two such passes, while *f* shows a pass partly closed and partly open. Any pass, such as *g* or *h*, is to be avoided, because the rolls would be pressed alternately right and left by the spread of the piece being rolled, and would cause trouble at the chocks, and make it difficult to keep the rolls aligned in the direction of their axes, so that a true section could hardly be produced by them; no grooves should be so cut that they can produce an unbalanced thrust of this kind.

The groove and collars are on the lower roll, and the "former" on the upper, not only because the bar is more easily entered in this way, but because the guard, which is used to peel the bar out of the groove as a chisel cuts a shaving off a piece of wood in a lathe, can rest by gravity on the bottom of the groove in the lower roll. If no guard were provided, the bar which had been wedged tightly between the sides of the groove by the pressure of rolling, would be carried on and wrapped round the roll. The breaking or displacement of a guard will sometimes give rise to an accident of this nature, known to the workmen as "collaring;" the breaking of a roll or housing is the usual consequence of thus forcing a double thickness of metal between the rolls.

Even with plain plate rolls the plate will occasionally stick to the upper roll and get carried round with it, and may even get welded around it, forming a ring, which has to be cut off by hand when cold. To prevent accidents of this nature, and to ensure that the bar or plate shall peel off along the guard and on to the mill floor, the upper roll is always made of a slightly larger diameter than the lower, the effect of which is that as both rolls are geared together by the pinions and so make the same number of revolutions, the speed of the surface of the upper roll is slightly greater than that of the lower, and the upper surface of the bar is consequently more stretched, the bar accordingly having a tendency to turn downwards. Were the lower roll the larger, the bar as it left the mill, if it did not wrap round the upper roll, would fly upwards towards the roof to the danger of those near.

A difference in diameter between the upper and lower roll of from $\frac{1}{8}$ inch in small to $\frac{1}{4}$ inch in large rolls, for working plates, sheets, or plain bars rolled in open passes, is sufficient; for sections rolled in closed passes the difference will run up to $\frac{1}{2}$ or 1 inch in large rolls, and in exceptional cases of complicated sections of considerable depth, compared with the diameter of the rolls, $1\frac{1}{2}$ inches or even more may be required.

Designing the Rolls.—When designing a pair of rolls, the roll turner commences by setting off on his drawing a "construction line," which is situated as much nearer the axis of the bottom than of the top roll, as may be considered necessary, and on this he marks off the forms of the successive passes, each differing from the preceding by the required amount of draft or difference in area, taking care that the construction line passes as nearly as may be through the centre of gravity of the section. The chief point he has to keep in view is so to shape his passes that every portion of the bar gets thoroughly worked, and to arrange that no two successive passes shall tend to form a fin on the same position on the bar, but so to contrive them that the fin formed in one groove shall be rolled down in the succeeding pass.

The first pair of rolls through which the ingot passes are the cogging rolls, the function of which is to reduce the ingot, usually 14 to 18 inches square, down to a bloom of 6 or 8 inches square, which is a size suitable for rolling down to most of the sections commonly required, but for large girders or other heavy sections the ingot will need to be as much as 20 or 24 inches square, and the reduction in the cogging mill will not need to be carried beyond 10 or 12 inches square, or to some equivalent rectangular section. By starting the rolling with the top roll raised, and screwing it down after each pass, almost any rectangular section may be obtained in very few grooves if the width of the grooves is judiciously selected.

The most usual plan is to have 6 or 8 box passes, the ingot going twice through each groove, the first time with the top roll raised and the second with it lowered, when the roll is again lifted, and the ingot turned on its axis through an angle of 90°, and rolled twice in the next pass, and so on until finished. If the material is "red short," the ingot may be "humoured" by passing it more than twice through the first two or three grooves, thus by reducing the draft reducing the tearing action of the rolls. The rolls in fig. 375, which is taken from a paper by Mr. Holland, of Ebbw Vale,* will give an idea of the form and dimensions of the grooves in general use.

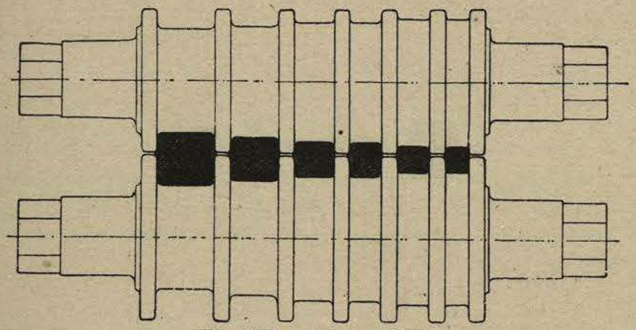


Fig. 375.—Cogging Rolls.

