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P. J. SHIPP

ROLLING

3,348,393

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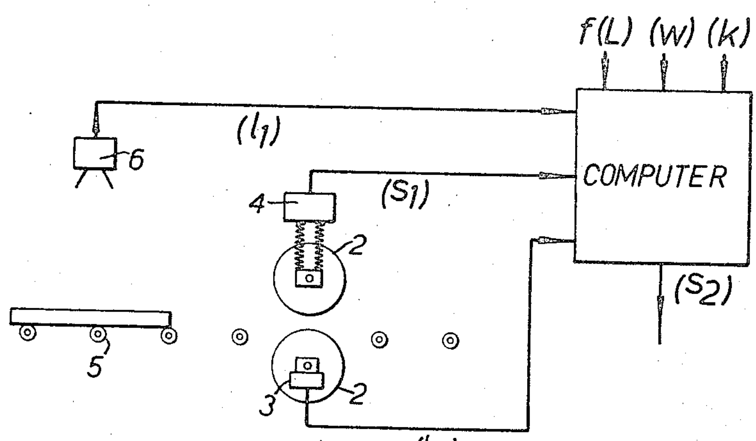

FIG. 1.

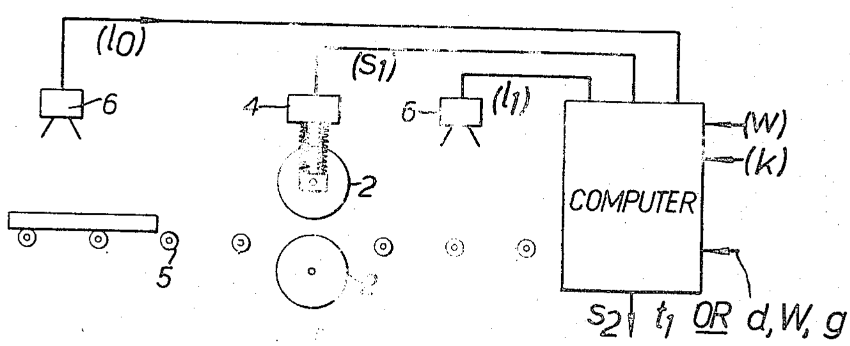

FIG. 2.

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This invention relates to rolling and more particularly but not exclusively to the rolling of steel plate from a slab.

Considering the above application of this invention to plate rolling, it is common practice in such an operation to roll a rectangular slab in one direction until its length in that direction is equal to the required, final rolled plate or so-called "as-rolled" width. The slab is then turned through 90° and rolled down to the required plate thickness.

It would be of advantage in the plate rolling operation just described to be able to predetermine the required screwdown setting for the last pass to make the rolled out length equal to the required plate width, that is, the last so-called broadsiding pass before turning, since this would obviate errors and the need for additional correcting passes. The required, as-rolled plate width, denoted hereinafter as w, will equal the desired finished width plus the side trim necessary for smooth operation of the rotary or guillotine shears normally used.

Considering then the basis for the present invention, during the rolling of a slab the volume of metal in the slab remains constant. Thus if l denotes the length, d the width, and t the thickness of the workpiece after any pass

$$l.d.t=\text{constant} \qquad (1)$$

In plate rolling, where the ratio t/d is always small, the lateral spread during rolling is negligible, so that during broadsiding d remains substantially constant and for all of the passes up to the turning operation (1) can be written

$$l.t=\text{constant} \qquad (2)$$

The actual thickness of the rolled workpiece after a pass, assumed constant over its whole area, is given by

$$t=s+x \qquad (3)$$

where s denotes screwdown setting for the pass in question, and x denotes mill stretch which is a function of the rolling load L. Thus, (2) can be written

$$l(s+x)=\text{constant} \qquad (4)$$

If P_1 and P_2 denote any two consecutive broadside passes, then from (4)

$$l_1(s_1+x_1)=l_2(s_2+x_2) \qquad (5)$$

and if P_2 is the last such pass before turning, then

$l_2=w$, the required as-rolled plate width,
s_2=the required screwdown setting on the last pass before turning, and
x_2=mill stretch during the pass.

Rewriting (5) to obtain an expression for s_2,

$$s_2=\frac{l_1s_1}{w}+\frac{l_1x_1}{w}-x_2 \qquad (6)$$

Equation 6 can be used as the basis of a method of predicting the required screwdown setting in conjunction

with any convenient method of measuring mill stretch. One such method, for example, is to relate mill stretch during a pass to the mill load experienced during that pass.

The mill stretch on any pass is given by

$$x=f(L)+k \qquad (7)$$

where:

L=rolling load during the pass in question
$f(L)$=total mill stretch, which is made up of two components, namely,
(i) housing stretch, which may be non-linear, and
(ii) roll deflection, which depends on workpiece width,
k=a constant correction which includes any zero error of the screwdown indicator, interface clearances taken up when the rolling load is applied, etc.

