 114 mm in diameter at welding speeds of up to approx. 90 m/min, depending on the wall thickness.
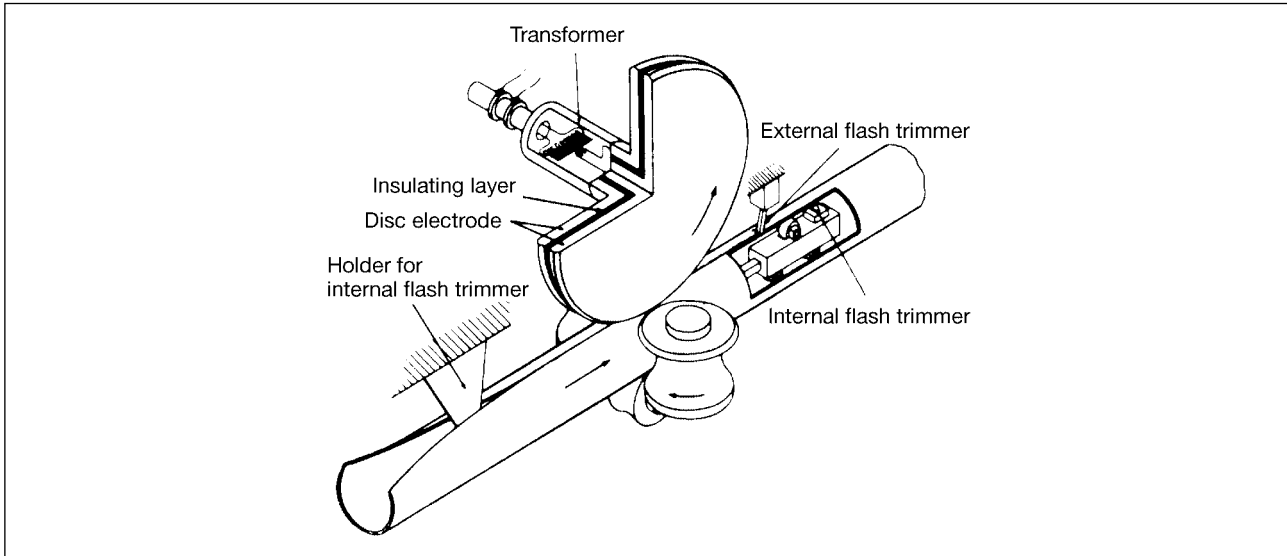
Fig. 40: Low-frequency pressure resistance welding

4.1.2.3 High-frequency processes

Following the development of the low-frequency electric resistance welding process, the 1960s saw the introduction of a high-frequency alternative. This welding technology has since achieved widespread market penetration. The process involves the application of a high-frequency alternating current in the range 200 – 500 kHz, with the tube forming and energy input operations being performed by separate units.

This welding method again simultaneously utilizes pressure and heat in order to join the strip edges of the open-seam tube together without the addition of a filler metal. Squeeze and pressure rolls in the welding stand bring the edges of the open-seam tube gradually together and apply the pressure necessary for welding. High-frequency alternating current offers a number of benefits as the energy source for generating the heat required for the welding process. For example, it has the advantage over normal alternating current of a very high current density (flux) over the cross section of the conductor. Because of its high frequency, HF current has the effect of building up a magnetic field at the centre core of the conductor. The conductor's ohmic resistance is at its highest in this field, so that the electrons follow the path of least resistance at the outer surface region of the conductor (skin effect). The current thus flows along the strip edges of the open-seam tube to the point at which the strip edges abut (welding point), and the ensuing concentration, promoted by the proximity of the negative conductor, results in a high level of energy utilization. Below the Curie point (768 °C), the depth of current penetration only amounts to a few hundredths of a millimetre. Once the steel is heated above this temperature, it becomes non-magnetic and the current penetration depth rises to several tenths of a millimetre at frequencies in the region of 450 kHz.

The welding current can be introduced into the open-seam tube both by conductive means using sliding contacts and by inductive means using single or multi-wind coils. Consequently, a distinction is made in the nomenclature between high-frequency induction (HFI) welding and high-frequency conduction welding. The strip or skelp is shaped in a roll forming mill or in an adjustable roll stand (natural function forming) into the open-seam tube for the manufacture of a wide range of products. These include line pipe and structural tube in the size range from approx. 20 to 609 mm OD and 0.5 to approx. 16 mm wall thickness, and also tube blanks as the feedstock for a downstream stretch-reducing mill. The starting stock is provided in the form of coiled steel strip or hot-rolled wide strip. Depending on the tube dimensions and application, and particularly in the manufacture of precision tube, the steel strip may either undergo an upstream pickling operation, or cold-rolled strip is used. The individual coils are welded together and, at high uncoiling speeds, the strip first passes through a loop accumulator. The tube welding machine operates continuously at a speed ranging from 10 to 120 m/min by drawing the strip from the loop accumulator.
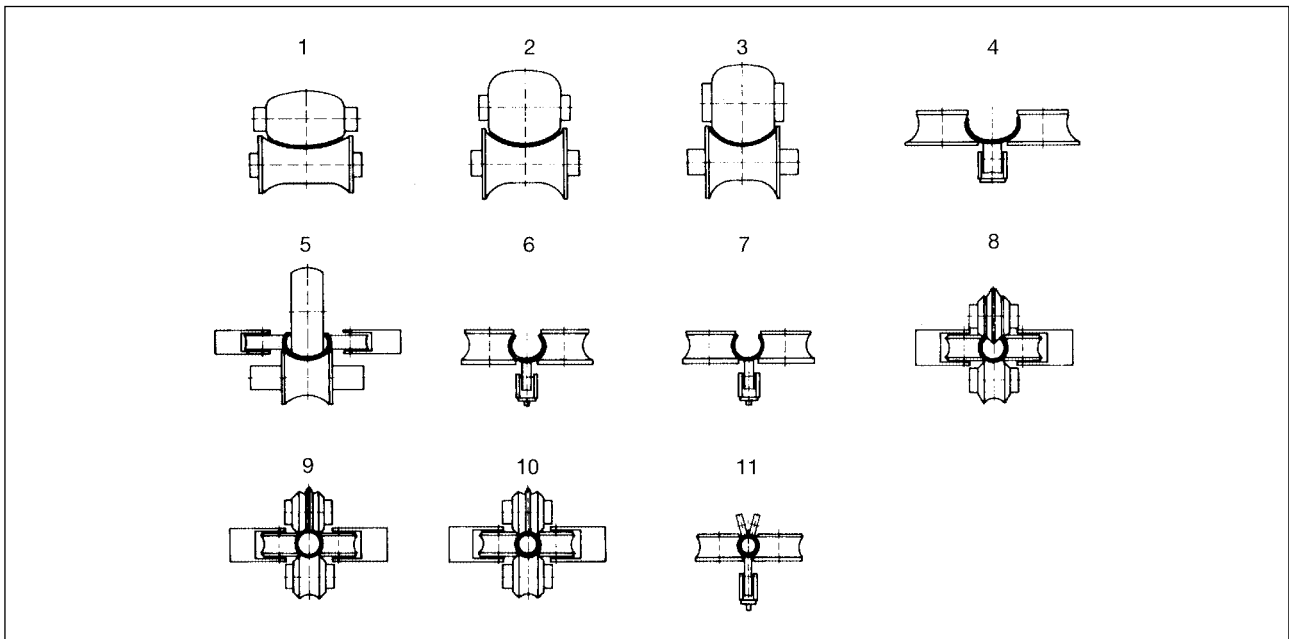
Fig. 41: Principles of the roll forming process

Fig. 42: Roll forming line
(Works photo: MHP Mannesmann Präzisrohr GmbH)

Fig. 41 shows a diagrammatic representation of the roll forming process, and Fig. 42 shows a corresponding facility.

The roll forming mill is used for tube diameters up to max. 609 mm, and generally consists of 8 to 10 largely driven roll forming stands in which the strip is gradually shaped into the open-seam tube – as indicated in stages 1 to 7 in Fig. 41. The three fin pass stands – 8, 9 and 10 – guide the open-seam tube toward the welding table 11. The forming rolls have to be precisely matched to the final tube diameter. For the manufacture of large-diameter pipe, the natural function forming process may also be applied. Fig. 43 shows the principles of this forming process involving a series of roll stands (roller cages). Fig. 44 shows a corresponding facility with the driven breakdown stand in the foreground.

The main features of the roller cage is that a number of non-driven internal and external forming rollers, adjustable within a wide product diameter range, are configured in a funnel-shaped forming line which gradually bends the strip into the open-seam tube shape. Only the breakdown stand at the inlet and the fin pass stands at the exit end are actually driven. The cross-sectional details A-B, C-D and E-F in Fig. 43 indicate the degree of deformation and the arrangement of the forming rollers at various sections along the line.

Owing to an increasing demand on the tube and pipe market for small production batches, high-strength low-alloy grades and extreme wall thickness/diameter ratios, a straightedge forming system has been developed in recent time. Here, instead of the bottom forming rollers, roller straightedges are used, resulting in a substantial reduction in the length of the forming line. Thanks to a virtually straight strip edge inlet, such a facility can form open-seam tubes with wall thickness/diameter ratios ranging between 1:8 and 1:100.

An increase in cost-efficiency, particularly in relation to small production batches, has been achieved by reducing the conversion times required from one tube dimension to another through the introduction of the innovative CTA (Centralized Tool Adjustment) forming process.

All the rollers of the forming line are mounted in a beam and are adjusted via the CTA system by a single motor. This means that throughout the size range no forming roller (i.e. tool) changes are
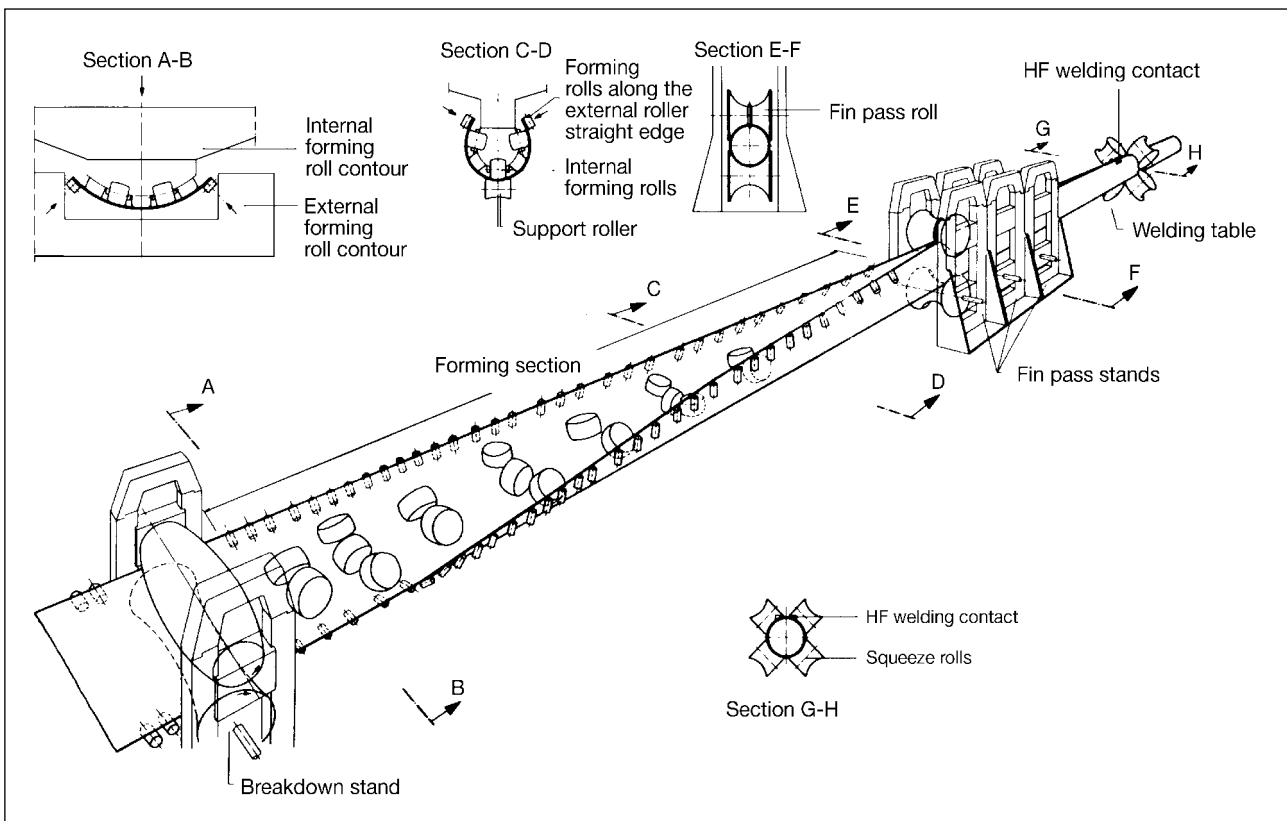

