slowly on the live roller beds, which are of great length—as much as 360 feet in one works—the entire length being covered with plates from end to end. The live rollers deliver the plate on to a series of "goose necks," which can best be compared to the legs of a table turned upside down, the plates being easily pushed in any direction on the castors, just as the table may be moved about on the floor. These goose necks are spaced about 20 inches apart centre to centre, and cover the whole floor, so that men can walk about conveniently between them to handle the plates, which are carried at a height of 2½ feet above the floor, a convenient height for marking off and shearing. When sheared the plate is pushed away, still on the castors, to be weighed, marked, and inspected, and is finally loaded by a crane into the railway waggon. By this method only about half as many men are required to handle the plates as are necessary for the old English method. A similar arrangement is now being adopted in works in this country.

The output of the American mill is about the same as that of the English mill. At Homestead they have turned out as much as 1,700 tons in a week.

Universal Plate Mills.—The economical working of a plate mill depends on the percentage of the plate which has to be sheared from it to remove the imperfect edges, the proportion of the plate thus cut to waste being clearly greatest in the case of long and narrow plates. To avoid having to shear anything whatever from the sides of such plates they are, in America, rolled in long lengths in a universal plate mill. Plates as much as 100 feet long by 3 feet wide and ½ inch thick, down to 1 foot wide by ¼ inch thick, are produced in this way. The waste on plates rolled in a universal mill is said to average 15 to 20 per cent. less than on those rolled in a plate mill. The universal plate mills are reversible, and the vertical chilled rolls, which are usually placed on one side, but in some instances on both sides of the horizontal rolls (which also are chilled) are driven by bevel wheels on their upper ends, gearing into similar wheels on a horizontal shaft across the top of the housings; this shaft in its turn is driven by a spur wheel gearing into the upper housing pinion.

To avoid the difficulties previously described (see p. 631), which are incidental to a difference in the surface speeds of the horizontal and vertical rolls, the horizontal rolls in the Bethlehem Mill are driven by one pair of 46 × 60 inch reversing engines, and the vertical rolls by a separate pair of 28 × 48 inch reversing engines. This mill is used for slabbing and not for finishing.

The Lukens Iron and Steel Co., of Coatsville, Pa., have just installed a three-high Lauth universal mill, a view of which, copied from *The Iron Age*,[*] is given in fig. 494. This mill has upper and lower chilled rolls 28 inches diameter, a middle roll with the usual lifting device 20 inches in diameter, and two pairs of vertical chilled rolls 18 inches in diameter. "In this three-high continuous running mill, the vertical rolls on the outgoing side are, as will be seen by the illustration, reduced in diameter, thereby clearing the plate, so that there is no danger at this point either of spoiling the plate or of back-lash in the machinery. On the entering side the vertical rolls have their full working diameter maintained, which may be properly proportioned to the horizontal rolls so as to avoid any conflict of speed. Thus the plate is operated upon by the vertical rolls on the side passing in, while the vertical rolls on the opposite side clear the plate by reason of their smaller diameter." This mill is said to have turned out 250 tons of plates in twenty-four hours. Several universal plate mills have been known to turn out as much as 900 tons per week. One with 25-inch horizontal and 16-inch vertical rolls will turn out 100 tons of plates per day.