TABLE CXI.

Depths of grooves,	Top roll,	$4\frac{3}{4}$	$3\frac{3}{4}$	$2\frac{3}{4}$	$2\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{3}{4}$ inches.
	Bottom roll,	7	6	5	5	4	4 ,,
Clearance between collars,		$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$,,
Final heights of openings,		12	10	8	8	6	6 ,,
Width of grooves,		$14\frac{1}{2}$	$12\frac{1}{4}$	$10\frac{1}{4}$	$8\frac{1}{8}$	$8\frac{1}{8}$	$6\frac{1}{8}$,,
Final areas of openings,		174	122	82	65	49	37 sq. inches.

In specially strong mills having steel rolls, 15-inch square ingots have been reduced to $7\frac{3}{4}$-inch square blooms in 6 grooves, with only one pass through each groove, but 12 to 16 passes may be considered the usual practice.

If the ingots are required to form slabs for plates, the cogging rolls are usually plain in the centre, and have a groove at each end, as in fig. 376, by which means the ingot may be rolled on the flat in the centre, and on edge in the grooves at the end to ensure sufficient work on the edges, and to keep the edges true. In a works where a variety of sections are being rolled at the same time, in the various finishing mills, considerable judgment is needed in selecting a form of cogging roll which shall serve for each of the succeeding mills, which must be served by the same set of cogging rolls.

From the cogging rolls the bloom passes to the roughing rolls, which are intended to bring it to a closer resemblance to the final form desired, both as regards size and shape, so as to permit of its being passed on to the finishing rolls for completion. The skill of the roll designer is displayed in making the grooves in the roughing rolls of such forms as shall serve for as many forms of finishing rolls as possible. Not only would heavy expense be entailed by making a pair of roughing rolls for every pair of finishing rolls,

* *Proceedings Inst. Mech. E.*, April, 1885.

out valuable time, during which the mill would be standing idle, would be wasted in changing them every time a fresh section was called for. Cogging rolls should never need changing, and roughing rolls but seldom, while the finishing, except for small ranges of size in simple sections, have to be changed for each section that is rolled. A form of pass much used for roughing out is the Gothic pass, *b* (fig. 374); the bar is given a quarter turn after each pass, so that the fin is regularly pressed back again into the body of the solid bar. The section produced will serve equally well for finishing either to squares or rounds, and with certain limitations may be used to rough out for flats and small angles or tees.

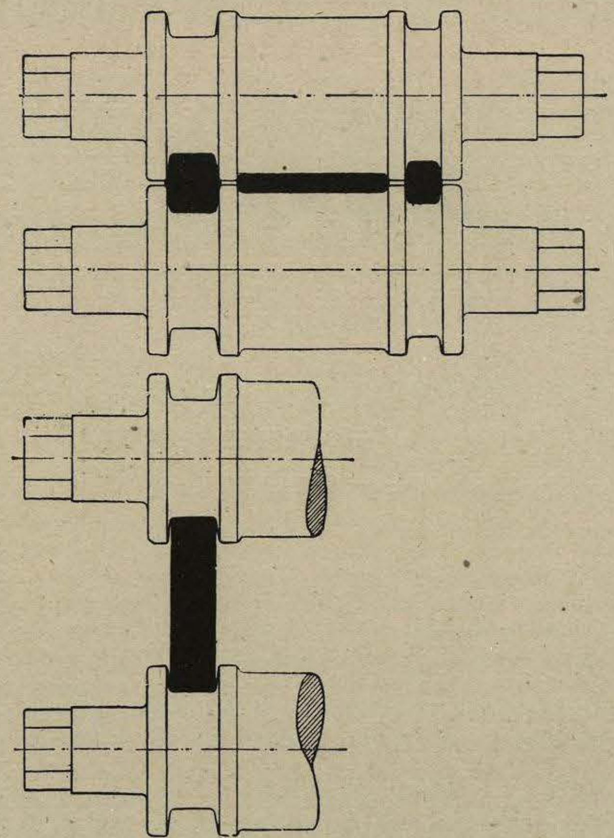


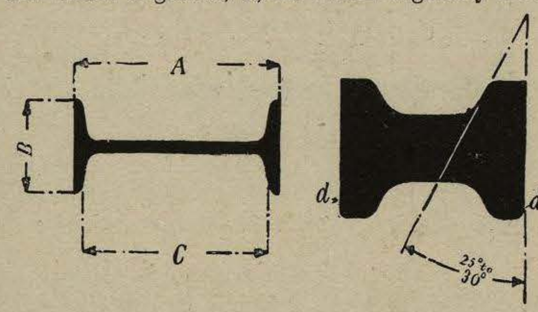
Fig. 376. —Slabbing Rolls.