Fig. 43: Diagrammatic illustration of the roll stands employed in the forming process (natural function forming)
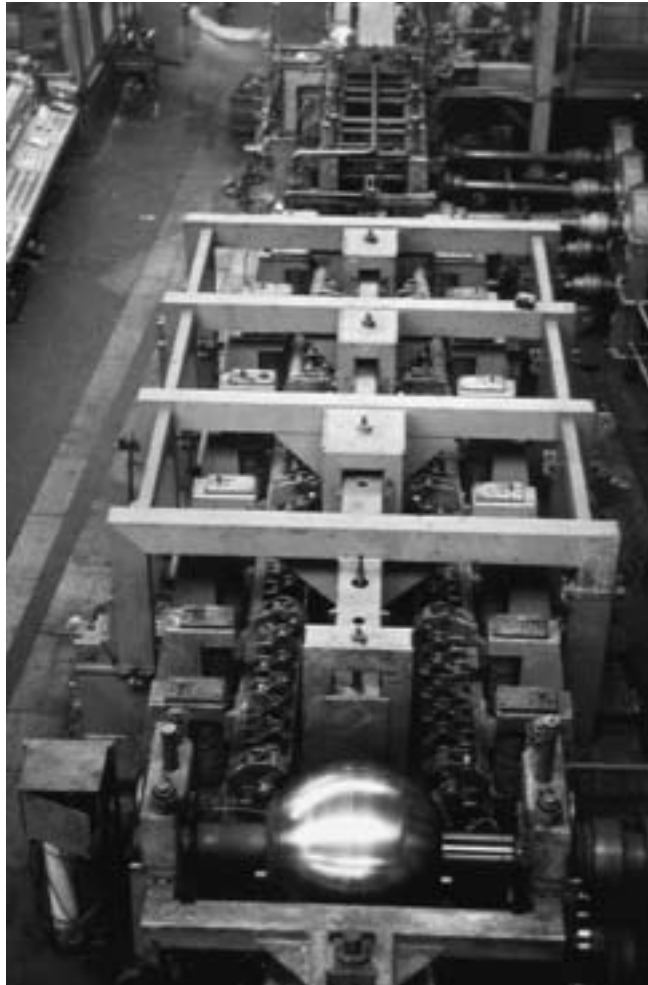
Fig. 44: Tube welding line with roll stand
(Works photo: Mannesmann Line Pipe GmbH)

1 Steel tube
2 Side forming roll
3 Bottom forming roll
4 Spindle incrementing gear unit
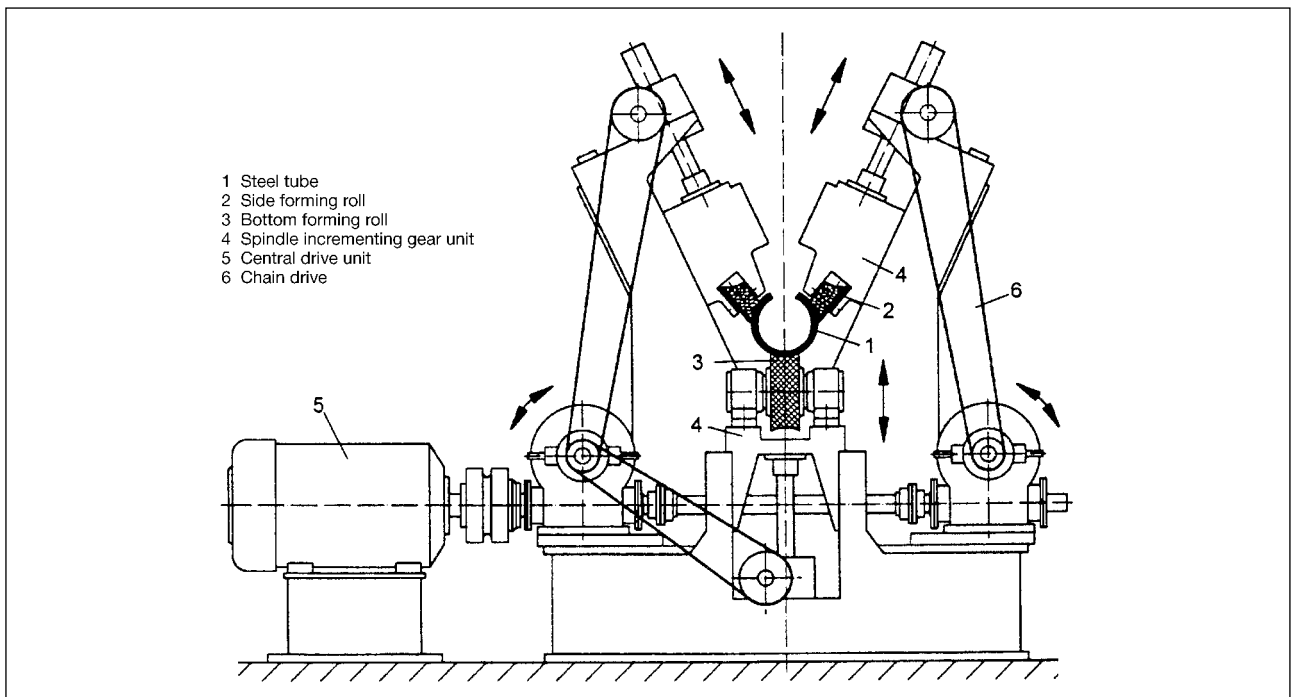5 Central drive unit
6 Chain drive

Fig. 45: Diagrammatic representation of the CTA forming process
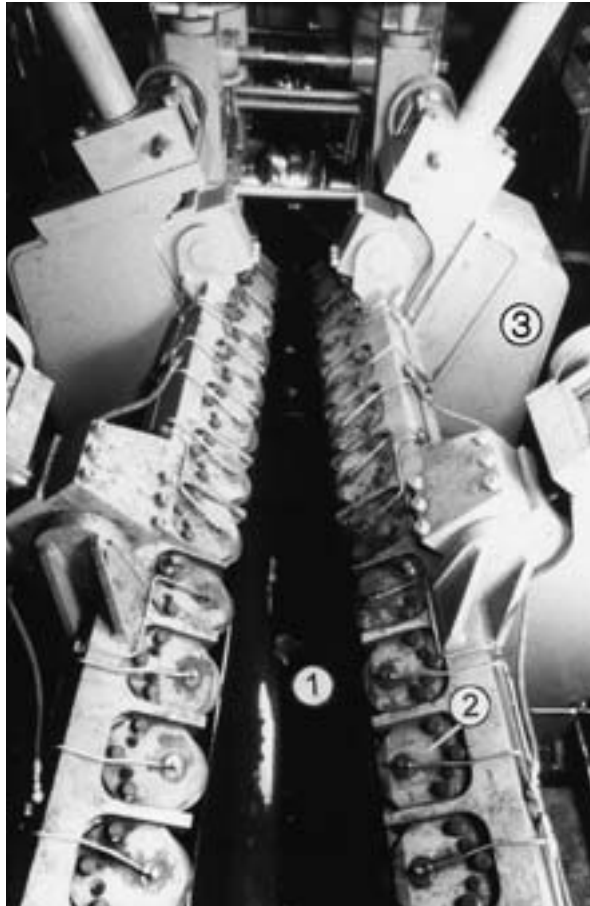(Drawing by courtesy of VOEST-ALPINE Industrieanlagen GmbH)

Fig. 46: Tube welding line with CTA forming section
    (Works photo: Röhrenwerke Gebr. Fuchs GmbH)
    1 Open-seam tube; 2 Side forming roller; 3 Spindle incrementing gear unit
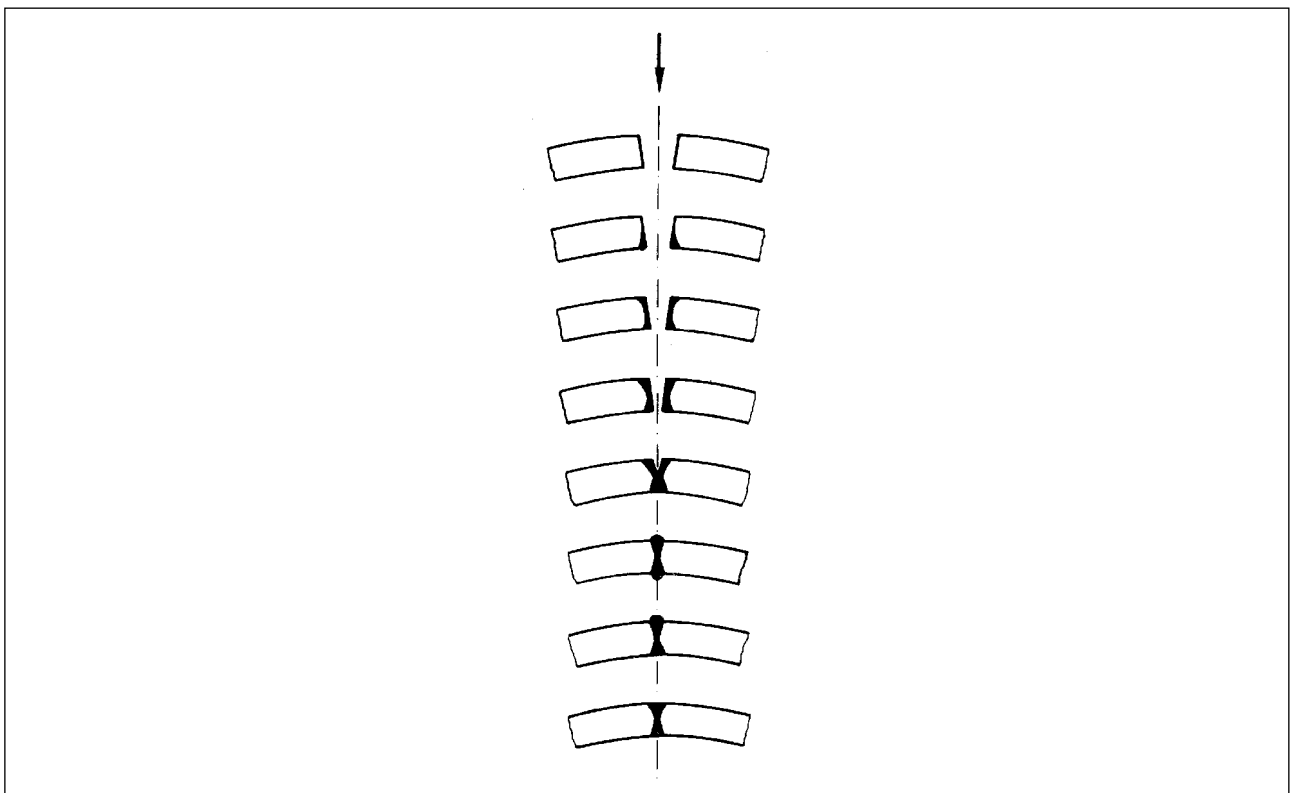

Fig. 47: Diagrammatic illustration of the merging strip edges and the formation of the HF weld

necessary. This results in substantial reductions in conversion and set-up times. Because all the setting adjustments performed on the CTA forming line are monitored by position transducers, system conversion to various tube and pipe sizes can be performed particularly quickly and with the utmost reliability. Fig. 45 shows a schematic of the CTA forming function, and Fig. 46 shows a corresponding facility.

Before the strip enters the forming section, it is straightened and cut to a constant width by a longitudinal edge trimmer. The cut edges may be additionally bevelled for welding preparation. The strip is then formed into an open-seam tube as described above, and with the gap still relatively wide, fed via three or four fin pass stands to the welding table. The overhead fin rolls, the width of which is tapered toward the welding point, determine the gap entry angle and control its central position in the
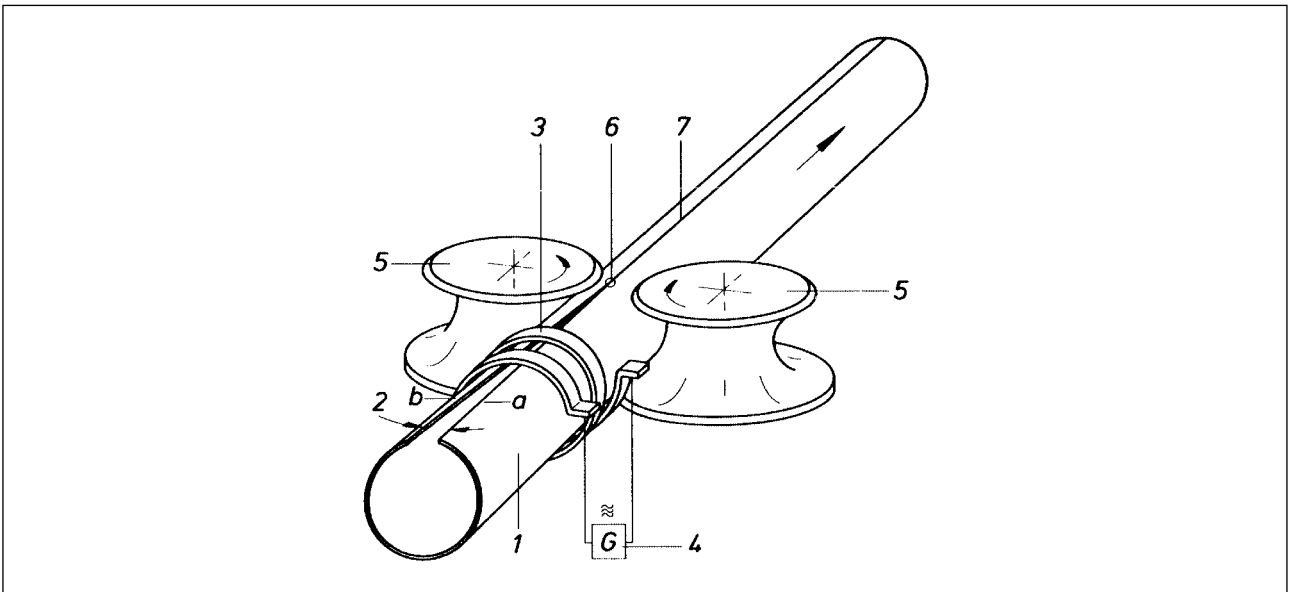