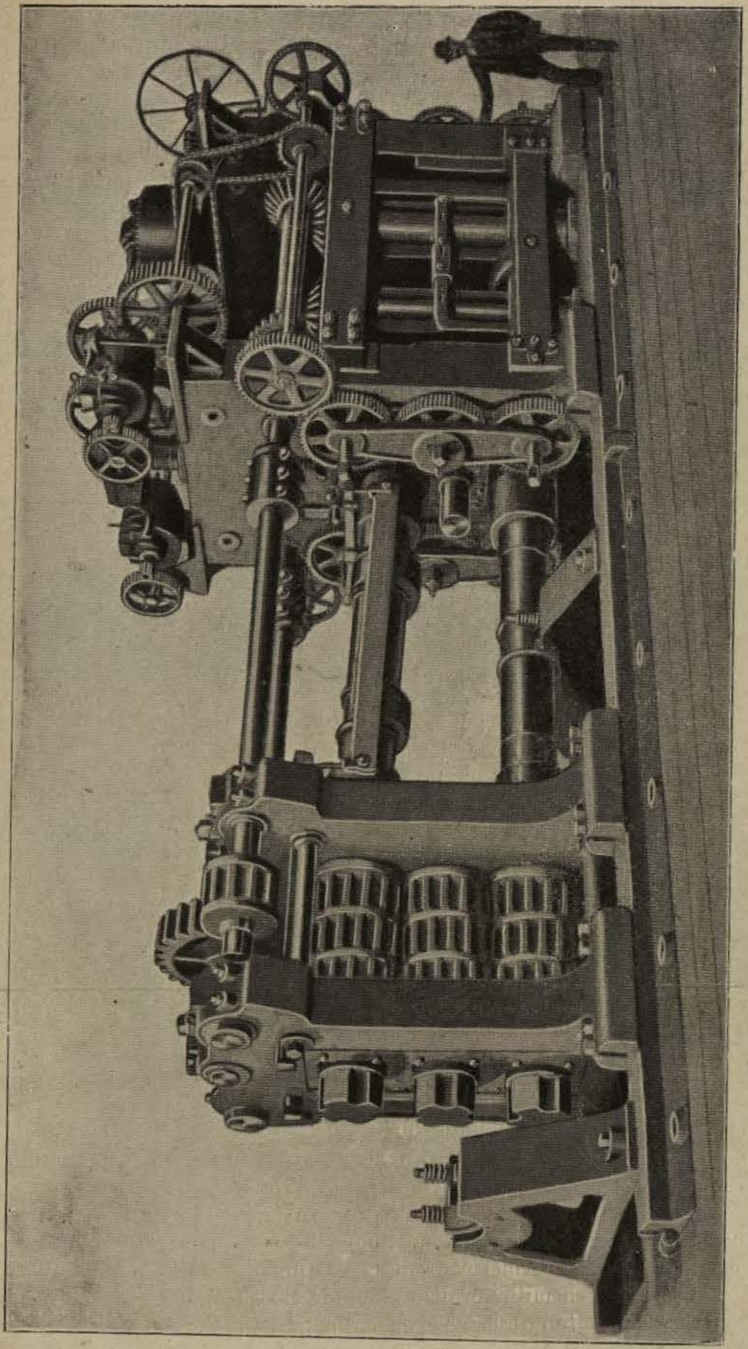

Fig. 494.—Three-high Lauth Universal Mill.

A few years ago the Americans rolled all their plates direct from flat ingots at a single heat, but the chief platemakers have recently put down large universal mills to cog the ingot to a slab, which is reheated before

---

[*] "The Lukens Iron and Steel Company's New Plant." *The Iron Age*, July 26, 1900.

passing it on to the plate mill to be finished. According to Mr. A. P. Head,* the best yield of finished plates in America, rolled direct from ingots, is 73·3 per cent., and from slabs 75·25 per cent. of the weight of the ingots. The vertical rolls save the necessity for turning up the slab when it requires to be edged. The addition of such a mill increases the output of the plate mill 50 per cent. or more.

Fig. 495 is a fine example of a universal cogging mill, which was designed by Mr. Julian Kennedy, who has kindly supplied the photograph from which the illustration has been prepared. The mill and pinion housings are steel castings, and the neck pinions and other gearing are of oil-tempered steel. The horizontal rolls are 34 inches diameter and 9 feet long in the barrel, driven by a pair of reversing engines with cylinders 46 inches diameter by 50 inches stroke. The vertical rolls are driven by a separate pair of reversing engines 28 inches diameter by 30 inches stroke, the pressure at the boilers being 150 lbs. per square inch. The mill will produce slabs 54 inches wide by 24 inches thick. The leading spindles are 20 feet long.

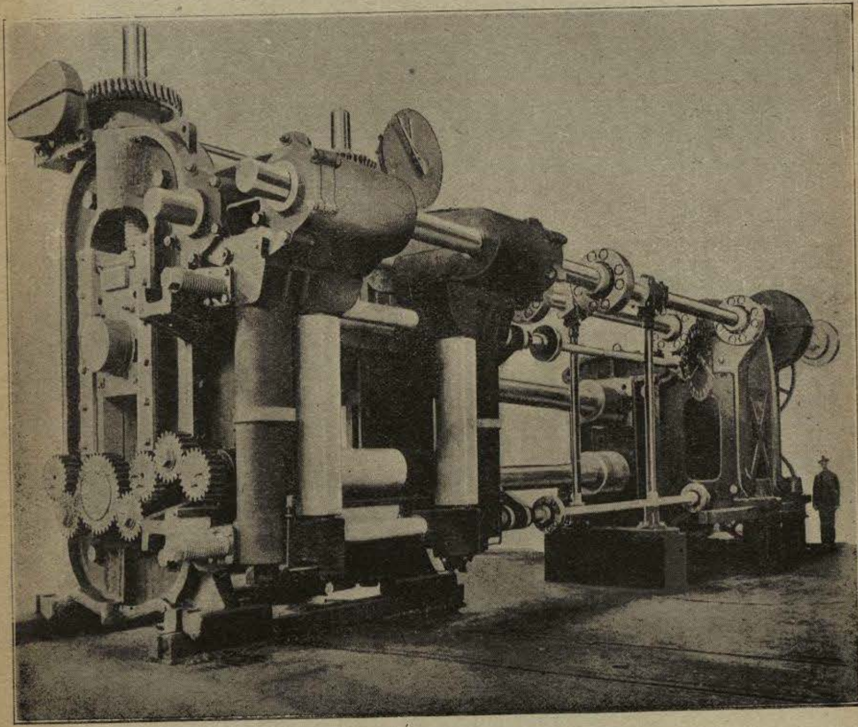

Fig. 495. —American Universal Cogging Mill.

The length and thickness of plate which a mill can turn out is independent of the dimensions of the rolls, but the width is determined by the length of their barrels. Americans describe the size of their mills by this dimension, "a 128-inch mill," probably having no roll more than 30 inches in diameter. They often describe their sheet mills in the same way.

Armour Plate Mills are merely large reversing plate mills having one stand of rolls from 36 to 48 inches in diameter by 10 to 14 feet long in the barrel, usually steel; they call for no special description.

---

[*] *South Staff. Inst.*, 1897-8, p. 117.

Sheet Mills.—Sheets are plates of iron or steel which are less than ¼ inch thick; those of or above this thickness being known as "plates." The larger sheets are produced in small plate mills, the term "sheet mill" being generally confined in this country to the small mills used for producing the thin sheets intended, usually, for galvanising or tinning.