Example of Rolling.—As a convenient example of the process of rolling we will take the production of a joist or girder of H section, as shown in A, fig. 377, measuring 12 inches in the direction *A*, and 5 or 6 inches in the direction *B*.

A cogged bloom, usually about 11 or 12 inches square, would be brought up to a good heat, and passed some 12 to 20 times through two or three pairs of rolls, according to the size and power of the mills and engines. If, instead of a square bloom, a rectangular slab were available, about 10 inches thick by 12 or 13 inches wide, the rolling would start with the slab on edge, and could continue in the same plane the whole time, the bloom being turned upside down after every pass, except, perhaps, in the case of the first one or two passes; but when starting with a square bloom the first, usually

an open pass, would need to reduce it to about 10 inches in one direction, when it would be turned on edge, and the rolling would be continued as in the previous case. The reason for requiring that the bloom shall not measure more than 10 inches in the horizontal direction as the piece stands in the rolls before beginning to shape it, is that the spread which takes place in every pass must be allowed for.

When the bloom has been reduced to 10 inches wide, it enters a series of closed passes, which form an approximately semi-circular furrow in the top and bottom, each pass continuously widening and deepening the furrows, and gradually squaring out the corners at the bottom of the furrow until, when the bloom has passed through a third or so of the grooves, it presents the section shown in B, fig. 377, the angle of the slope of the sides being 25° or 30°, the web being 3 or 4 inches, and the flanges 2 or 3 inches thick, with bold rounded corners joining the web to the flange. The succeeding passes keep continuously reducing the angle of slope till in the finished section it measures about 5°, reducing the thickness of the web till it measures $\frac{1}{3}$ to $\frac{1}{2}$ inch, and of the flanges till they may be $\frac{5}{8}$ to $\frac{7}{8}$ inch thick, the bottom corners (*d*) in all except the last pass being rounded outwards, so that any fins formed on the top edges may be pressed home, and no sharp edges will be left to cool before the rolling is completed. All the time the vertical dimensions in the direction *B* have been regularly decreasing, and the over all width *A* and width of groove, *C*, have been regularly increasing.



A B

Fig. 377. —A, Section of girder when finished; B, while being roughed out.

The length of the finished girder being 10 to 15 times that of the original bloom, it would require a furnace of most inconvenient proportions to reheat the partially rolled bloom; this fact, apart from the additional time, labour, and fuel which would be expended in the operation, makes it almost a necessity to roll off at one heat. To do this economically, the rolls must be large enough to withstand the heaviest reduction practicable in every pass, whereby the number of passes, and consequently of stands of rolls, may be as few as possible, and the engines must be powerful enough to drive the rolls at high speed, so that the girder may be finished while the metal is fairly hot, and therefore soft, whereby much wear and tear of the rolls and other machinery is avoided.

Variation in the Forms of Succeeding Passes.—The above instance is the simplest and most easily understood form of reduction, as the bar has been rolled in one plane only, and in grooves each one of which approaches continuously nearer in form to that of the finished article, but it should be understood that a pass is frequently of a totally different form from the one before and after it, with the object either of getting work on certain parts of the bar, or of enabling it to be drawn down with greater speed in each pass. For instance, in rolling down to small rounds or squares, where cooling occurs rapidly on account of the small size of the sections, the object which must be kept in view in all except the last one or two passes, is not the shape of the bar, but its reduction in sectional area as speedily as possible by drawing it out endways in grooves of any shape which will reduce the cross section of the bar most rapidly. Such passes, known as "drawing passes," when intended for working iron, were generally approximately square grooves, such as A in fig. 378, the top and bottom corners being flattened, so as to make the height of each pass less than the width of the succeeding one, the flat in each groove pressing well down into the body of the section any fin formed in the previous pass, so giving it no time to cool.