Fig. 48: High-frequency induction welding
1 Open-seam tube; 2 Welding gap entry angle; 3 Induction coil; 4 Welding generator; 5 Squeeze rolls; 6 Welding point; 7 Weld
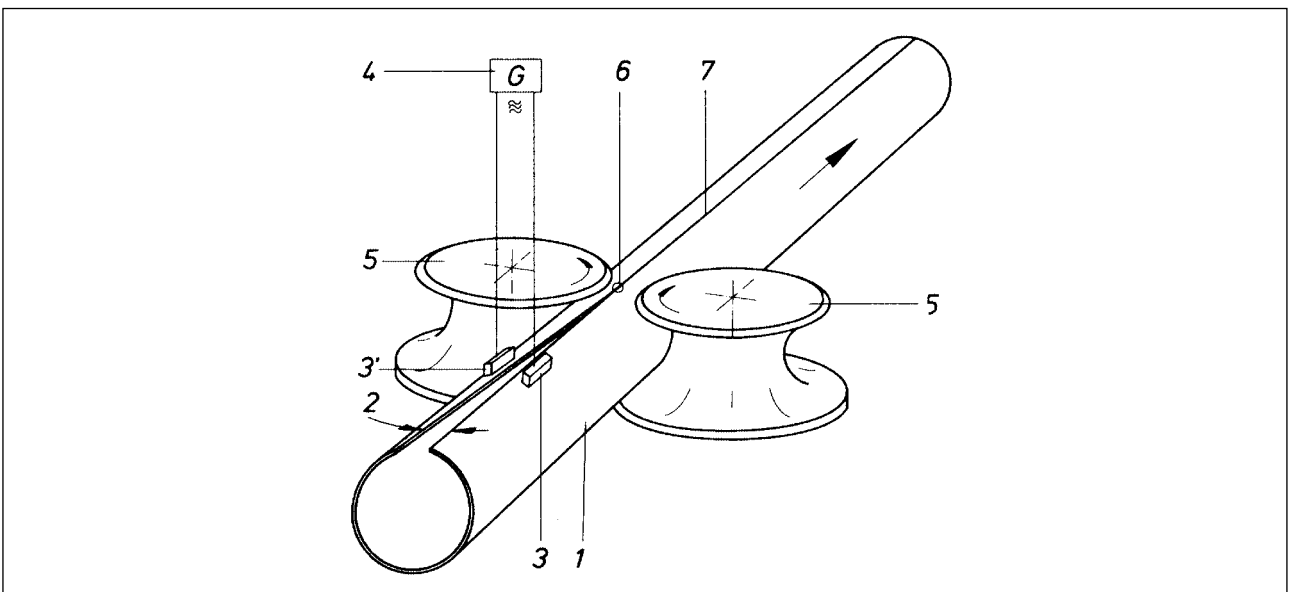

Fig. 49: High-frequency conduction welding
1 Open-seam tube; 2 Welding gap entry angle; 3 and 3' Sliding contacts; 4 Welding generator; 5 Squeeze rolls; 6 Welding point; 7 Weld

welding table. There the converging strip edges are pushed against each other by shaped squeeze rolls and then welded by means of the high-frequency electric resistance process (Fig. 47).

As already mentioned, the current can be transferred either inductively (Fig. 48) via a coil arranged around the open-seam tube, or conductively (Fig. 49) via sliding contacts running along the open seam edges.

The internal and external ridges which occur during pressure welding tubes with inside diameters of around 30 mm and higher, are usually trimmed by planing or scraping with the material still hot. The tube is then rounded and sized in between two and six sizing stands designed for circumferential reduction. This process also results in a straightening effect. The inclusion of an additional multi-stand shaping roll sizing unit in the tube runout section can also enable the round tube to be directly formed into specialty sections.

Following non-destructive examination of the trimmed weld (this inspection is performed as part of in-process production control), the continuous tube string is cut into defined lengths by a flying cut-off machine. Thus cutting operation can be performed by breaking the tube off at a narrow, inductively heat ring zone, rotational cutting by means of discus-type blades or by cold or friction parting-off saws.

The HF pressure weld can either be left in its as-welded condition (Fig. 50) or subsequently heat-treated in the normalizing range (Fig. 51), depending on the application. Partial inductive annealing of the weld may also be performed on the continuous tube, or the individual tubes may be subjected to a separate heat treatment following cutting to length, depending on the material flow conditions within the plant.

In the subsequent tube finishing department, the tubes are further processed on straightening machines. The straightening operation may be preceded by a heat treatment, depending on the tube dimensions and application. Nondestructive examination facilities and the performance of a visual inspection serve to monitor the production process. Once completed, the tubes are subjected to the relevant, specified acceptance procedures irrespective of the in-process tests and inspections performed on them.
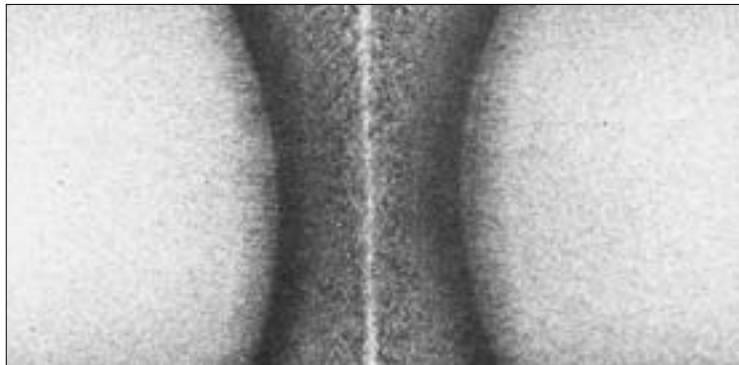

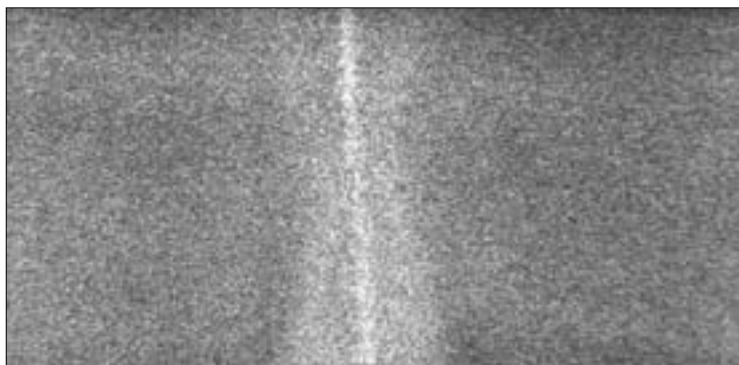Fig. 50: HF pressure weld in as-welded condition

Fig. 51: HF pressure weld following heat treatment

High-frequency induction welding process

In the high-frequency induction welding process (HFI or Induweld process), welding speeds of up to 120 m/min may be attained, depending on wall thickness and application.

Fig. 48 shows a diagrammatic representation of the process. The open-seam tube 1 to be welded is introduced in the direction of the arrow to the welding table where it is engaged by the squeeze rolls 5. These initially press together the incoming open seam edges approaching at angle 2. The high-frequency current supplied by the welding generator 4 forms an electro-magnetic field around the induction coil 3 which induces an AC voltage in the open-seam tube corresponding to a current travelling around the tube circumference. This current is concentrated at the open seam edges, and travels along edge a via point 6 to edge b and back to the circumferential plane of the induction coil, with the circuit being closed at the rear of the tube. The heated edges are pressed together and welded by the squeeze rolls 5. The internal and external ridges (weld flashes) which form are trimmed from the finished weld 7.

High-frequency conduction welding process

The high-frequency conduction welding process (also known as the Thermatool process) differs from the HFI process in that the current is input via copper sliding contacts located upstream of the welding point on the edges of the open-seam tube.

Depending on wall thickness and forming process, welding speeds of up to 100 m/min can be achieved.

Fig. 49 shows a diagrammatic representation of the current input process.

Contacts 3 and 3' are located very close to the opposing edges. The high-frequency alternating current supplied by a generator 4 is directly conducted into the open-seam tube and runs from contact 3 along the edge to point 4 and back to contact 3'. At point 6, the edges are pressed together and welded by the upsetting pressure applied by the squeeze rolls 5. The internal and external ridges or flashes are subsequently trimmed off by means of planing or similar.
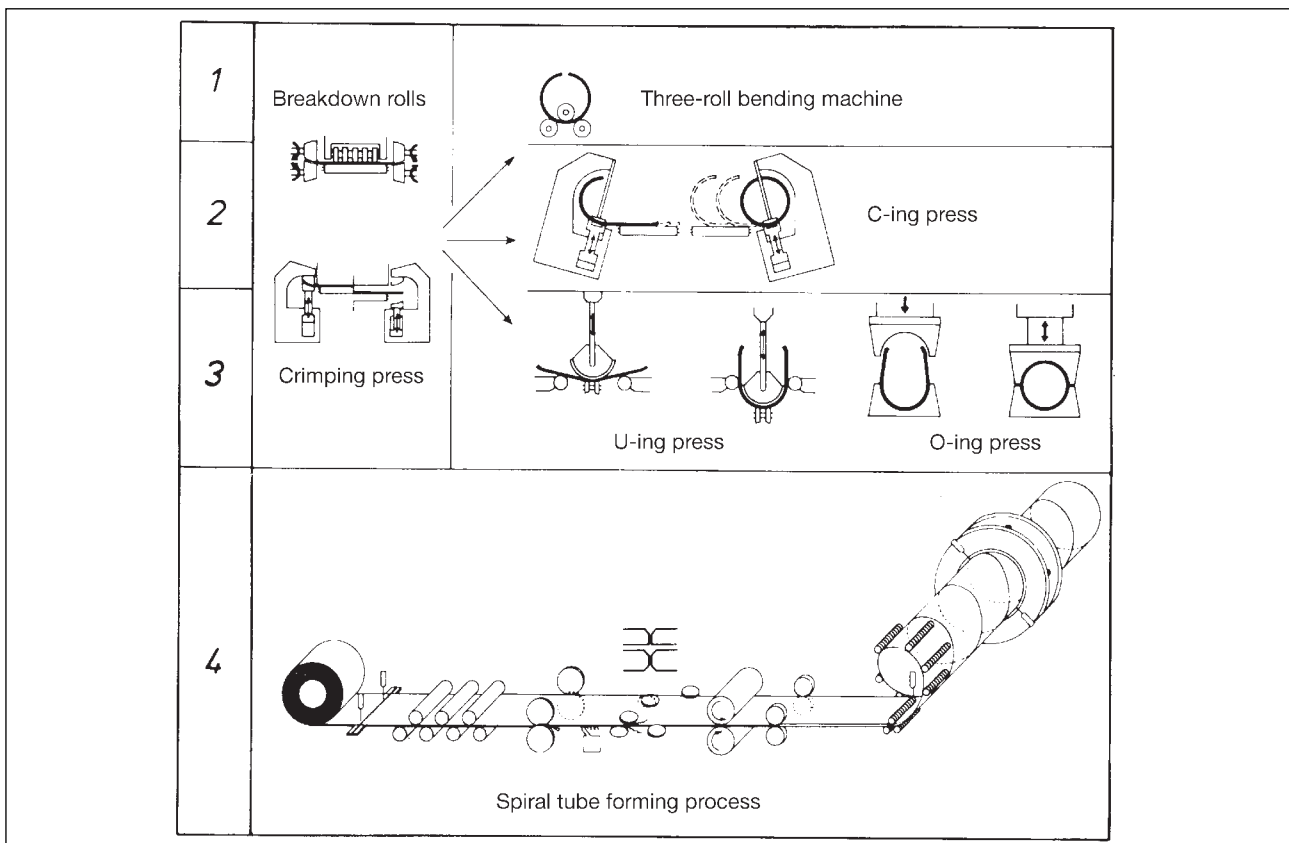
Fig. 52: Tube forming processes

4.2 Fusion welding processes

Fusion-welded steel pipe is nowadays predominantly manufactured in diameters in excess of 457.2 mm (18") and is extensively employed as large-diameter pipe for pipeline construction. The processes used for forming the pipe are essentially as follows (Fig. 52).

– The three-roll bending process for plate forming, employed as either a cold or hot forming process

– The C-ing press process for cold-forming plate

– The U-ing and O-ing press process for cold-forming plate

– The spiral tube forming process for cold-forming wide strip or plate.

In today's mass-production facilities, it is predominantly the latter two processes which are most frequently used around the world, and consequently it will be these which will be dealt with in most detail in the following.

The submerged-arc welding process or a combination of gas-shielded tack-welding with downstream submerged-arc welding has become widely accepted as the standard method for the welding of large-diameter pipe. Another major area of application for the fusion welding processes can be found in the manufacture of spiral and longitudinally welded tube and pipe of high-alloy stainless steels and nonferrous metals (e.g. titanium, aluminium, copper). The products in this case generally take the form of thin-walled tube and pipe in the diameter range from approx. 10 to 600 mm. Aside from the pure TIG process, various combined welding methods are also employed (e.g. TP + TIG, TP + MIG, TP + SAW) (abbreviations explained under section 4.2.2).

4.2.1 Submerged-arc welding process

The submerged-arc welding process is an electric fusion welding method performed with a concealed arc. In contrast to arc welding with welding electrodes, the arc in this case is hidden from view and burns under a blanket of slag and flux. One of the characteristic features of submerged-arc welding (SAW) is its high deposition rate, which essentially stems from the high current strength which is applied combined with a favourable heat balance.