Sheets are rolled from "sheet bars," which are bars 10 to 12 inches wide, and from ⅜ to ⅞ inch thick, or from "tin plate bars," which are 7, 8, or 9 inches wide, and ⅜ to ½ inch thick; they are ordered to weigh so many pounds and ounces per foot, so that when cut up into lengths each piece shall be of the exact weight needed to make the sheet required. The original Staffordshire sheet mills had rolls 18 or 20 inches in diameter, and the standard sizes to which sheets were rolled were 4 or 6 feet long by 2½ feet wide. The rolls of modern English mills are mostly 22 or 24 inches in diameter, and of American mills 24 to 26 inches. Most English mills recently put down have rolls 30 inches in diameter. If the brasses are not very deep, so as to cover a large part of the circle of the neck, side brasses are fitted to steady the rolls and keep them truly parallel with each other, otherwise the sheet would be buckled. The sheets are rolled in very carefully-finished chilled rolls, which, in the Staffordshire mills, are turned up in position in their housings every Monday, the works being laid off on that day for that purpose, and the housings are made to fit so closely up to the necks of the rolls (see fig. 347) that they cannot be got out endways, but the one housing must be moved to change the roll. To enable the rolls to be turned in place, a double reduction gear, much the same as the "back gear" in a lathe, is provided, and the ordinary driving spindle having been removed, the engine slowly revolves the rolls, which, if 24 inches in diameter, must make not more than three-fourths of a revolution per minute. The rolls must be very accurately turned, and the barrel must run perfectly true with the necks, or the thickness of the sheets will vary in different parts, and it used to be considered that this degree of accuracy could only be attained by turning the rolls in place, but the Americans make the housings of their sheet mills sufficiently wide to enable the rolls to be changed, so that a redressed roll can be substituted for the one worn, which is turned up at leisure lying in bearings in the lathe bed, and by this means one turn every week need not be wasted in roll turning. Fig. 496 shows an American mill for rolling sheet metal. As the rolls are comparatively light, and are always so close that there is little distance for the top roll to fall when the piece leaves the rolls, they are not balanced.

Sheet mills are usually coupled up in a line of three or four mills on each side of an engine, provided with a flywheel of 100 to 150 tons weight, running at two to three times the speed of the rolls. The engine is generally coupled to the mills by gearing, sometimes now by ropes, and should be capable of exerting 250 H.P. for each mill, consisting of two stands of rolls, which is driven by it. The best speed for the surface of the rolls is found to be 200 to 220 feet per minute.

Sheet mills in England are not fitted with neck pinions, because the piece being rolled is so thin in comparison with the diameters of the rolls that there is no fear of their failing to grip it; the upper roll simply rests on the lower, which drives it by frictional contact. The amount of reduction effected at each pass is so slight that the power needed to screw the rolls down is too trifling to render any power-screwing gear necessary. The workmen set the screws by means of a chalk mark on the screw-head, which is turned round until the mark on the screw faces a pointer attached to the

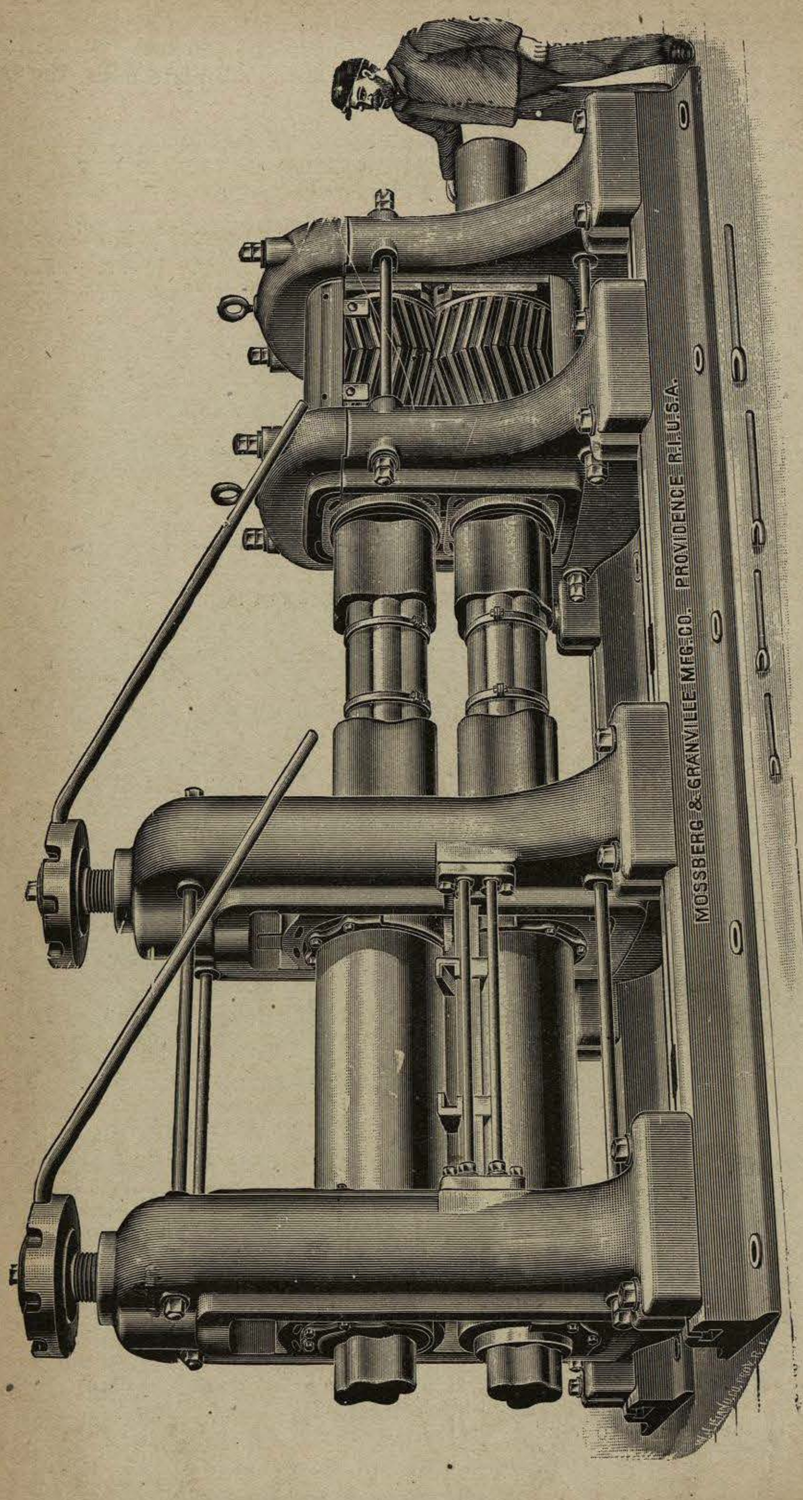

Fig. 496.—American Sheet Mill.

housing. In some modern mills carefully-graduated circles replace the chalk marks.