Wrought iron may be likened to a faggot formed of a bundle of lengthened strands held more or less loosely together, and if subjected to a heavy vertical pressure between the rolls without ample support laterally, cracks will open between its constituent strands. But steel being homogeneous, will not thus open, and it has been found possible, when dealing with it, to use "diamond-" or lozenge-shaped passes, such as B, fig. 378,

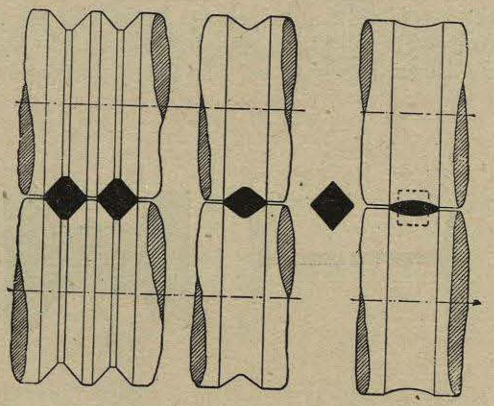

A B C D

Fig. 378.—Drawing Passes for Iron and Steel.

the alteration in the angle of the sides effecting a much more rapid reduction of section. The greater the width to which a section may spread, the larger may be the vertical reduction. By using a square and a flat oval alternately, as in C and D, fig. 378, it has been found possible to increase the reduction of 15 to 20 per cent. usual for iron, to as much as 50 per cent., and even more, in a single pass, in the case of steel; the oval is the more effectual of the two, giving a reduction nearly half as great again as the square.

When finishing squares, rounds, or octagons, the bars are got true by passing them two or three times through the last groove, turning them through a quarter of a revolution between one pass and the next, so as to ensure correctness of form and dimensions, and to remove the last trace of any fins which may have been formed; but other sections cannot be treated in this way, and must be finished by once passing through the last or finishing groove.

Difficulties in Shaping Rolls.—Considerable difficulty arises from the fact that the thin parts of a section cool faster than the thick parts, and for this reason the thinner portions are usually left to be worked out of the section as late as possible. Moreover, the temperature of the metal at the moment of rolling makes a considerable difference in the amount of reduction it is possible to effect, so that the same form of pass which at the commencement of the rolling would reduce a bar 40 or 50 per cent may not at the finish, when the bar is colder, be able to reduce it more than 10 or 15 per cent.

The function of the lower roll is generally not so much to shape the piece as to hold and support it in such a way that it can be acted upon in the most effective possible manner by the upper roll; hence in closed passes the bottom roll is the one which is grooved, the groove being closed in by the "former" on the upper roll projecting down into it.

Grooves for forming sections having the two sides uneven, such as unequal angles, are cut in the rolls in such a manner that the branches to right and left shall end on portions of the rolls having nearly similar diameters, as in fig. 379. so as to avoid end thrust. Moreover, if one wing projected much deeper into the roll than the other, the angle would curl up and twist as it left the mill.

Except when rolling plates, it is obvious that the surface speed of the various parts of the roll in contact with the piece being worked must vary considerably, the velocity decreasing from a maximum at those places furthest from the axis. The surface which is travelling at the greater speed always tends to, and to some extent actually does, drag the parts in contact with it at a higher speed than the rest of the mass, so that all portions of the section are not drawn out equally. With complex sections care must be exercised to balance the opposing forces by raising or lowering the centre of gravity of the section relatively to the centre line between the axes of the respective rolls, and so obviate this tendency as far as practicable, or reduce it to its lowest limit; otherwise the bar as it leaves the rolls will twist or curl in all sorts of curious ways. The larger the section in proportion to the diameter of the rolls, the more troublesome is it in this respect, and it is often necessary to vary the draught on different parts of the section, to prevent those portions of the bar where the rolls travel fastest from being torn asunder, or others where the rolls run slowly being crumpled up as the bar leaves the rolls. Irregular sections frequently cause trouble by leaving the rolls curved in a horizontal plane, and the draught has to be arranged not so much with a view to obtaining the greatest reduction in area as to correct this irregularity by enlarging the portion of the pass forming the outer side of the curve, in order to correct the curvature by drawing out that edge less than the other.

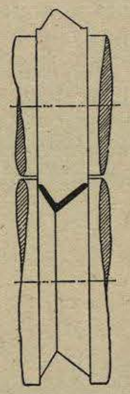


Fig. 379.—Pass for Unequal-sided Angles.

Those sections having great variations in the thickness of the different parts cause considerable trouble, which can only be partially corrected by side guides and devices of that nature, which partially straighten the naturally crooked bar as it leaves the rolls.