The filler metal employed takes the form of coiled, bright welding wire which is continuously fed into the molten metal pool by feed rolls at a speed dictated by the deposition rate. Just above the parent metal (pipe), the welding current is conducted by sliding contacts into the wire electrode and returned via the ground lead connected to the pipe material (Fig. 53).
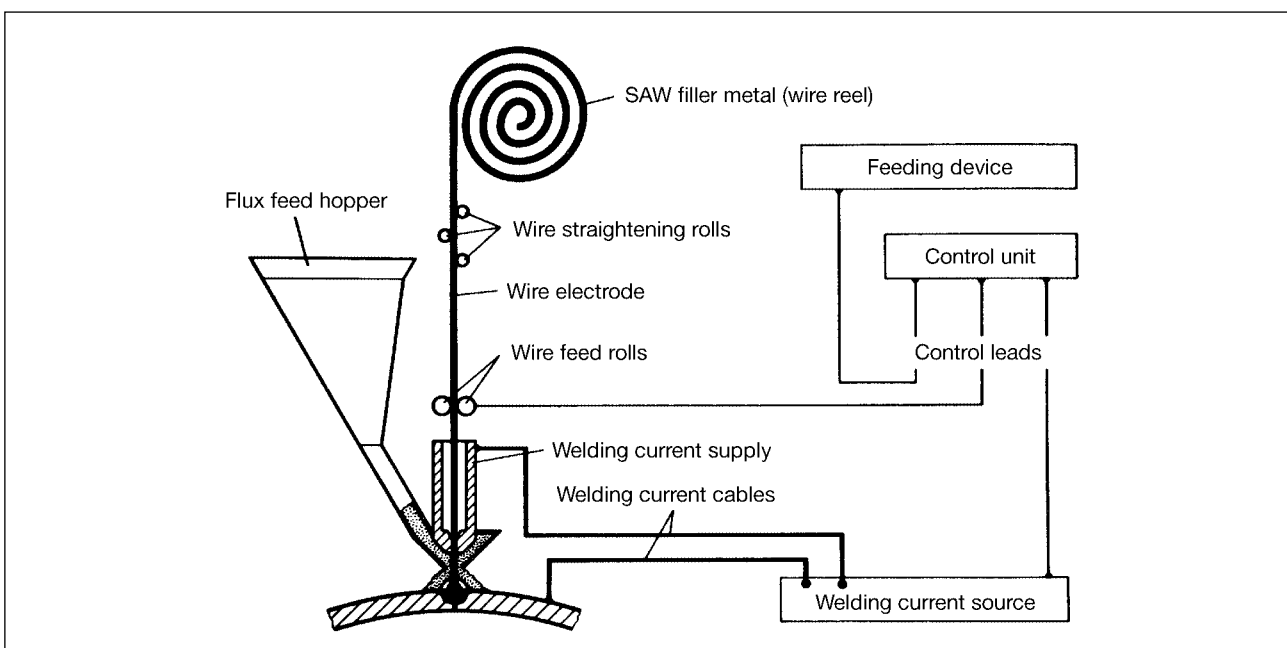

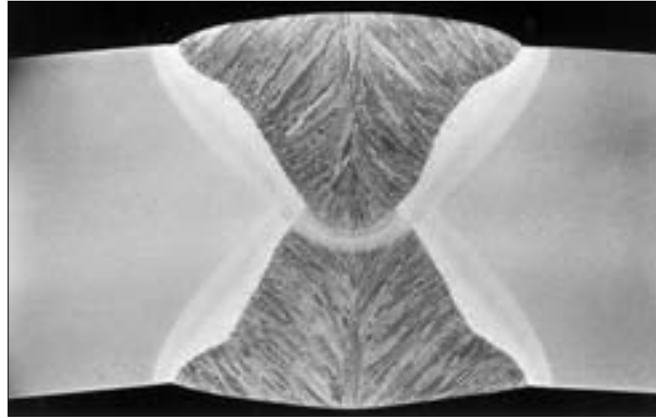Fig. 53: Submerged-arc welding process

Fig. 54: Submerged-arc weld

The arc causes the incoming wire and the open seam edges to melt. A portion of the similarly continuously fed welding flux is also melted by the heat of the arc, causing it to form a liquid covering of slag which shields the weld pool, the melting wire electrode and also the arc itself against atmospheric influences.

In addition, the welding flux also facilitates formation of the weld bead and serves as a donor of alloying elements in order to compensate for melting and oxidation losses. In many cases, it is also used specifically to alloy the weld metal in order to impart to it specific mechanical and chemical properties. As the arc moves on, the liquid slag which is left behind solidifies.

The welding flux which has not melted is recovered by vacuum extraction and re-used. The slag is easily removed once it has solidified. The chemical composition of the wire electrode and the welding flux must be matched to the material being welded. The submerged-arc welding of pipes in the usually applied two-pass method (i.e. first run followed by sealing or backing run) is normally performed with the inside pass first and the outside pass second. This ensures that the two passes sufficiently overlap (Fig. 54).
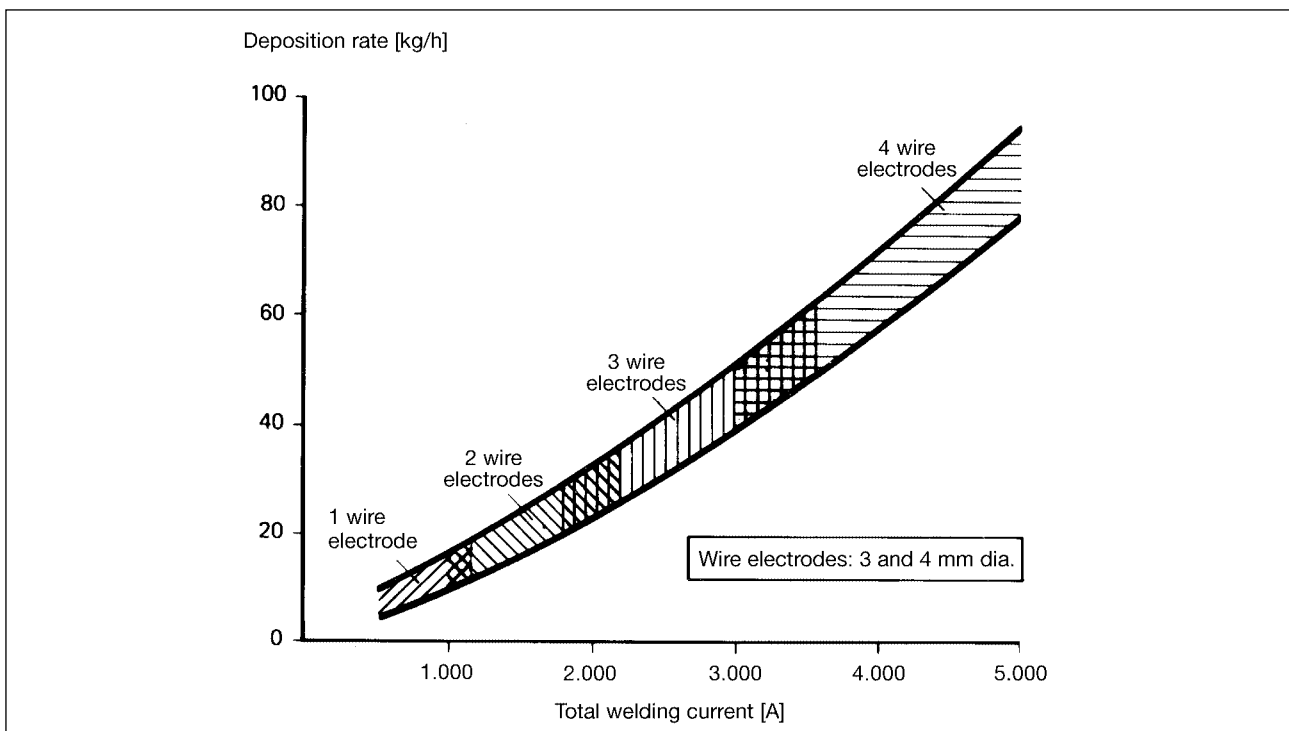

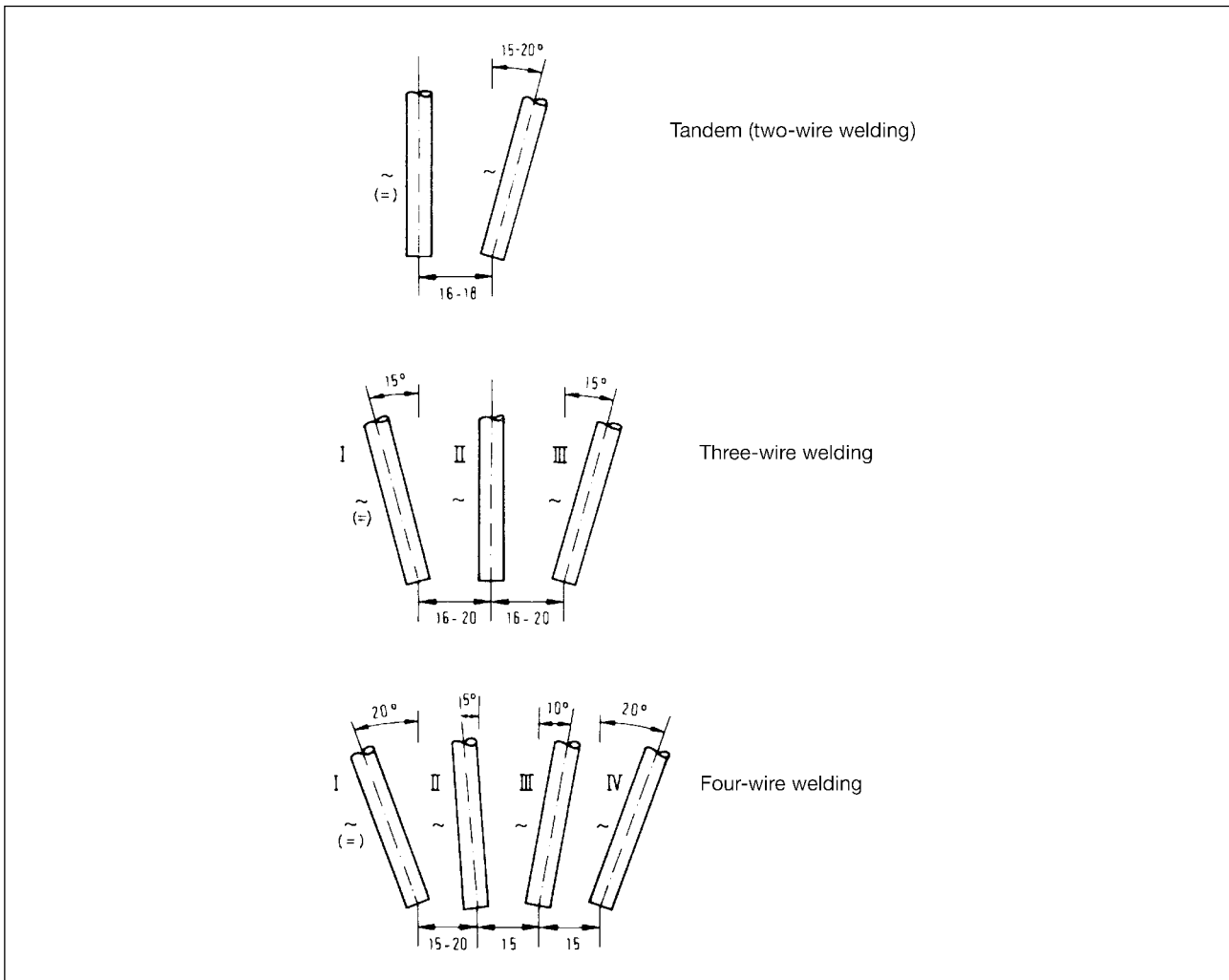Fig. 55: Deposition rate in submerged-arc welding

Fig. 56: Wire configurations in multi-wired submerged-arc welding (wire spacing intervals in mm)

The result is a fusion weld which normally does not require any further heat treatment. Submerged-arc welding can be performed with both direct and alternating current, and in multi-wire systems a combination of DC and AC can be used. The efficiency of this welding process is characterized by the rate of filler metal deposited per unit time (rate of deposition) and the resultant – invariably high – welding speed which is possible.

The rate of deposition can be raised by increasing the welding current. However, owing to the limited current carrying capacity of the welding flux, performance can only be increased in single-wire welding up to a maximum input of around 1200 A.

Any increase in the rate of deposition beyond this limit requires the employment of several wire electrodes. This then allows a higher overall current to be applied for the welding work without the danger of the current carrying capacity of the flux being exceeded at any of the individual wire electrodes. In practical operations, increased performance is obtained by employing a multi-wire welding configuration with 2, 3 or 4 electrodes.

Fig. 55 shows the rate of deposition as a function of welding process.

The wire configurations employed in multi-electrode welding are shown in Fig. 56.

The higher rate of deposition available with multi-wire welding converts readily into a higher welding speed under practical production conditions.

With today's high-performance fluxes, the three-wire welding process is usually sufficiently efficient for wall thicknesses up to 20 mm.

Where wall thicknesses exceed 20 mm, an additional, fourth wire is used in order to maintain welding speed and thus production efficiency.

A prerequisite for the cost-effective application of multi-wire welding is that the process parameters be optimized in order to ensure reliable achievement of the specified quality requirements imposed on the weld.