Sheet Mill Rolls.—The rolls used in sheet mills are always chilled rolls, and the output of the mill is determined largely by the endurance of the rolls, which break if heated or cooled too rapidly. They are already in a condition of internal stress, on account of the "chilling" to which they are subjected in the process of manufacture, as described on p. 573, the extent of which cannot be measured. Contact with heated material expands the surface of the rolls and produces further severe stresses, some idea of the nature and extent of which may be obtained from the following calculation :—

Cast iron expands $\frac{6}{10,000}$ parts of its length for each 100° F. rise, and shortens by the same amount for the like fall in temperature ; and if the iron from which the rolls are cast has an elastic modulus of 5,000 inch-tons, an extension or compression of $\frac{2}{10.000}$ parts of its lineal dimension is accompanied by a stress of 1 ton per square inch in the stressed material.

Fig. 497 shows a sheet roll $23\frac{15}{16}$ inches diameter, by 36 inches long in the barrel, and for the sake of clearness we will regard it as entirely free from any initial stresses due to casting, and at a temperature of 50° F. Let us assume that contact with the heated sheets then raises the temperature of the surface of the barrel for a depth of $1\frac{1}{2}$ inches inwards to 1,550° F., the portion so heated being marked black in the figure, but the rest of the roll retaining its original temperature of 50° F. There is then an inner core, shown cross-hatched in the figure, having a cross-sectional area of 350 square inches, still retaining its original temperature and length ; and an outer shell, shown black in the figure, having a cross-sectional area of 100 square inches, which, having been raised in temperature 1,500°, has been increased in length by $\frac{1}{8}$ inch, as shown (exaggerated) in the figure, where A represents the increased length of the surface, and B the original length, which, by supposition, the centre portions of the roll still retain.

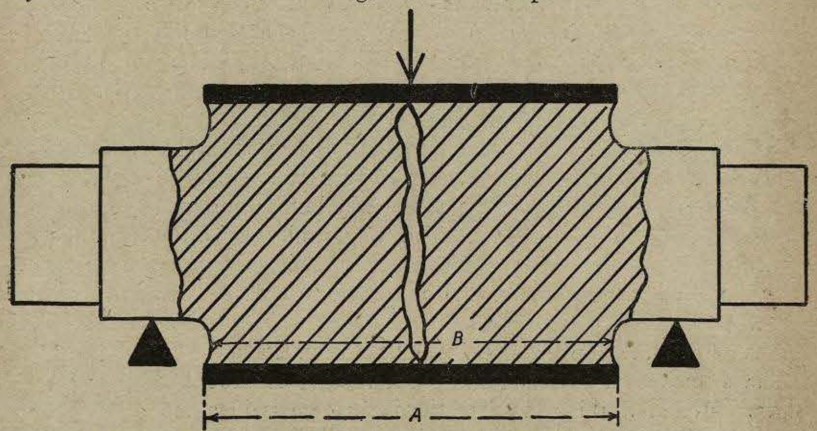

Fig. 497.—Sheet Mill Roll Diagram to explain Method of Fracture.

But the outer shell and the inner core form integral portions of one solid casting, and are attached rigidly one to the other, and so, if the inner core is to hold back the outer shell from expanding, it must exert upon it a restraining force, which, as shown above, must amount to 3,500 tons, thus imposing on itself a tensile stress of 10 tons per square inch, which is just above the tensile strength of the cast iron from which the roll is made. If, on the other hand, the shell be considered as attempting to pull out the inner core to its own extended length, it imposes on it an equal stress of 3,500 tons, which is equal to 35 tons per square inch compression on the area of the outer shell, just about the strength of the material under compression.

If, again, the roll should attain a uniform temperature throughout of 1,550° F. without fracture, and the outer shell $1\frac{1}{2}$ inches thick be suddenly cooled down to 50° F., just the same stresses per square inch are induced, but now in a reverse direction, the outer shell in this case being subjected to a tensile stress, to resist which the cast iron has only $\frac{7}{20}$ of the power it possesses to resist a compressive stress, so that fracture of the surface is certain to occur as the thin cooled shell contracts on to the hot expanded core.

Of course, such sharp lines of demarcation between the hot and cold portions of a roll do not occur in practice—the metal is too good a conductor of heat to permit of it—while a temperature of 1,550° F., which would raise the roll to a dull cherry-red colour, is hardly attained, though it must be sometimes approached. The conditions are selected to show that heating and cooling alone are enough to induce stresses sufficient to fracture a roll, and to emphasise the importance of maintaining it at as uniform a temperature as possible. In some works, to ensure this, the chilled rolls, while slowly revolved, are warmed in place by gas jets at the beginning of a run, and are covered up with bags to protect them against too sudden cooling when stopped at the end of each week.

The work to be done in reducing the thickness of the sheet produces a considerable dynamic stress in the roll over and above the unavoidable initial stresses caused by the inevitable method of casting, and those stresses induced by heating and cooling. The lower roll, when at work, is in the condition of a beam resting on supports represented by the black triangles below the necks in the figure, and subjected to a more or less distributed load above acting in the direction of the arrow. This load produces a compressive stress in the upper, and a tensile stress in the lower half of the roll.