The grooves in rolls of different diameter cannot be made precisely alike to produce identical sections, owing to the greater spread produced by the larger rolls, and similarly the speed at which the rolls are driven has considerable influence upon the extent of the spread, and so has the temperature at which the bar is rolled. When sections identical in form but differing in size are to be produced in the same size of roll, the form of the grooves may have to be varied if the section is a complicated one. In this case the more rapid cooling which occurs in these portions having the smaller section introduces a further disturbing factor; small light sections are always difficult and costly to produce owing to this rapid loss of heat, which adds to the trouble of rolling and increases the wear on the rolls.

The draughts on different parts of the bar must be properly proportioned to each other. If that on the flanges of a channel, for instance, is too great compared with that on the web, the edges of the flanges are unduly stretched, and will be waved from side to side; if, on the other hand, too much draught is put on the web, making it unduly thin, it will be cockled; in either case the bar would only be fit for scrap.

In the case of an unusual section of complicated or irregular form, even an experienced roll-turner may be much at fault at first, if he has not prepared rolls previously for somewhat similar sections, and the rolls may require altering several times, or entirely new ones may occasionally have to be made, before satisfactory results are obtained. Accordingly rolls are most successfully designed by the empirical method of referring to previous designs which have been found to work satisfactorily in the production of the type of section nearest to the one required, sound judgment, based on extensive practical experience, being the best guide in the matter. As the successful running of the mill, and its output, depend so largely on the correct form of the rolls, the roll-turner is a man of considerable importance in a steel works.

Change in Form of Rolled Sections on Cooling.—Bars when finished and laid on the floor to cool change their shape during the process; the thicker parts, which hold the heat longer, contract last, so that these parts form the inner side of a curve when the bars are cold, the cold bars being curved although they left the rolls straight when hot. For instance, flange rails (A, fig. 380) will be curved several inches, sometimes

A B

Fig. 380.—Sections of Rails.

nearly a foot, in a length of 30 feet when cold, owing to the difference in thickness between the head and foot, and to correct this as they come hot from the rolls they are often passed through a cambering machine, which gives them such an amount of curvature in the opposite direction as will render them nearly straight when cold.

Even the form of section may alter during cooling. For instance, the inner and lower part of the head of the bridge rail (B, fig. 380), which is protected by the surrounding hot parts, cools later than the upper surface on which the wheel is intended to run, with the result that the opening at the foot of the section narrows during cooling. To compensate for this change, the section as rolled has the outer edges of each foot bent upwards about 1°. So also in square bars the central portion remains hot after the corners have cooled, and by its contraction last would cause the cold bar, if it were truly square when hot, to have hollow sides when cold, to prevent which the corners are rolled to an angle of 91° or $91\frac{1}{2}$°, and become 90° only when cold.

By setting the rolls closer together or further apart, sections are produced which are thinner or thicker in the vertical direction than the normal section which the rolls are intended to produce; the roller must therefore check the section occasionally to make sure that wear in the brasses or

variations in the temperature of the rolls or housings have not introduced errors of this nature. It is often convenient to be able to roll sections more than usually heavy. Fig. 381 shows how metal can be added to some of the sections in common use by slightly lifting the top roll; the black portions of the cuts show the normal sections, and the white portions where the extra metal can be added. If carried too far, this system leaves ugly fins on the edges of the finished section, to avoid which angle rolls are sometimes designed so that the bottom roll may serve for all thicknesses, while there are two top rolls to match it, one or other of which is put in according to the thickness of angle required.

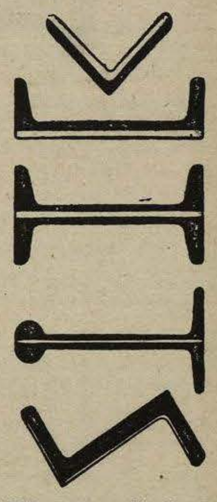


Fig. 381.—Where Sections can be increased in Thickness.

Examples of Rolls.—It is not possible, within the limits of this work, to show how every section is produced, but in addition to those illustrated in other places, the figs. 382, 383, 384, have been selected as fairly typical of ordinary work. If any well-designed rolls are examined, it will be found that the passes have been so contrived that when nearing the finishing passes, fins cannot occur on the same portion of the bar in two succeeding passes, and it will be noticed that where possible the bar is given a quarter or half turn after each pass, with the object of ensuring that the scale which forms on any bar due to oxidation in the air may fall off. If this precaution were not taken, the scale which formed on the upper side of the bar could not fall off, but would be rolled into the bar, and when the bar was handled cold it would drop out and spoil the appearance of the surface.