In practice, the welding speeds attained range between 1 and 2.5 m/min, increasing in some cases to 3 m/min, depending on the welding process, wall thicknesses and type of flux used.

4.2.2 Gas-shielded arc welding processes

Like submerged-arc welding, gas-shielded arc welding is an electric fusion process.

The weld pool is produced by the effects of an electric arc. The arc is quite visible as it burns between the electrode and workpiece. The electrode, arc and weld pool are protected against the atmosphere by an inert or active shield gas which is constantly fed into the welding zone.

The gas-shielded welding processes are classified according to the type of electrode and gas employed.

According to DIN 1910 (Part 4), the various processes divide into two main categories:

– Gas tungsten arc welding
  – Tungsten inert gas welding (TIG)
  – Tungsten plasma arc welding (TP)
  – Tungsten hydrogen arc welding (THG)

– Gas metal arc welding
  – Metal inert gas welding (MIG)
  – Metal active gas welding (MAG)

The processes predominantly employed for tube and pipe manufacture are the TIG, MIG and MAG methods.

The TIG and MIG welding processes are mainly used for the manufacture of stainless steel tube. In the TIG welding process, the arc burns between a non-melting tungsten electrode (non-consumable electrode) and the workpiece. Any filler metal is fed predominantly without any direct current input. The shield gas flows from a gas nozzle and protects the electrode, filler metal and molten pool from contact with the air.

The shield gas is inert and generally takes the form of argon, helium or mixtures of these.

In the MIG and MAG welding processes, in contrast to the TIG process, the arc burns between the workpiece and a melting, consumable electrode, i.e. the donor of the filler metal.

The shield gas employed in MIG welding is inert and again generally takes the form of argon, helium or mixtures of these two. In MAG welding, the shield gas is active. It may consist of pure CO_2 or of a gas mixture (generally made up of the components CO_2, O_2 and argon).

The MAG process is being increasingly used for tack-welding in the manufacture of spiral and longitudinally welded large-diameter pipe. The tack weld also serves as the weld pool backing for the subsequent submerged-arc welding process. The prerequisites for an optimum weld are a precise edge preparation (double-V butt joint with wide root faces) and a good, continuous tack weld. In large-diameter pipe production, the welding speeds for the tack weld range from approx. 5 to 12 m/min.

Fig. 57: Planing the two longitudinal edges including the run-in and run-off tabs
(Works photo: EUROPIPE GmbH)
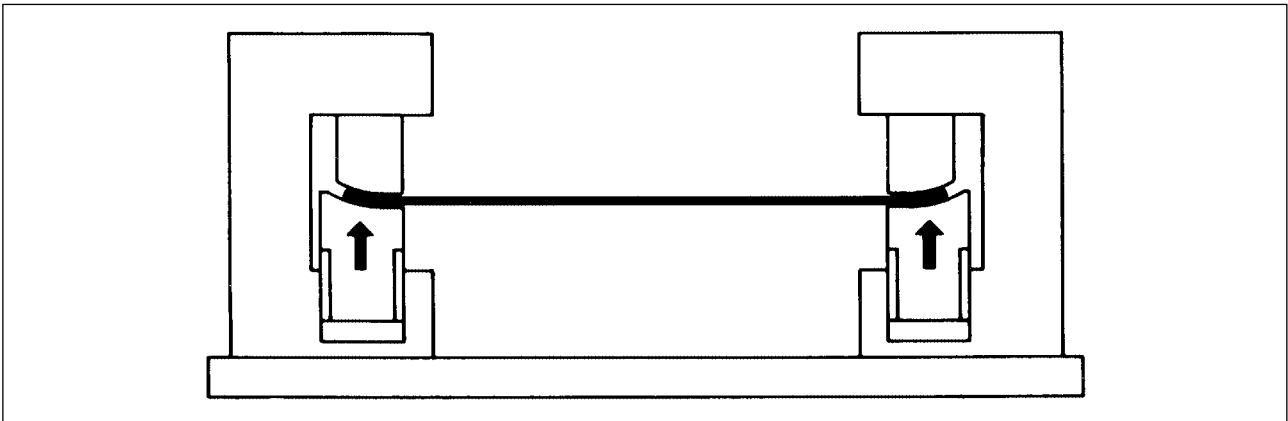
Fig. 58: Crimping the longitudinal plate edges

4.2.3 The production of longitudinally welded pipe (U-ing/O-ing process)

The plates employed for longitudinally welded pipe are formed on presses featuring open dies for the U-ing and closed dies for the O-ing operation. The process is also sometimes referred to as the UOE process (U-ing, O-ing, Expanding) and is applied in the manufacture of longitudinally welded large-diameter pipe in individual lengths up to 18 m. Modern plants employing this process are variously designed for a pipe diameter range from approx. 400 to 1620 mm. Depending on the material and diameter, the wall thicknesses range from 6 to 40 mm. The starting material invariably takes the form of steel plate as indicated above.

At the start of the production process, run-in and run-off tabs are welded on to the flat plates in order to ensure that the lead and trail phenomena associated with submerged-arc welding occur outside the actual pipe metal.

Before the plate is bent into an open-seam pipe by the various stages and forming presses employed, the two longitudinal edges undergo machining in a planer to ensure that they are parallel, and the welding bevel required for the plate thickness concerned is also cut (Fig. 57).

Fig. 59: Forming in the U-ing press
(Works photo: EUROPIPE GmbH)

Fig. 60: Completion of the open-seam pipe in the O-ing press
(Works photo: EUROPIPE GmbH)

Fig. 61: Continuous longitudinal tack-welding of large-diameter line pipe
(Works photo: EUROPIPE GmbH)

In the first forming stage (Fig. 58), the plate is crimped in the area of its longitudinal edges. The bending radius corresponds roughly to the diameter of the open-seam pipe. Crimping is performed in special forming presses.

In the second stage (Fig. 59), the plate is bent into a U-shape in one operation involving a circular-radius tool pushing the plate down between two supports. Toward the end of the operation, the distance between the supports is reduced in order to apply a small degree of overbend to counter the spring-back effect.

In the third forming stage, the U shape is placed in the O-ing press to produce, in a single operation, the round open-seam pipe.

Fig. 62: Longitudinal inside pass submerged-arc welding of large-diameter line pipe
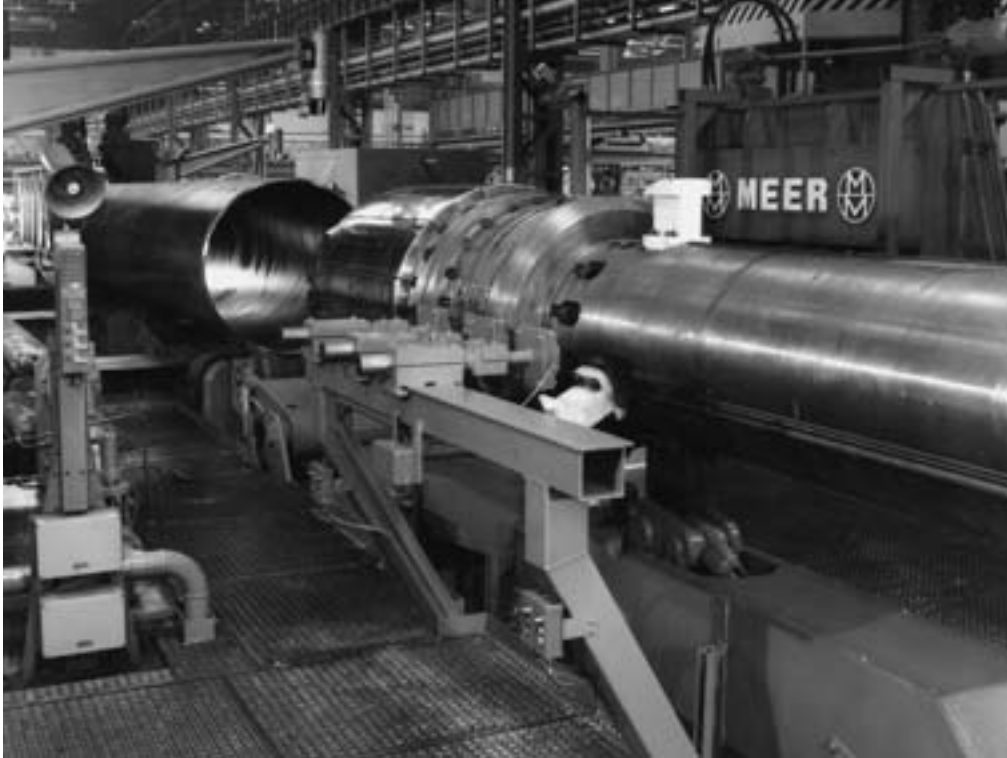(Works photo: EUROPIPE GmbH)

Fig. 63: Mechanical expander
(Works photo: EUROPIPE GmbH)

The deformation processes performed in the U-ing and O-ing presses are coordinated so as to ensure that the spring-back effect is effectively countered and the open-seam pipe is as circular as possible with the longitudinal edges flush. These operations require high press loads.

Fig. 60 shows an O-ing press with a capacity of 600 MN (currently the largest O-ing press in the world).

The edges of the open-seam pipe are then pressed together (eliminating any offset) in tack-welding stands, which may be designed in the form of roller cages, and then joined by a continuous seam deposited by automatic MAG welders (Fig. 61). Depending on the pipe thickness, the welding speed applied can range from 5 to 12 m/min.

The tack-welded pipes are then conveyed by a roller table and distribution system to the submerged-arc welding stands where, at separate lines, they are provided first with the inside and then with the outside pass. These runs are deposited by moving the pipe on a carriage under a stationary welding head. For the inside pass, the welding head is mounted on an arm which extends inside the pipe. In order to preclude the possibility of weld offset, both the inside and outside pass welding heads are continuously monitored and controlled for perfect alignment to the weld centerline. Any of the above-described multi-wire SAW processes may be employed, depending on the pipe dimensions (diameter and wall thickness) (see section 4.2.1).

Fig. 62 shows the inside pass welding lines.

Following welding, the pipes are taken to the finishing department.

The as-welded pipes are not yet able to satisfy the tolerance specifications in relation to diameter and roundness. In the finishing department, therefore, they undergo a thorough inspection and are sized by cold expansion (Fig. 63). This operation is performed by hydraulic or mechanical expanders. The amount of expansion applied is approx. 1 %, and this value is taken into account when determining the initial circumference of the open-seam pipe.