The sequence of events leading to fracture is probably somewhat as follows:—When working, at first the inner core is in a more or less permanent condition of tension, which is increased when the sheet passes through the mill. The lower side of this core is ruptured, and the crack gradually extends in a circle within the skin, as each portion of the roll in turn comes to the bottom, and spreads inwards towards the centre, till a fissure is formed occupying the whole of the centre portion of the roll, as shown (exaggerated) in the figure, and finally the outer surface gives way.

Rolling Sheets.—English sheet mills are all two-high, but when sheets are small the men keep two pieces going through the rolls at the same time, the catcher laying the piece, which has just come to him through the mill, on to the top of the upper roll at the precise instant that the roller is putting the second piece in between them; exchanged thus these light pieces can be rolled in a pull-over mill more rapidly than in a reversing mill, or even in a three-high mill, in which the third roll would prevent either man seeing what the other was doing, and the slightest delay in getting either piece to enter would disorganise the work, by bringing both pieces on to the same side of the mill at the same time.

The terms "singles" and "doubles," which will be defined later on, arose from the fact that originally all sheets of 20 G or over were rolled one at a time, and when this reduction was effected, the sheet being then about 6 to 8 feet long, the roller turned that end of the sheet which he held in his tongs over the other end, and, laying his foot on the folded sheet to prevent its springing back, grasped the two ends at once with his tongs and thrust the fold into a doubling machine; this consisted of a pair of flat surfaces, whose action was that of a pair of shears with very blunt edges falling flat on, instead of passing by, each other. The doubled sheet was then reheated and rolled out as if it were only a single sheet; the sheets thinner than doubles were produced by folding this doubled sheet a second time, four thicknesses being passed through the rolls at once. Now that two separate pieces are worked at once from the beginning, they are each rolled individually until about 13 G by 3 feet long, when they are simply laid one over the other and rolled as in the case of a single sheet, the doubling being effected in a very similar manner, so that most "doubles" now pass through the mill four thicknesses at once. In some cases three sheets are laid together in this way, the operation being known as "matching."

The furnaces in which the pieces of bar are first heated are known as the "bar furnaces," and are kept at a high heat, while those in which the roughed-out sheets are reheated in preparation for the second or third rolling are called "the pair furnaces," and must be kept at a much lower temperature or the sheets will stick together, and cannot be separated after rolling. They are sometimes heated by the waste heat from the bar furnaces.

Sheets are made from mild steel containing about 0·1 Carbon; the Phosphorus must not be lower than 0·04, as it imparts a good surface, which prevents the sheets in the pack sticking together. To separate them when finished, a workman grips the corner of each sheet in succession, and tears it away from its neighbour, if necessary using a hatchet to separate one from the other. In some works the "pack" is passed through a mill having two pairs of rolls close together, with a guide having a serpentine opening between the pairs, which bends the pack of sheets in waves upwards and downwards alternately. The outer surface of any curve being longer than the inner, when two sheets are bent the one on the inner side projects beyond the other, as the one cover of a book with paper covers projects beyond the other when the book is bent over; the adjacent surfaces of the sheets are consequently caused to rub sufficiently one over the other to break up the film of Oxide which sticks them together. In some works the sheets are straightened by placing them in a machine which grips each end along its whole extent and pulls the sheet out.

The extent to which the housings of a mill stretch when working, is shown by the fact that to roll very thin sheets, the screws must be set down so as to jam the two rolls together as fast as they can be screwed, before starting to pass the sheet through, the stretching of the housings sufficing to give the space needed for the sheet to pass. To reduce this stretching the housings are now usually steel castings.

In England sheets are completely finished in one pair of rolls, but in America they are roughed in one pair and finished in another pair, because in this way the temperature of the material in contact with the rolls varies less, than where one pair of rolls only is employed. This is believed to diminish the risk of breaking the rolls, and the second pair are said to retain their surface longer, when they have to deal only with the cooler material. Most modern English works now work on the American plan, of roughing in one pair of rolls, and finishing in a second.

In the English and American sheet mills, in which several thin sheets are rolled together, the sheets keep each other hot enough to enable them to be finished at a fair heat; the speed of the rolls is usually only 30 to 35 revolutions per minute, and the workmen need no lifting-tables to catch the sheets as they leave the mill. In Continental works, where the sheets are rolled singly, the rolls are run at 80 or 90 revolutions per minute (in one instance 20-inch rolls are said to be running at as much as 100 to 120 revolutions per minute),* and lifting-tables become necessary. English managers who have increased the speed of their rolls to 45 revolutions per minute, have found it more satisfactory to return to the slower speeds formerly in use, because higher speeds required lighter draughts; 30-inch rolls are only run at 25 or 26 revolutions per minute.

Sheets too thin and large to be handled by ordinary methods may be produced by laying a sheet, finished to ordinary size and thickness, between two fairly thick hot plates, and rolling down the pack thus formed. The two thick hot plates will impart sufficient heat to the thin sheet, which can be polished before being inserted; the thin sheet protected from oxidation by the other two, will come out soft, thin, and with a fine surface. Such methods, however, are too costly to be regarded as ordinary commerical transactions. The Hoerde Works exhibited at the Dusseldorf Exhibition of 1902 a fine soft sheet of apparently very even thickness and fine surface, measuring 4,300 × 1,280 × ·02 mm. = 14 ft. 1¼ ins. × 4 ft. 2⅜ ins. × $\frac{7}{1000}$ in., probably produced by some such means.