In the case of material which is intended to be reheated and worked again before use, this consideration does not, however, apply. Tin-plate bars, which are flat bars of dead soft steel, 7 to 9 inches wide by $\frac{3}{8}$ to $\frac{1}{2}$ inch thick, intended to be cut up into short lengths for re-rolling into sheets at the tin-plate works, are commonly rolled with the same side upwards until finished, and are then dipped while hot into water, which causes a sudden contraction of the steel and effectually cracks off the scale.

Plates, which are very awkward to turn over while hot, are rolled the whole time with the same side upwards when anywhere near their finished dimensions. The scale in such cases is removed by gangs of men stationed on each side of the mill who brush the plates continuously with wet besoms during the last few passes. Owing to the heat of the plates the water runs about over their surfaces in the spheroidal state, but when caught between the roll and plate, the globules of water are forced into intimate contact with the hot plate, and are instantly flashed into steam, which escapes with a report like a pistol shot. In most modern mills the men and their besoms are now replaced by a line of steam jets which issue from a perforated pipe placed as close as possible to the rolls. The jets are brought into play during the last few passes, when they impinge on the plate in a direction contrary to its travel, and remove the scale just at the moment when the plate is entering the rolls.

When portions of the sections to be rolled are undercut, they will not leave the rolls in the ordinary way, and the difficulty is got over by finishing the portions to the correct area in such forms as will leave the rolls, and

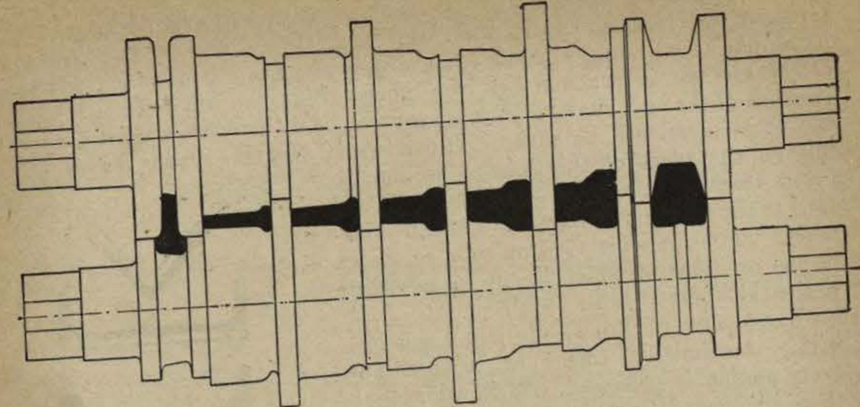


Fig. 382 —Rolls for Bulb Bars.

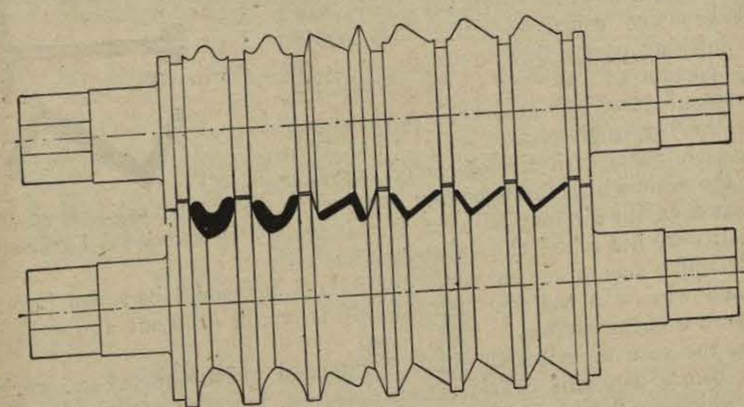


Fig. 383 —Rolls for Angles.