The production process is completed in the finishing department with the machining of the pipe ends and any necessary rework.
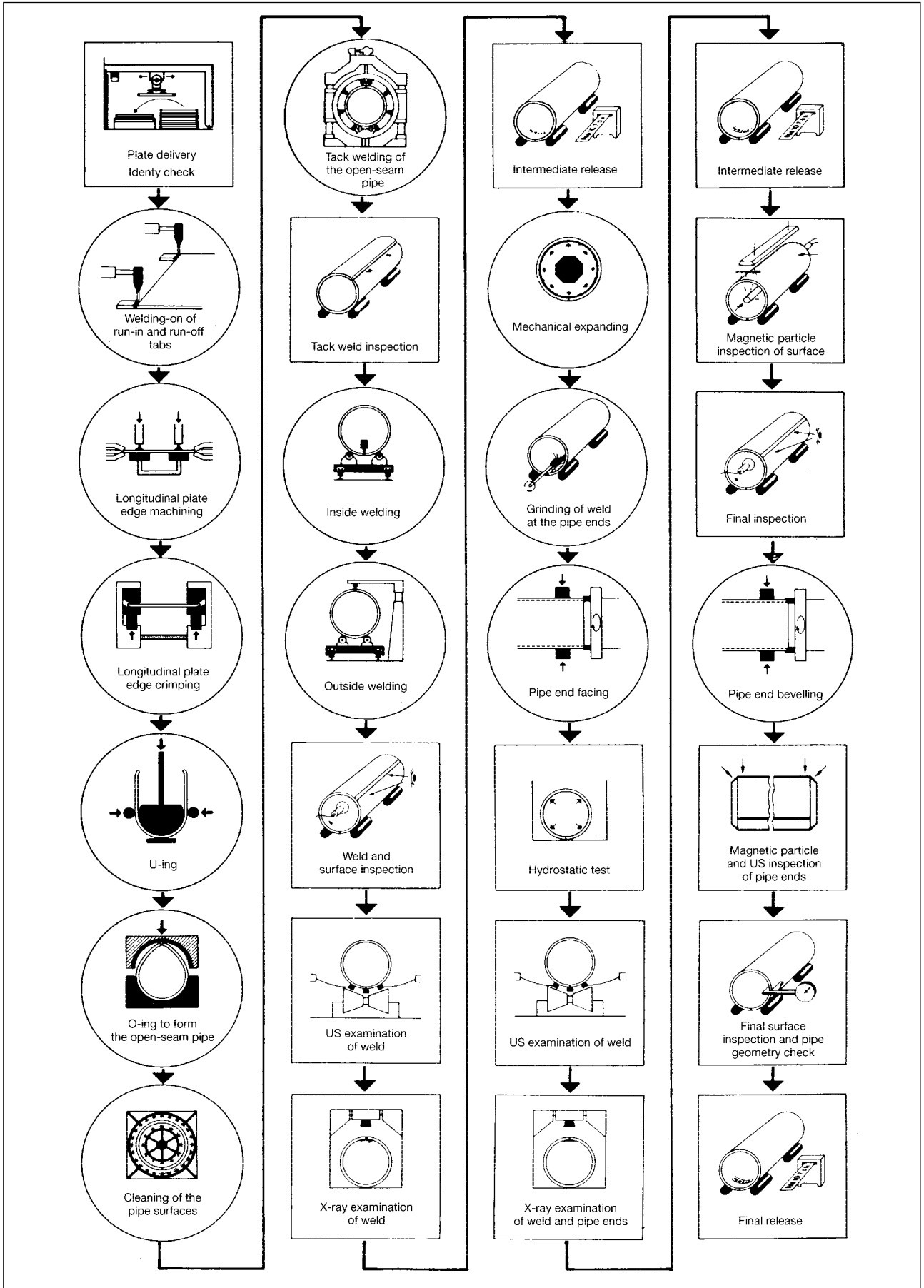
Fig. 64: Schedule of production and test operations in a modern plant for the longitudinal welding of large-diameter line pipe. Circle = production stage; Square = test stage
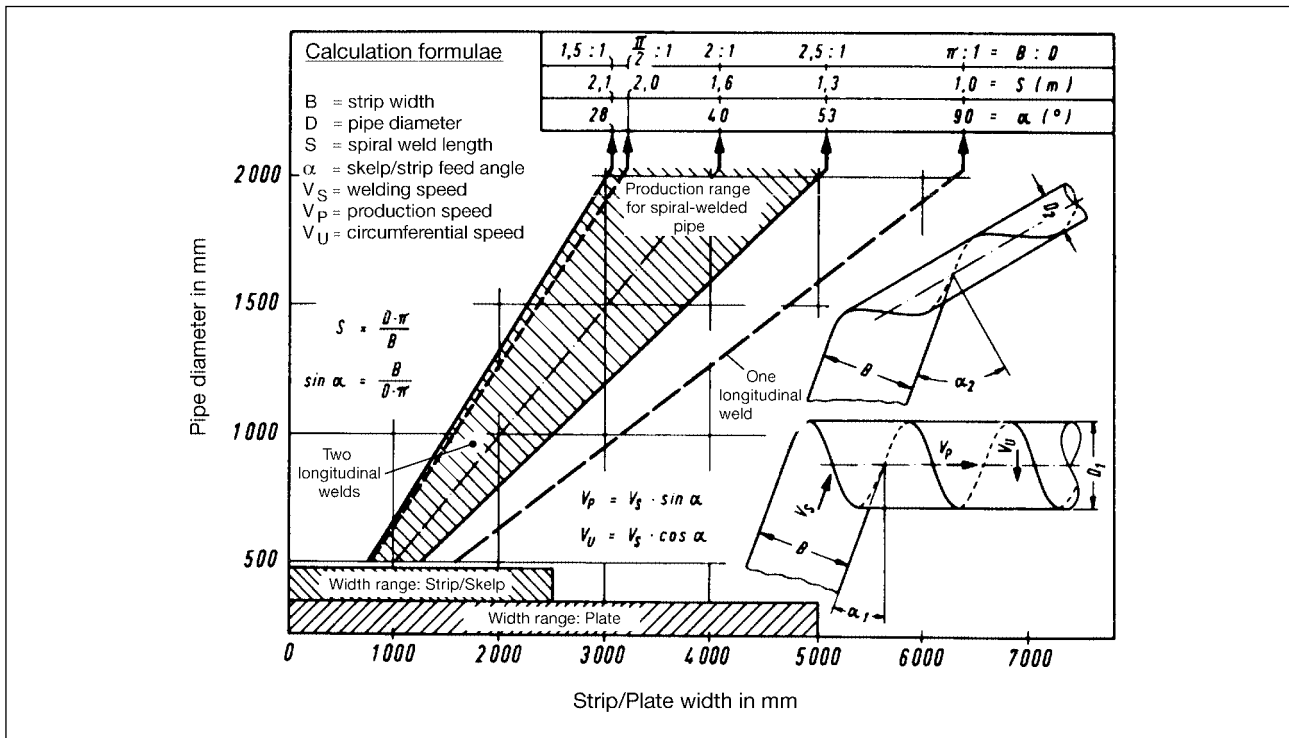
Fig. 65: Strip width in relation to pipe diameter
(Comparison between longitudinal welding and spiral pipe manufacture)

Prior to the final pipe end machining operation, the pipes are subjected to a hydrostatic test. A final ultrasonic inspection is then performed over the entire length of the weld zone. Indications revealed by this automatic US examination, and also the weld regions at the ends of the pipes, are additionally checked by X-ray inspection. All pipe ends are also ultrasonically inspected for laps and laminations.

As part of the quality assurance regime, both in-process nondestructive inspections and offline mechanical tests are performed as production proceeds.

After the pipes have successfully passed through all the test and inspection stages, including the dimensions check, they are presented for final inspection and acceptance.

The most important fabrication and inspection stages incorporated within a modern plant for the manufacture of large-diameter pipes are indicated in diagrammatic form in Fig. 64.

4.2.4 Spiral pipe production

In the production of spiral pipe (also known as helical seam pipe), hot strip or sheet is continuously shaped into a tube by a spiral forming facility applying a constant bending radius, with the abutting strip edges also being continuously welded inline.

In contrast to longitudinally welded pipe production, in which each pipe diameter requires a certain plate width, spiral pipe production is characterized by the fact that various pipe diameters can be manufactured from a single strip (skelp) or plate width.

This is because the approach angle of the strip as it is fed into the forming unit can be modified. The smaller this inlet angle, the larger the pipe diameter (for a given strip width).

The technical and economic optimum in spiral pipe fabrication lies at a ratio of pipe diameter to starting material width of between 1:2 and 1:2.2.

Fig. 65 shows the ratio of pipe diameter to starting material width in a comparison between longitudinally welded and spiral pipe production, and also the mathematical dependences which apply in spiral pipe production between feed angle, strip/skelp width and pipe diameter.

At the current state of large-diameter pipe production technology, the range of pipe diameters covered by the spiral welding process lies between approx. 500 and 2500 mm. The starting material employed for pipe wall thicknesses up to approx. 20 mm takes the form of wide hot-rolled strip. Plate in individual lengths up to 30 m are usually required for pipe wall thicknesses in excess of 20 mm.

Spiral pipe production methods fall into two main categories:

– Facilities with integrated forming and SAW welding lines

– Facilities with separate forming and SAW welding lines

4.2.4.1 Spiral pipe production in integrated forming and SAW welding lines

The integrated forming and SAW welding line can be regarded as the more conventional spiral pipe manufacturing facility. In this configuration, the production process comprises

– a strip preparation stage, and

– the pipe forming operation with simultaneous inside and outside pass submerged-arc welding.

Aside from welding the strips or plates together (this forms the skelp), the strip preparation stage also serves to straighten the skelp and trim it to an exact width. The skelp edges have to be accurately machined within close tolerances, and a defined edge crimping operation also has to be performed in order to prevent impermissible ridge formation/peaking if the pipe forming operation is to be successful.

Fig. 68 (see also section 4.2.4.2) provides a diagrammatic representation of the strip preparation and pipe forming processes in the case of a two-stage spiral pipe manufacturing configuration.

The strip being fed in from the uncoiler is joined to the trailing end of the previous coil by submerged-arc welding from above. The weld is deposited along the face which later will form part of the inside surface of the pipe. The outside SAW pass is deposited in a separate line on the finished pipe. The strip/skelp then runs through a straightening mill and is cut to a constant width by an edge trimmer. Additional tools also bevel the edges in preparation for the main SAW welding operation. Before entry into the forming section, the strip edges are crimped in order to avoid ridging/peaking at the join.

In an integrated facility, the strip preparation stage is immediately followed by the forming process with simultaneous inside and outside submerged-arc welding. A pinch-roll unit feeds the skelp at a predetermined entry angle into the forming section of the machine.

The purpose of the forming section is to bend the exactly prepared skelp of width B at a certain feed angle into a tubular cylinder of diameter D in line with the mathematical relationships indicated in Fig. 65.

Copper welding rail at 6 o'clock point
3-roll bending system
Inside diameter roller star configuration
Copper welding rail at 6 o'clock position

Copper welding rail at 6 o'clock point
3-roll bending system
Ouside diameter roller cage
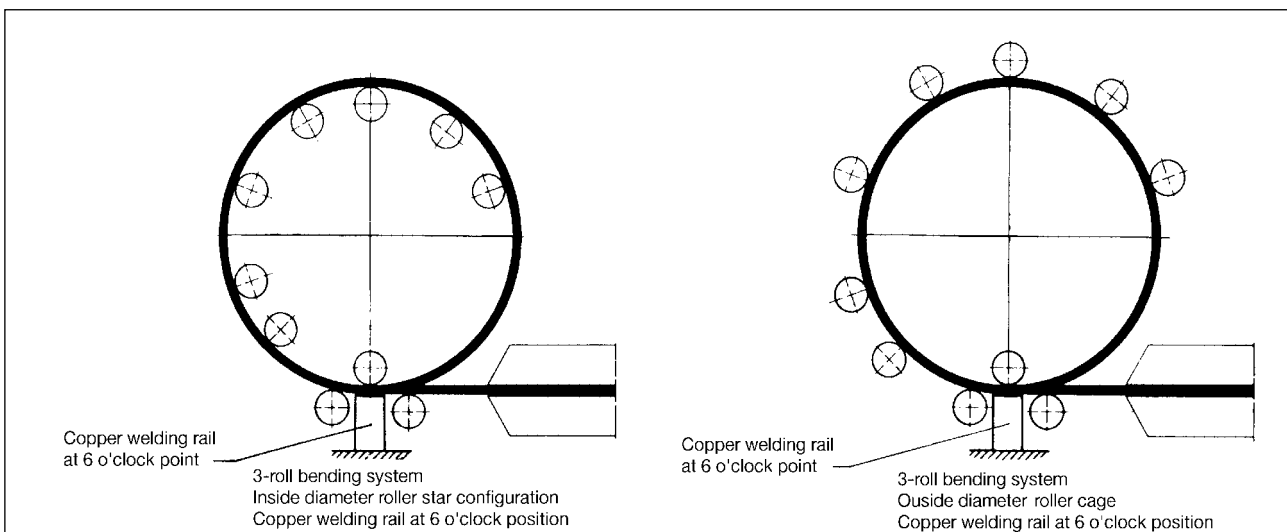Copper welding rail at 6 o'clock position

Fig. 66: Spiral pipe forming processes

Fig. 67: Hydrostatic testing line with downstream pipe end machining section
(Works photo: Salzgitter Großrohre GmbH)

Various forming techniques may be applied to produce the spiral pipes. Aside from the direct forming shoe process – which has its limitations – there are two main methods which are generally employed (Fig. 66):

– 3-roll bending with an inside diameter roller cage and

– 3-roll bending with an outside diameter roller cage.

In a 3-roll bending system, numerous individual shaping and guiding rollers are employed rather than a single forming roll.

The roller cage serves to fix the pipe axis and maximize the roundness of the pipe in order to ensure offset-free convergence of the strip edges at the welding point. This facilitates attainment of accurate pipe dimensions, so that the pipe exiting from the machine is already manufactured to within the standardized diameter, roundness and straightness tolerances.

Expansion/sizing of the pipes after welding is therefore not necessary.

In the spiral pipe forming and SAW welding machine, the converging strip edges are first inside-welded at approximately the 6 o'clock position and then, half a pipe turn further, outside-welded in the 12 o'clock position. Welding head alignment to the weld centre, and gap control, are performed automatically.

The manufactured pipe string is subsequently cut to length by a flying parting-off device.

The individual pipes are then taken to the finishing department where the production process is completed by machining of the pipe ends and the performance of any necessary rework. Prior to pipe edge machining, the pipes undergo a hydrostatic test (Fig. 67). The entire weld region is then ultrasonically inspected, with the weld zones at the pipe ends also being X-rayed.

In addition, each pipe end is also ultrasonically inspected over its full circumference for laps/laminations. If required, the weld zone and also the parent metal may be ultrasonically inspected following the hydrostatic test.

As part of the quality assurance regime, both in-process nondestructive inspections and offline mechanical tests are performed as production proceeds. After the pipes have successfully passed through all the test and inspection stages, including the dimensions check, they are presented for final inspection and acceptance.

The productivity of this process is determined by the speed of the submerged-arc welding operation. The pipe forming process is capable of substantially higher production speeds.

In order better to utilize the efficiency of the spiral pipe forming section, newer plants are being designed on the basis of separate forming and SAW welding lines.

In this case, the spiral pipe forming machine features a tack-welding facility which is capable of production speeds commensurate with those of the forming section.

The submerged-arc welding of the seams is then performed offline in a number of separate welding stands.

4.2.4.2 Spiral pipe production with separate forming and SAW welding lines

The main feature of this new technology is that there are two separate manufacturing processes:

Stage 1 – Pipe forming with integral tack welding

Stage 2 – Inside and outside submerged-arc welding on separate welding stands.