The output of a sheet mill is very low. In Staffordshire about 4 tons of sheets were rolled per shift in one pair of rolls; 6 tons could be got through, but there was then considerable risk of breaking the rolls, and 5 tons of mixed sheets were considered a fair average. Few mills, taking one week with another, made more than 40 tons per week from one pair of rolls, and, when rolling very thin sheets, not more than 25 to 30 tons. Strong modern mills, having rolls 26 inches diameter, running at 30 revolutions per minute, and driven by 250 horse-power per stand, make 65 to 75 tons per stand per week.

The recognised output of 30-inch modern mills with two stands of rolls is—

12 tons of 16 gauge per 8-hour shift.
10 " 18 " "
6 " 24 " "
3 " 30 " "

and in computing the labour and cost of rolling—

9 tons of singles are considered equal to 7 tons of doubles.
6 " lattens " " "
4½ " 28 gauge " " "
4 " 29 " " " "
3½ " 30 " " " "

In the trade, calculations are all based on 24 gauge.

The sheets are sheared to size in guillotine shears; those in the American works have blades set in pairs at right angles, so that one end and the adjacent side is sheared at one cut, and, the sheet being turned round, the sheared edges are placed against stops, and the second cut leaves the sheet accurately square and correct to size. In England each side is sheared separately.

The Sheet Gauge.—In this country sheets have always been sold by thickness measured by a sheet gauge, in which No. 1 is the stoutest, the sheets decreasing in thickness as the number rises. The numbers of the old sheet gauge did not vary much from the similar numbers in the wire gauge

---

* *The Iron and Steel Industries of Belgium and Germany*, pp. 38 and 42.

TABLE CXVIII.—SHEET AND HOOP IRON STANDARD GAUGE (B.G.)*

Issued by the South Staffordshire Ironmasters' Association for the use of Sheet and Hoop Iron Makers, March 1st, 1884.

Equivalent thickness in decimals of an inch and millimetres, also the approximate weight per superficial foot, in lbs. and ounces.

Old B.W.G. Lbs. per ft.	No. Gauge.	Inch.		Millimetres.	Lbs.	Ounces.	Old B W.G. Lbs. per ft.	No. Gauge.	Inch.		Millimetres.	Lbs.	Ounces.
	3/0	½	·500	12·700	20	320	·8075	26		·01961	·498	·7844	12·5504
	2/0		·4452	11·308	17·808	284·928	·72	27		·01745	·4432	·698	11·168
	1/0		·3964	10·068	15·856	253·696	·65	28	1/64	·015625	·3969	·625	10
	1		·3532	8·971	14·128	226·048	·56	29		·0139	·3531	·556	8·896
12	2		·3147	7·993	12·588	201·408	·50	30		·0123	·3124	·492	7·872
11	3		·2804	7·122	11·216	179·456	·42	31		·0110	·2794	·440	7·04
10	4	¼	·250	6·350	10	160	·40	32		·0098	·2489	·392	6·272
8·74	5		·2225	5·651	8·90	142·40	·37	33		·0087	·2210	·348	5·568
8·12	6		·1981	5·032	7·924	126·784	·34	34		·0077	·1956	·300	4·80
7·50	7		·1764	4·480	7·056	112·896	·31	35		·0069	·1753	·276	4·416
6·86	8		·1570	3·988	6·28	100·48	·28	36		·0061	·1549	·244	3·904
6·24	9		·1398	3·551	5·592	89·472	·25	37		·0054	·1371	·216	3·456
5·65	10	⅛	·1250	3·175	5	80	·23	38		·0048	·1219	·192	3·072
5·0	11		·1113	2·827	4·452	71·232	·21	39		·0043	·1092	·172	2·752
4·38	12		·0991	2·517	3·964	63·424	·19	40		·00386	·0980	·1544	2·4704
3·86	13		·0882	2·240	3·528	56·448	·17	41		·00343	·0871	·1372	2·1952
3·40	14		·0785	1·994	3·14	50·24		42		00306	·0777	·1224	1·9584
3·0	15		·0699	1·775	2·796	44·736		43		·00272	·0691	·1088	1·7408
2·50	16	1/16	·0625	1·587	2·50	40		44		·00242	·0615	·0968	1·5488
2·26	17		·0556	1·412	2·224	35·584		45		·00215	·0546	·086	1·376
2·0	18		·0495	1·257	1·98	31·68		46		·00192	·0488	·0768	1·2288
1·76	19		·0440	1·118	1·76	28·16		47		·00170	·0432	·068	1·088
1·50	20		·0392	·996	1·568	25·088		48		·00152	·0386	·0608	·9728
1·37	21		·0349	·886	1·396	22·336		49		·00135	·0343	·054	·864
1·25	22	1/32	·03125	·794	1·25	20		50		·00120	·0305	·048	·768
1·12	23		·02782	·707	1·1128	17·8048		51		·00107	·0272	·0428	·6848
1·0094	24		·02476	·629	·9904	15·8464		52		·00095	0241	·038	·608
·90	25		·02204	·560	·8816	14·1056							

As formulated for and at the request of the Ironmasters' Association by Mr. William Hatton.

* It is important that in all transactions in sheet and hoop iron the initial letters B.G. should appear, to distinguish the *Sheet and Hoop Iron Gauge* from the Standard *Wire Gauge*.

(*q.v.*) then in use, although the difference was nevertheless appreciable. The gauges varied in different districts. Stubbs of Warrington, whose wire gauge was largely used, gave the equivalents of his numbers in decimals of an inch, so that they were capable of independent verification, but there were various versions of the Birmingham wire gauge, usually written B.W.G., according as Townley's, Partridge's, or other gauge makers' gauges were employed, giving rise to such endless confusion and disputes that the Board of Trade prepared a new standard wire gauge, particulars of which will be found in Chapter xliii., which deals with the manufacture of wire. By an Order in Council of 23rd August, 1883, the new standard was to become the only legal one after the 28th February, 1884, and was to apply not only to wire, but also to sheets and strip.