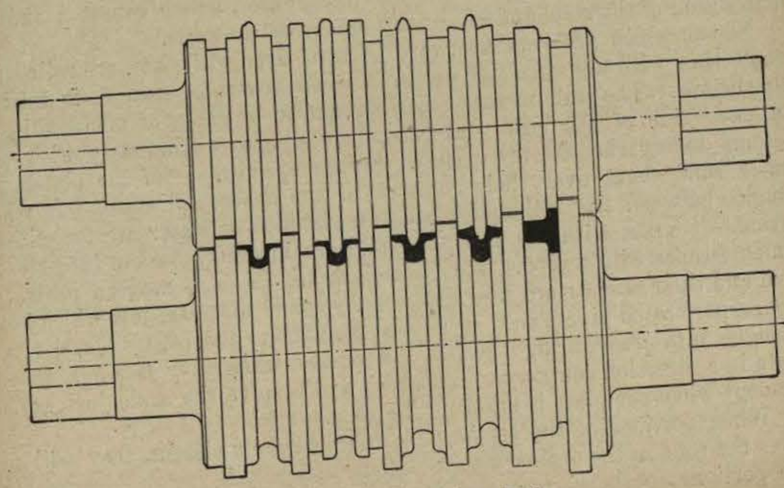


Fig. 384. —Rolls for Bridge Rails.

then turning over the projecting edges in a final "closing pass." For instance, the sections of tramway rails (B, fig. 385, and B, fig. 386) are rolled as shown in A, fig. 385, and A, fig. 386, and the edges are then turned over in a final closing pass. When first made, the section B, fig. 386, was rolled with a solid head, and the groove planed out when the rails were cold,

Fig. 385. —Box Tram Rail.—A, in last shaping pass; B, when closed in the finishing pass.

but the enormous cost of such a method of production is prohibitive when any quantity of the section is required. The latest method is to finish the rail with a solid head, until the last pass or two, and to roll the groove in during the last passes by means of a small forged steel roll running on a vertical axis, this roll being carried in what is substantially a chock placed between the necks of the main rolls. The small roll is free, and is not driven in any way.

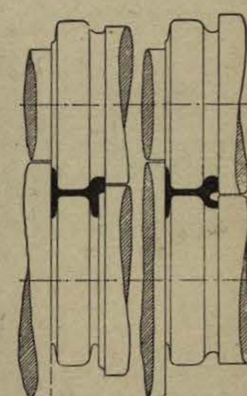


Fig. 386.—Girder Tram Rail. A, in last shaping pass; B, with guard turned over in finishing pass.

In some very complicated small sections where sharp corners are needed, the turning over of the edge would not be sufficient, and a mandril is placed between the rolls over which the corners are bent, in much the same way as is adopted when a tube is rolled (see the section on rolling tubes in Chapter xlii.

Turning the Rolls.—The lathes used for turning rolls differ considerably from ordinary metal turning lathes, which have travelling saddles and slide rests. The roll lathe is a much more massive machine, and its rest, which can be bolted down anywhere on the bed, remains a fixture while the tool is cutting, the tool being so secured in the rest by screws or wedges that it can be fed up to its work by other wedges or screws. Fig. 387 shows a roll lathe made by Thomas Perry & Son, Ltd., of Bilston. The roll has a countersunk hole drilled at each end to fit the centres of the lathe, neither of which revolve, and is placed between the centres while the necks are turned. If a roughing roll, it may be finished between the centres, but where accuracy is essential, only the necks are thus turned so as to secure a bearing at each end, and the roll is then placed in two chocks resting on the bed of the lathe in which the necks revolve, the centres being used merely to prevent end play. When finished between centres, the holes in which they fit wear irregularly, so that the part of the roll which is turned first does not run truly concentric with those parts which are turned later, hence the necessity for running the roll in bearings while turning it.

For turning chilled rolls a peculiar form of tool is employed, consisting of specially hard steel containing 1·5 per cent. of Carbon, about $1\frac{3}{4}$ inches square by some 4 to 6 inches long, having a semi-circular groove running the length of each of the four sides, forming it into a bar of a cruciform section. The four corners are ground sharp, and the tool is dropped into a recess in a cramp bar of an L section which is attached at either end to one of the