Fig. 68 shows a diagrammatic representation of the pipe forming and tack welding facility.

$$\sin \alpha = \frac{B}{\pi \cdot D}$$

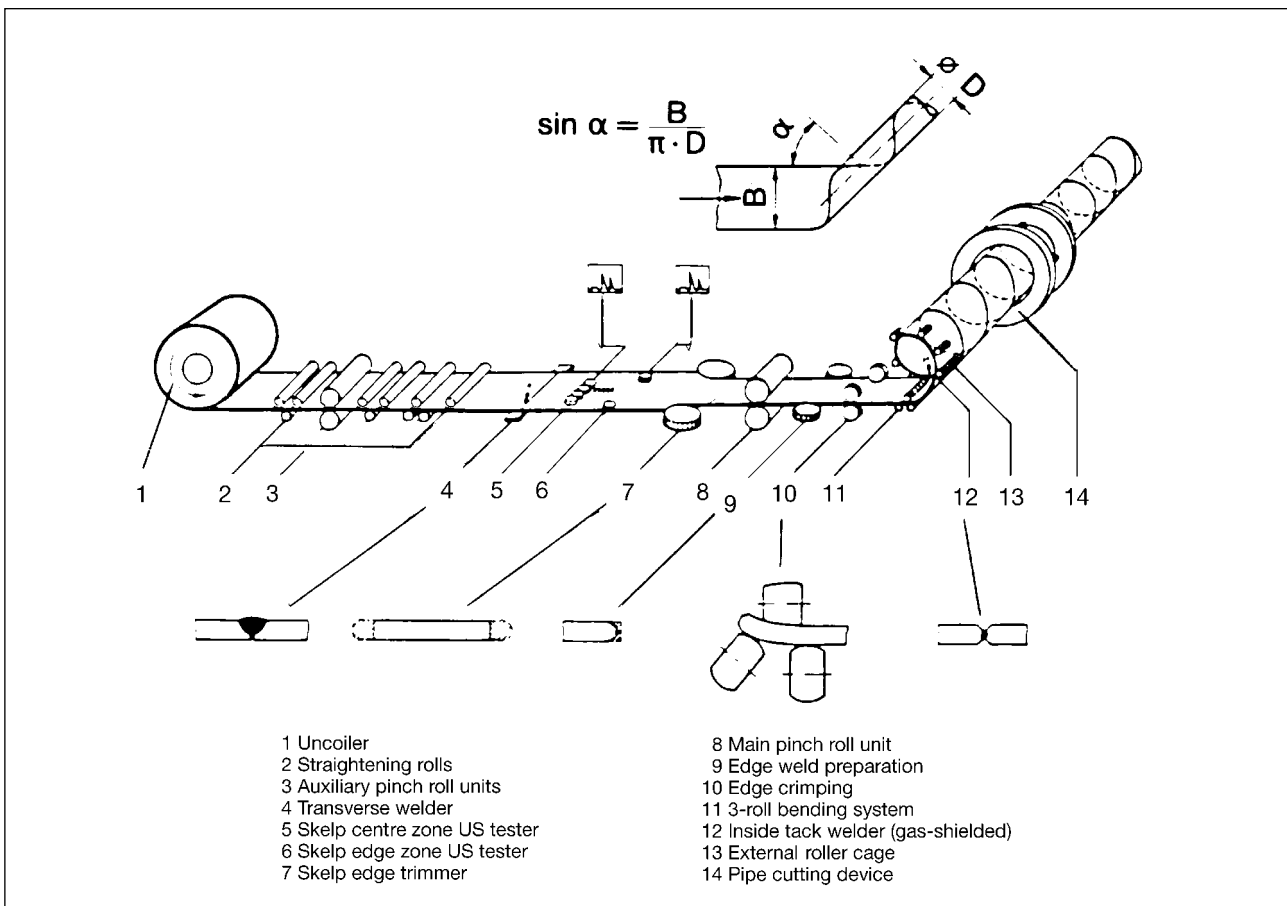|	
1 Uncoiler	8 Main pinch roll unit
2 Straightening rolls	9 Edge weld preparation
3 Auxiliary pinch roll units	10 Edge crimping
4 Transverse welder	11 3-roll bending system
5 Skelp centre zone US tester	12 Inside tack welder (gas-shielded)
6 Skelp edge zone US tester	13 External roller cage
7 Skelp edge trimmer	14 Pipe cutting device

Fig. 68: Diagrammatic representation of a spiral pipe manufacturing line (pipe forming and tack-welding facility)
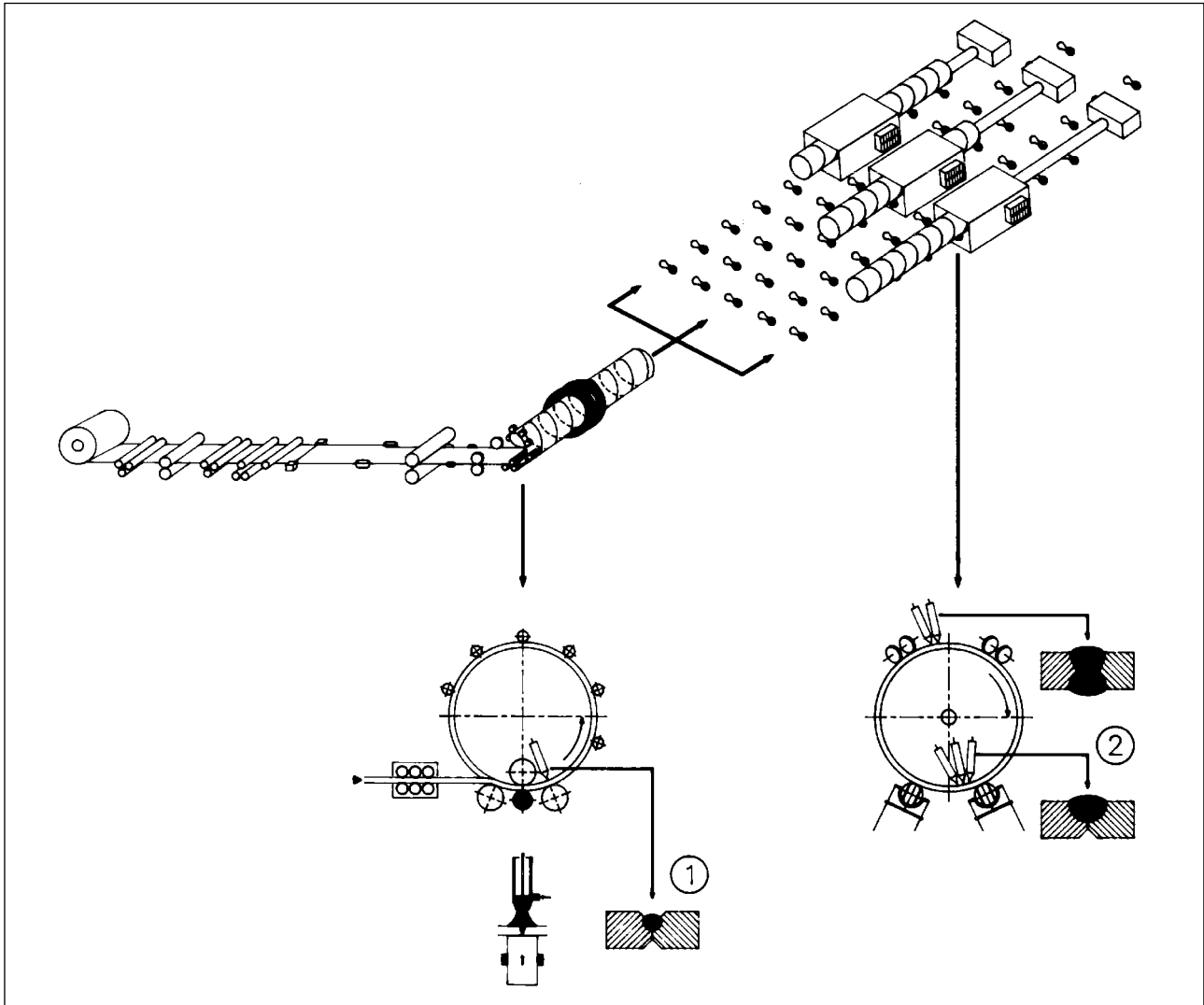
Fig. 69: Diagrammatic illustration of the spiral pipe manufacturing process with separate forming and welding lines
1 Forming and tack welding; 2 Combined two-pass submerged-arc welding stands (inside and outside passes performed simultaneously)

Fig. 69 shows a schematic of the distributed spiral pipe manufacturing concept with separate forming and SAW welding facilities.

Aside from the higher cost-efficiency of this process (achieved owing to the faster forming and tacking operation) there are also technical benefits derived from separating the pipe forming stage from the main welding stage, as both operations can be individually optimized.

In the spiral pipe forming section, the merging strip edges (one on the already formed pipe section and the other on the incoming skelp) are continuously joined by inside tack welding.

The tack-welding process is performed by the MAG method (see section 4.2.2) at a speed of 12 m/min in the region of the 6 o'clock position. The shield gas employed is carbon dioxide. The weld edges below the welding position run with virtually no gap over a rigidly fixed guide roller.

A flying parting-off device cuts the tack-welded pipe string into the required individual lengths. This pipe cutting process constitutes the last operation performed in the spiral forming machine. Because of the high tack-welding speeds achieved, it has become necessary to replace the conventional oxy-acetylene torch cutter by high-speed plasma torches operating with water injection.

The cut-to-length pipes are then fed to the downstream combined two-pass SAW stands for final welding.

Fig. 70: Computer-controlled combined two-pass submerged-arc pipe welding stand for simultaneous inside and outside weld deposition
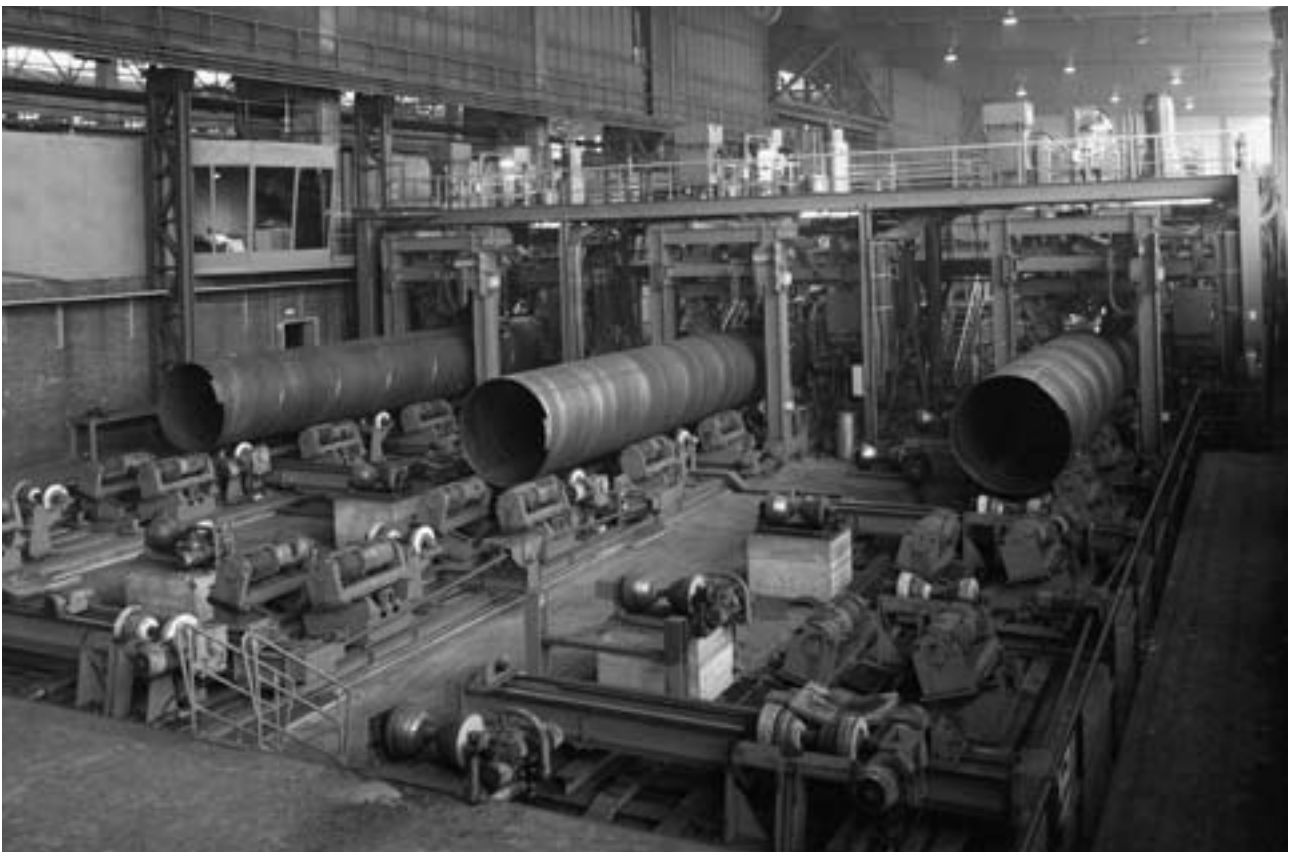(Works photo: Salzgitter Großrohre GmbH)

Fig. 71: Integrated plant with three combined submerged-arc spiral pipe welding lines for simultaneous inside and outside weld deposition
(Works photo: Salzgitter Großrohre GmbH)

1 Coil store
2 Coil preparation
3 Uncoiler
4 Straightening stand
5 Auxiliary pinch roll unit
6 Transverse welder
7 Skelp centre zone US tester
8 Skelp edge zone US tester
9 Skelp edge trimmer
10 Main pinch roll unit
11 Edge weld preparation
12 Edge crimping facility
13 Forming system
14 Inside tack-welding unit
15 Pipe cutting device
16 Production data input
17 Pipe preparation for
   submerged-arc welding
18 Welding stands
   Inside/outside SAW