The South Staffordshire Iron Masters' Association, whose members produced the larger bulk of such materials, represented that so much inconvenience would arise in applying the new standard to sheets and strip, both to the purchaser, who would not understand the new gauge, and to themselves and to their workmen, who were paid for rolling sheets on a complicated system of piecework prices based on the old standard, and subject to a sliding scale dependent on selling prices, that the Board of Trade consented to exempt sheets from the Order. The Association had asked Mr. William Hatton of Bradley, one of the largest sheet makers of the day, to prepare a gauge suitable for their use, in which his nephew, Mr. Henry Hatton, assisted him. They found that if the highest and lowest number of the existing sheet gauge were employed for the highest and lowest of the new system, each number could be about 11 per cent. thinner than the previous one, so securing a regular variation of thickness throughout.

The use of this gauge, known as the "B.G.," for measuring the thickness of sheets, strip, and hoops, was permitted by the Board of Trade. It is given on the previous page, and opposite each number are the weights per square foot of sheets rolled to it, kindly supplied by Mr. Henry Hatton.

The use of the wire gauge for measuring sheets, nevertheless, still continues; even now they are occasionally ordered to a certain number of Stubbs, or some other old gauge.

It would be a difficult point, under the circumstances, to decide what thickness of sheet would constitute a legal tender in execution of an order for "No. 20 G."

Sheets of 20 G or over in thickness are known as "singles," 21 to 24 G as "doubles," 25 to 27 G as "trebles," or "Lattens," and those below this, down to 29 G, as "Extra Lattens."

Ordinary "black sheets" rolled hot can be relied upon to vary not more than about $\frac{1}{100}$ of an inch from the thickness specified, and ordinary cold rolled sheets, which cost about 50 per cent. more than black sheets, may not vary perhaps by more than one-half or one-third this amount, while bright cold rolled sheets, which are accurate to $\frac{1}{1000}$ of an inch, may be had at about double the price of ordinary cold rolled. For particulars of close annealing and cold rolling see Chapter xliv. dealing with the manufacture of tin plates.

Strip Mills are small mills, having rolls 8 to 12 inches diameter, used for rolling thin strip, such as barrel hoops or cotton ties, and other material less than 6 or 8 inches wide by less than ⅛ thick.

The strip is reduced from a billet in grooved rolls until the last two passes, which are made between a pair of plain rolls, called the "planishing rolls," and then between a pair of plain chilled rolls, known as the "hard rolls," running at about half the speed of the preceding rolls.

For giving a good finish the strip passes over and under scrapers (fig. 498), which are situated just in front of the hard rolls. As soon as these rolls have gripped the strip the scrapers are put in action, and bend the material sharply up and down over their sharp edges, thus cracking and removing the scale. Care is taken to pass the strip through this last pair of rolls when at such a heat that no more scale is formed, and a bright blue surface is left. But as the strip passes through the hard rolls at about 4 or 5 feet per second, and the boy who works the scraper cannot lower it on to the strip until he sees that the rolls have gripped the end of it, he is unable to lower the scraper fast enough to clean the first 5 or 6 feet. By Hall & Scarf's patent scraper (fig. 499), in which power is used to drive down the scraper far faster than is possible by muscular exertion, the unscraped portion may be reduced by one-half.

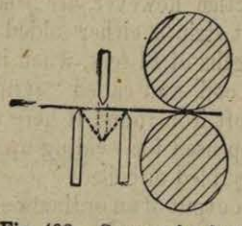

Fig. 498.—Scraper for Strip.

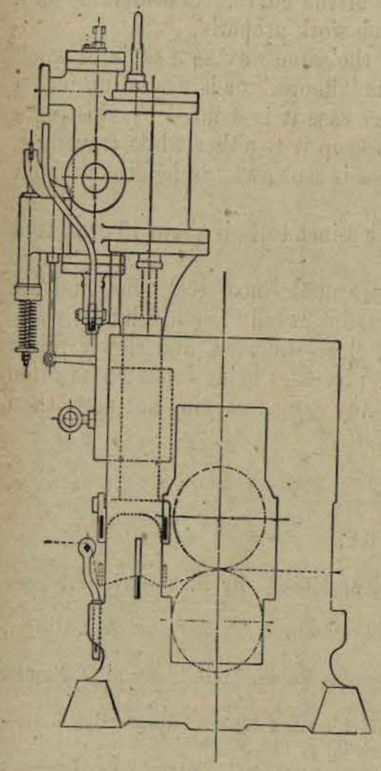

Fig. 499.—Patent Scraper.

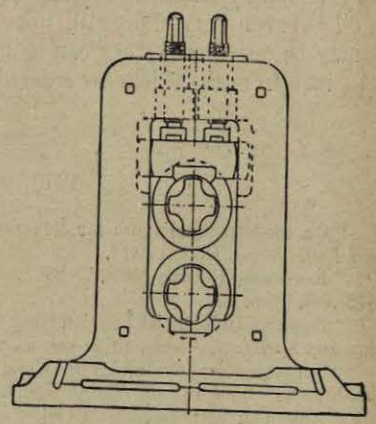

Fig. 500.—Housing for Strip Mill.

The friction caused by pushing the strip along the floor offers a greater resistance than so thin a section can withstand, so that after the first 30 or 40 feet have left the mill, the front end ceases to travel, the remainder doubles up under the thrust, and as it issues from the rolls is thrown into curves which cannot afterwards be straightened out. When long lengths are to be rolled this difficulty is surmounted by perforating with small holes that portion of the floor plates over which the strip has to pass, and maintaining below them such a pressure of air as will suffice to float the strip free of the floor, whereby friction is avoided, and long lengths can be got out almost perfectly straight.