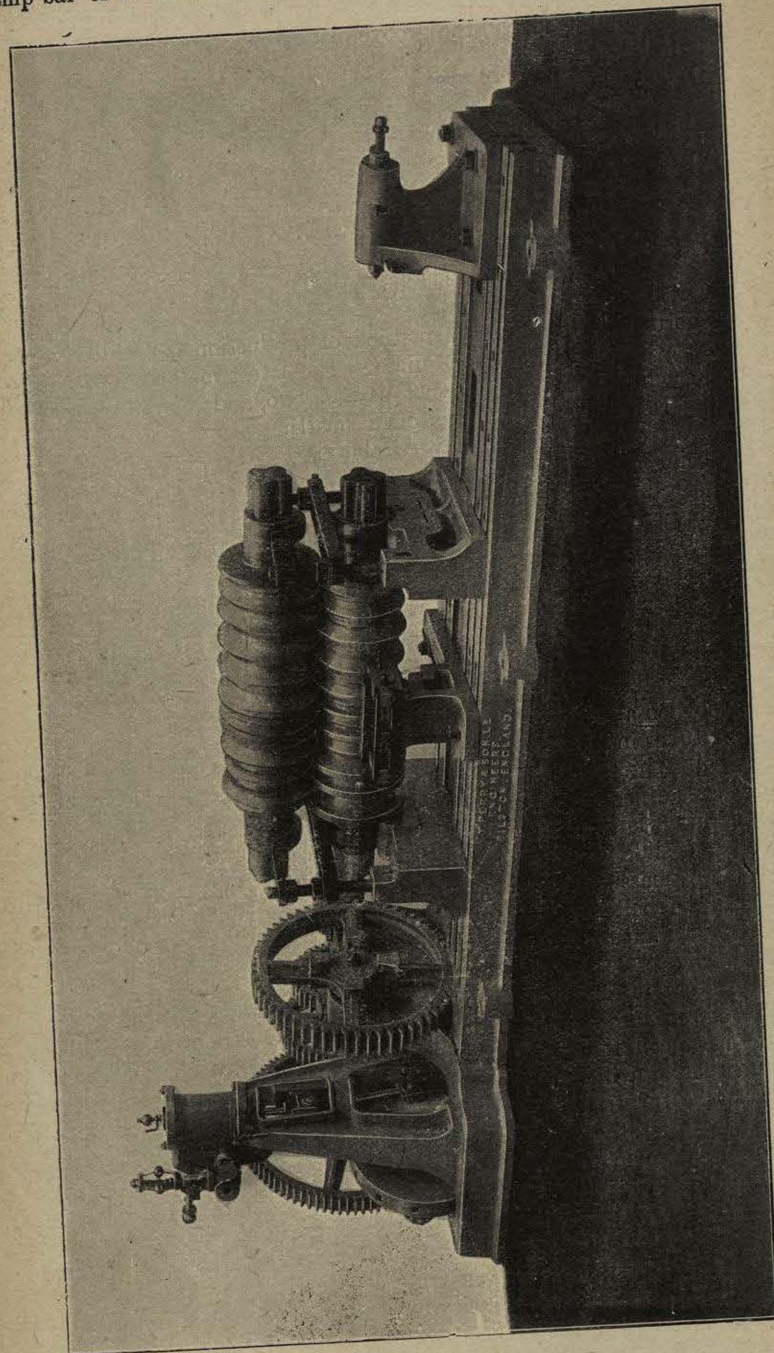


Fig. 387.—Lathe for Turning Rolls.

bearings, so as to be parallel with the barrel of the roll, and as close to it as possible. Wedges and packing pieces are placed behind the tool (fig. 388),

which is fed up to its work by hammering down these wedges at either end as required, the tool cutting along practically its entire length at once. When sufficient metal has been removed, the wedges are knocked out, and the tool moved to a fresh position along the bar.

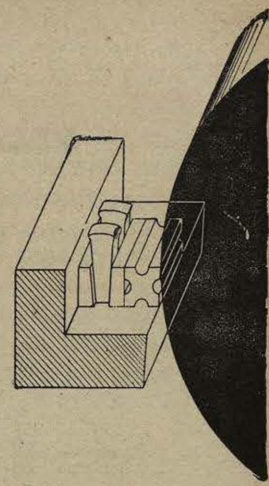


Fig. 388.—Turning Chilled Rolls.

The roll turner, when cutting grooved rolls, works to templates of sheet iron made to the exact section of the groove which is required, the tools being usually shaped to these templates. The arrangement looks crude and primitive, but the absence of sliding surfaces in the rest secures a rigidity otherwise unobtainable, and as ample power is provided to drive the lathe, the cuts taken can be very wide. Formerly the surface of a chilled roll could only travel about 4½ feet per minute, but the introduction of high-speed steels has enabled this speed to be increased to 6 feet with heavier cuts and less frequent grinding of the tools. A large amount of metal can be removed in a given time by using such heavy cuts, and the men, who become very expert in using the tools, are able to finish work with marvellous accuracy and despatch. According to Mr. Gledhill, speeds as high as 11 feet per minute are sometimes possible with some brands of steel.

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