19 Visual inspection
   Inside/outside
20 Welding stand
   Outside pass joint welding
21 Pipe finishing section
22 Pipe cutting line
23 Welding stand
   Girth weld
24 Hydrostatic test
25 Pipe end machining
26 Pipe weighing machine
27 US examination
   Weld/pipe ends
28 X-ray examination stand
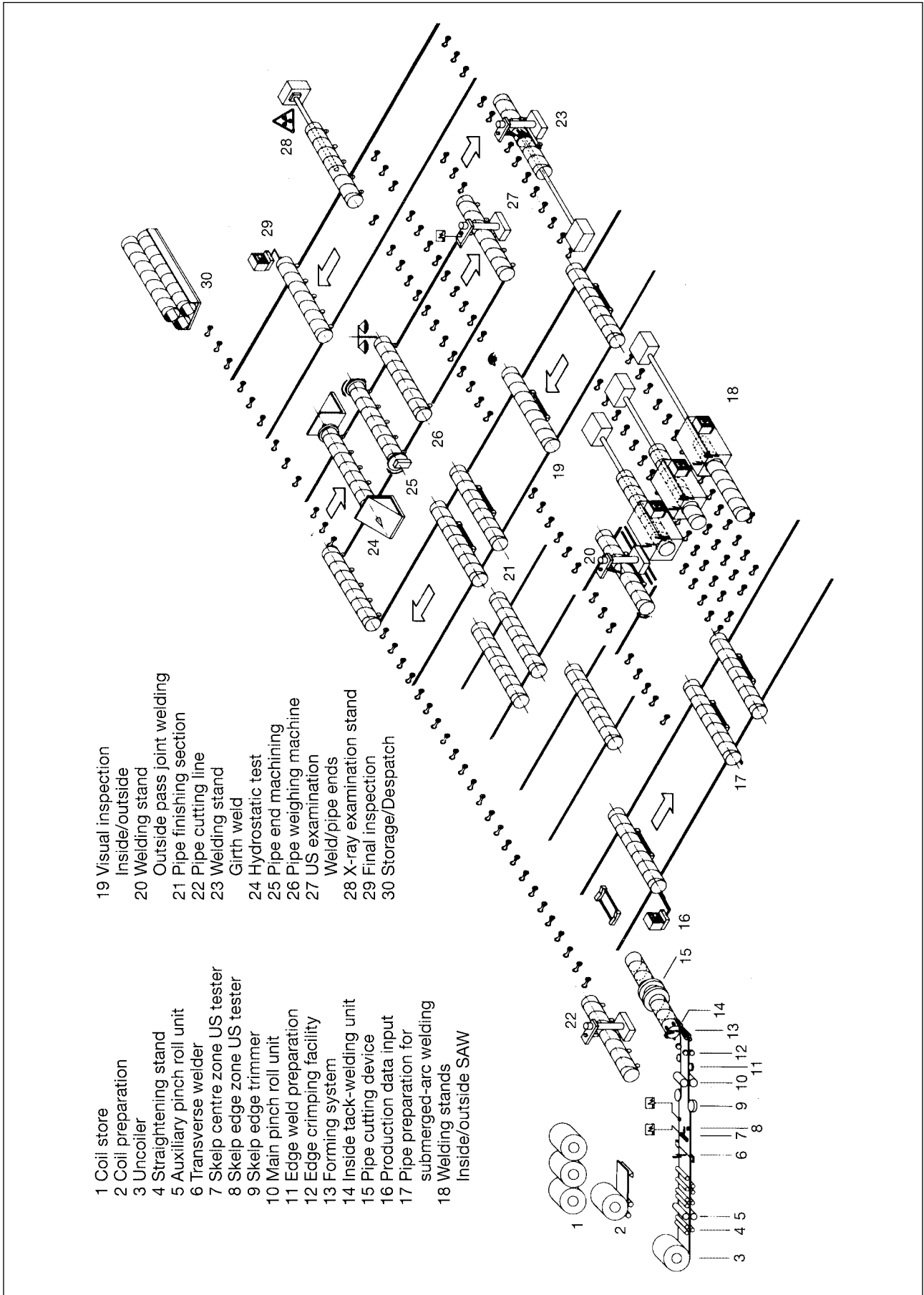29 Final inspection
30 Storage/Despatch

Fig. 72: Diagrammatic representation of the production flow of a spiral pipe manufacturing plant with separate forming and welding lines

A special roller table rotates the pipe in precise accordance with its spiral joint, so enabling the SAW welding heads to perform first the inside and then the outside passes. Precise weld centerline alignment control of the inside and outside welding heads is required in this operation in order to minimize weld offset.

Fig. 70 shows a computer-controlled spiral pipe welding stand designed for simultaneous inside and outside pass SAW.

Fig. 71 shows an integrated facility with three combined SAW spiral pipe welding stands for simultaneous inside and outside pass welding.

The two- or three-wire method is employed for the inside and outside pass welding operations (see section 4.2.1).

Aside from a few modifications, the subsequent production stages such as pipe end machining, hydrostatic testing and also the nondestructive examinations and mechanical tests, are in principle the same as those applied in the conventional spiral pipe manufacturing process.

Here again, a high standard of quality is achieved by in-process quality control activities which are performed after every stage of production. The results of these tests and inspections are immediately fed back to the individual production stage concerned in order to ensure continuous product quality optimization.

Fig. 72 shows the production flow with all the fabrication, test and inspection stages employed in a spiral pipe manufacturing facility featuring separate forming and welding lines.

5 Bibliograhy

Handb. d. Eisenhüttenw. Walzwerkswesen: Vol. 3, Publisher J. Puppe. Düsseldorf 1939, Verlag Stahleisen, Berlin 1939.

Verlag Julius Springer Tube Mill Practice. Association of Iron & Steel Engineers, Pittsburgh 1953

Neumann, H.: Stahlrohrherstellung. VEB Deutscher Verlag f. Grundstoffindustrie, 3rd edition, Leipzig 1970

Müller, H. G. and M. Opperer: Das Stahlrohr, Düsseldorf 1974, Verlag Stahleisen

Herstellung von Rohren. Publisher Verein Deutscher Eisenhüttenleute. Düsseldorf 1975, Verlag Stahleisen

Hütte: Taschenbuch für Eisenhüttenleute. 5th edition, Berlin 1961, Verlag Wilhelm Ernst & Sohn

Vogt, J.: Herstellung nahtloser Rohre auf einer modernen Rohr-Stoßbankanlage. Special reprint from DEMAG-Nachrichten, Vol. 180

Freckmann, S.: Abmessungsbereiche nahtloser Rohre bei den heute gebräuchlichen Herstellverfahren. Special reprint: Blech, Rohre, Profile, 12/1970

Asselwalzwerke zur Herstellung dickwandiger Rohre. Meer-Bericht 1192

Groß, H.: Das Umformen von Stahl auf hydraulischen Strangpressen. Special reprint from Klepzig Fachberichte 75 (1967) 11

Mechanische Strangpressen zur Herstellung von Stahlrohren. Meer-Bericht 142/I

Schrinner, W. D.: Werkzeuge zum Stangpressen von Stahl. Bänder Bleche Rohre 12 (1972) 9, pp. 407/10

Rohrwalzwerke zum Maßwalzen. Reduzieren, Streckreduzieren. Meer-Bericht 143/1

Bohnen, I. K.: Stahlrohrziehereien (II). Bänder Bleche Rohre, June 1963, pp. 305/14

Sander, W.: Tendenzen bei der Entwicklung von Rohrzieh- und Rohrwalzmaschinen. Special reprint: Blech, Rohre, Profile, Sept. 1977

Schmoll, S.: Das nahtlose Präzisionsstahlrohr in neuer Dimension. Special reprint: Der Konstrukteur, Vol. 4/1980

Das Kaltwalzen von Rohren. Meer-Bericht 151/4

Maschinen und Anlagen zur Herstellung nahtloser Rohre. DEMAG-MEER Bericht 1549

Herstellung und Prüfung von Stahlrohren. Mannesmannröhren-Werke

Zur Entwicklung des Rohrschweißens. Meer-Bericht 1152

Rohrschweißwalzwerke. Meer-Bericht 1520

Groß, H.: Kontinuierliche Rohrumformung. Presented at Haus der Technik, Essen

Oppermann, W.: Vollkontinuierlich arbeitende Rohrschweißanlage für Rohre kleinster Abmessungen. Bänder Bleche Rohre 10 (1969) 8, pp. 495/99

Schmitz, H.: Einzelrohrfertigung längsnahtgeschweißter Rohre. Presented at Haus der Technik, Essen

Groß, H.: Fertigung und Gebrauchseigenschaften von spiralgeschweißten Großrohren für Hochdruckfernleitungen. Haus der Technik Conference Proceedings, Vol. 303, pp. 16/29

Schmidt, W.: Herstellung und Verwendung längs- und schraubenliniennahtgeschweißter Stahlrohre. Bänder Bleche Rohre (1964) 2, pp. 66/75

Flick, K.: Das Umstellen vorhandener Rohrschweißanlagen auf induktive Hochfrequenzerwärmung. Special reprint: Bänder Bleche Rohre (1967) 2, pp. 70/76

Paton, E. O.: Automatische Lichtbogenschweißung. VEB Marhold-Verlag, Halle (1958)

Uttrachi, G. D.; Messina, J. E.: Three-Wire Submerged-Arc Welding of Line Pipe. Welding Journal 6/1968, pp. 475/81

Groß, H.: Fertigung und Einsatz von spiralgeschweißten Rohren mit hohen Festigkeiten. Presented at the "8th World Petroleum Congress" in Moscow, USSR, 1971

Groß, H.: Fertigung und Gebrauchseigenschaften von UP-geschweißten Spiralrohren. Special reprint from "3R international", Vol. 10-11/76 and 2/77, Essen

Jahn, E.: Die Verwendung längsnahtgeschweißter Rohre im Kesselbau. Special reprint from "VGB-Werkstofftagung", 1969, pp. 118/27

Messer Griesheim GmbH (Publisher): UP-Handbuch. Handbuch für das Unterpulverschweißen, Frankfurt/Main

Schiller, A.: Stahlsorten und Herstellungsverfahren für Rohre und Rohrleitungsteile für Pipelines. Pipeline-Seminar-Wilgersdorf, Paper No. 11/1977

Schmidt, W.: Stahlsorten und Herstellungsverfahren für Rohre und Rohrleitungsteile. Pipeline-Seminar-Wilgersdorf, Paper No. 11/1975

Wiedenhoff, W. and Peters, P.: Fertigung und Qualitätssicherung von UP-längsnahtgeschweißten Großrohren. 3R international, Vol. 3/4-1978

Groß, H. and Wennemann, W.: Moderne Verfahren zur Herstellung von UP-spiralgeschweißten Rohren. 3R international, Edition 10, October 1978

Hartmann, K. and Berner, K.: Gütesicherung, neue Prüfmethoden und Erkenntnisse für die Qualitätskontrolle von schraubenliniennahtgeschweißten Großrohren. 3R international, Edition 8/9, August/September 1978.

Zobl, R.: Herstellung und Qualitätsprüfung von spiralgeschweißten Großrohren für hochbeanspruchte Leitungen in Salzgitter. Peine + Salzgitter Berichte 1/81

Düren, C.; Felleisen, R. and Hieber, G.: Beitrag zur Technologie des Unterpulver-Vierdrahtschweißens. DVS-Berichte, Vol. 65, S. 8-14

Mannesmann-Großrohre, Technische Information, December 1980 edition, No. 6042/1, Mannesmannröhren-Werke

HFI-geschweißte Stahlleitungsrohre, Hochfrequenz-induktiv-längsnahtgeschweißt, Technische Information. December 1980 edition, No. 6102/1, Mannesmannröhren-Werke

Oberem, K.: Herstellung nahtloser Rohre. Stahl u. Eisen 104 (1984), No. 25-26, 1339/43

Biller, H.: Verfahren zur Herstellung nahtloser Stahlrohre. Stahl u. Eisen 99 (1979), Vol. 22, pp. 1228/32

Mannesmann Demag Hüttentechnik. Technische Information über Längsnaht-Rohrschweißanlagen mit Linealein-formung, February 1985 edition, No. 3416

Mihara, Y. et al.: Evaluation of Seamless Tube Rolling Process. NKK Technical Report No. 41 (1984), pp. 41/51

Schifferings, B.: Herstellverfahren für nahtlose Rohre mit kleiner und mittlerer Kapazität. Neue Hütte, Year 32, Vol. 1 (1987), pp. 12/17

Oberem, K.: Das Schrägwalzwerk als Lochaggregat beim Rohrwalzen. Stahl u. Eisen 107 (1987), No. 16, pp. 733/36

Kümmerling, R.: Das Schrägwalzen von Rohren. Stahl u. Eisen 109 (1989), No. 9, 10, pp. 503/11

Bellmann, M. and Kümmerling, R.: Optimierung des Spreizwinkels von Lochschrägwalzwerken für die Herstellung naht-loser Rohre. Stahl u. Eisen 113 (1993) No. 9, pp. 111/17

Niederhoff, K. A.: Schweißen von Großrohren aus TM-Stählen. DVS proceedings of special conference "Schweißen im Anlagen- und Behälterbau", 17 to 19.02.1993, Munich

Gräf, M. K.; Hillenbrandt, H. G. and Niederhoff, K. A.: Production of large diameter line pipe and bends for the world's first long range pipeline in grade X80 (GRS 550). Proceedings of the 8th Symposium on Line Pipe Research, Sept. 26-29, 1993, Houston, Texas