In strip mills, instead of there being only one housing screw to keep down the top chock, there are usually two, one near each end of the chock (fig. 500). This prevents any tendency of the chock to rock; the rocking, by allowing the short rolls to get slightly out of parallel with each other, causes the strip to be curved sideways and uneven in thickness.

The rolls must be adjusted with great nicety; if a strip intended to be finished 2 inches wide by No. 12 B.G. thick enters the finishing rolls quite straight, but leaves them with one edge $\frac{1}{10000}$ inch thicker than the other, it will be found to be bent so much out of line that a straight line drawn between the two ends of the strip will show it to be hollow on the edge by more than 1 foot in 40 feet.

The strip, if not straight, can be straightened by tapping it with a hammer, in the same way as a saw blade is straightened—namely, by very slightly crushing, and so stretching the inner side of the curve. Considerable skill and practice, however, are needed to do such work properly.

Light strip is either folded up in much the same way as a skein of wool, into lengths of 14 feet, when it is known as "hoops," or is wound up into a circular coil, and called "strip"; in either case it is secured by twisting a bit of soft iron round it here and there to keep it together while travelling. Gas strip used for welding up into gas pipes is sent away in lengths without being doubled or coiled.

The output of an ordinary strip mill, with 9-inch rolls, is about 15 or 16 tons of strip, 3 inches wide, per shift.

"Bright cold rolled sheets," such as are made into steel pens, and are used for other special purposes, consist of strip, usually about 6 inches wide, cut into handy lengths, carefully pickled, close annealed, and slowly rolled in oil between very short stiff rolls, these processes being repeated as often as may be necessary; they can be had to any gauge, varying not more than $\frac{1}{1000}$ inch from the thickness ordered.

BIBLIOGRAPHY.

"On Modern Appliances for Reversing Rolling Mills." By B. Walker. *Iron and Steel Inst. Journ.*, 1871, p. 417.

"Reversing Rolling Mills." By Graham Stevenson. *Iron and Steel Inst. Journ.*, 1872, vol. ii., p. 47.

"Napier's Differential Friction Gear for Reversing Rolling Mills." By R. D. Napier. *Iron and Steel Inst. Journ.*, 1872, vol. ii., p. 43.

"Suggested Improvements in Handling and Shearing Steel Plates." By Andrew Lamberton. *West of Scot. Inst. Journ.*, 1895, vol. ii., p. 143.

"American and English Methods of Manufacturing Steel Plates." By Jeremiah Head. *Min. Proc. Inst. C.E.*, May 5, 1896, vol. cxxvi.

"The New Armour-Plate Mill at Creusot." *Engineering*, May 1, 1903, p. 583.

CHAPTER XXXV.

ROD MILLS.

Introductory.—No mills have undergone such interesting developments as those employed for rolling the small rods intended to be drawn out when cold into wire. Such bars are so very small in section, and therefore cool so rapidly, that when rolled by hand in the old form of mill it was not easy to deal with billets more than 10 lbs. in weight, or to finish them to sizes below ½ inch in diameter and 14 feet in length. In 1860, a mill starting with a billet 1¼ inches square, could not turn out more than five tons of ⅜ rods in twenty-four hours. Since then inventors have been continually devising means to run the rod faster through the trains of rolls, until so little time is now occupied in the transit, that the rod leaves the mill practically as hot as it enters, the high speed of travel naturally yielding greatly increased outputs.

A single modern mill with finishing rolls of the same size as those used in 1860 has turned out as much as 400 tons of No. 5 rod 0·212 inch in diameter in twenty-four hours, from billets 5 inches square, and has produced a No. 6 rod 0·160 inch in diameter, weighing about 1 ton, 6½ miles long, all in one length. How this has been rendered possible will be explained in this chapter.

The Belgian or Looping Mill.—In no branch of rolling was the advantage of the three-high mill so naturally conspicuous as in the production of these small sections, which could be finished in half the time when they could be rolled on the backward as well as on the forward journey; sections down to ¼ inch in diameter, which formerly had to be drawn cold through dies, were at once rolled off hot, with enormous saving in the cost of production. Moreover, it was soon perceived that as such small sections were extremely flexible when hot, it was not necessary to wait for the whole piece to leave the rolls, and to then enter the end which had last left into the second pass. Immediately the first end of the piece emerged from between the rolls, on the catcher's side, he could seize it with his tongs, bend it round in a half circular loop, and return it through the next return pass to the roller, who in his turn could catch it, bend it round, and pass it back once more through the third pass. The rod was thus bent in the form of the letter **S**, one end being between the middle and bottom roll, the centre between the middle and top roll, and the other end between the bottom and middle roll again, and all parts travelling on through the rolls; seeing that three portions of the rod were being rolled at the same instant, of course a further great decrease was effected in the time needed to finish it.

With rapid rolling the catcher returned the rod so soon that the roller, who was occupied in entering the rod into the first pass, had not time to turn his attention to the bar just rushing towards him before it was upon him, and accordingly a third man was employed to enter the rod into the third pass. Then, to give the men room to work properly, instead of putting all three passes in one stand of three-high rolls, each pass was in a separate pair of rolls, and each pair of rolls in its own housings. Fig. 501 shows a mill of this description, which is generally known as the Belgian wire mill. The billet was roughed out or broken down in the first stand of rolls in the ordinary way, but when small enough to bend readily—*i.e.*, about ¾ inch in diameter—it was passed to the second stand forming a loop, a mill of this type being therefore known as a looping mill.

The number of stands of rolls which were coupled up thus was not