Substituting (7) in (6) gives

$$s_2=\frac{l_1s_1}{w}+\frac{l_1}{w}\cdot f(L_1)-f(L_2)+k\left(\frac{l_1}{w}-l\right) \qquad (8)$$

The reduction ratio on the last pass before turning, r_2, is given by

$$\frac{t_1-t_2}{t_1}$$

which from (2) is equal to

$$\frac{w-l_1}{w}$$

and (8) may therefore be rewritten as

$$s_2=\frac{l_1s_1}{w}+\frac{l_1}{w}\cdot f(L_1)-f(L_2)-r_2k \qquad (9)$$

This last expression represents the basis for the method and apparatus, and in accordance with the present invention there is provided an automatic system for setting the rolls of a rolling mill for one pass of a plurality of passes to produce a predetermined workpiece length by that one pass comprising means for producing a signal according to the relationship

$$\frac{l_1s_1}{w}+\frac{l_1f(L_1)}{w}-f(L_2)-r_2k$$

where:

l_1=the workpiece length before the one pass.
w=the predetermined length.
s_1=the roll setting in the preceding pass.
$f(L)$=the mill stretch during the one pass as herein defined.
r_2=the reduction ratio at the pass to produce the predetermined length.
k=a constant mill characteristic as herein defined.

and feeding that signal to means for moving the rolls relative to one another.

Equipment has been proposed whereby the length of a workpiece on a roller table can be measured automatically, so that a representation of l_1 is readily available. The required dimension w is already known, and from this the reduction ratio can be obtained as

$$\frac{w-l_1}{w}$$

A representation of the screwdown setting s_1 can be obtained from the screwdown indicator, and the load L_1

from a loadmeter. The value of k will be constant for any particular mill and can thus be determined at the commencement of any operational sequence or shift, and in association with any roll change. The mill stretch $f(L)$ is, as noted above, made up of the housing stretch which may be non-linear but will remain constant for any particular mill, together with the roll deflection which will depend on the known slab width being rolled; again these factors can be determined.

Thus, the only unknown in (9), apart from s_2 to be predetermined, is the rolling load L_2 which will be experienced during the pass under consideration.

Measurements taken on a production plate mill during broadsiding have shown that the reduction ratio r in a pass and the rolling load L during that pass obey approximately the relationship L/r=constant. Thus the rolling load L_2 may be calculated from the known required reduction ratio r_2 and from the measured value of r_1 and L_1 for the previous pass, or from the average of the values of r and corresponding values of L measured on several preceding cross-rolling passes on the same slab.

The measurements have also shown that the draft c in a pass and the rolling load L in that pass obey approximately the relationship $L/\sqrt{c}$=constant. Thus the rolling load L_2 may be calculated from the known required draft c_2 and from the measured or calculated values of c_1 and L_1 for the previous pass, or from the average of the values of $\sqrt{c}$ and L for several preceding passes. The draft c on a pass is equal to the difference between the slab thicknesses before and after a pass. The thickness after a pass is, from Equations 3 and 7, given by

$$t=s+f(L)+k \tag{10}$$

and the thickness before the pass is equal to the thickness issuing from the preceding pass, which can be obtained in a similar manner. The required issuing thickness on the turning pass may be calculated from Equation 2 thus

$$t=\frac{l_1 t_1}{w}$$

where l_1 and t_1 are the measured slab length and thickness on any preceding pass and w is the requred as-rolled width.

Alternatively the principle may be applied without measuring mill loads. For many mills the stretch curve is linear with respect to load above some fixed low value of load, and the working loads of a mill are normally, or can be arranged to be, within the range corresponding to the linear portion of the stretch curve. Equation 7 can then be written

$$x=ML+k \tag{11}$$

where M=elastic modulus of the mill over the linear portion. Equation 9 then becomes

$$s_2=\frac{l_1 s_1}{w}+\frac{l_1}{w}ML_1-ML_2-r_2 k \tag{12}$$

Assuming one of the relationships between the load in a pass and the geometrical factors associated with it mentioned previously, for example L/r=constant, the formulae

$$L_2=ar_2$$

$$r_2=\frac{w-l_1}{w}$$

may be substituted into Equation 12 to give

$$s_2=\frac{l}{w}(l_1 s_1+aM(2l_1-l_0-w)-k(w-l_1)) \tag{13}$$

As before, all the quantities on the right hand side of the equation are known or can be measured directly, except the factor aM. To obtain the value of the factor aM for any slab we note that for any pass

$$t-s-k=ML=aMr$$

where the symbols have their previous significance. Thus by measuring the thickness t, screwdown setting s and reduction ratio r on one or more cross-rolling passes, and knowing the screwdown zero error k, the value of the factor aM for the particular slab being rolled can be calculated. The reduction ratio in a pass may be obtained from the slab lengths before and after the pass according to

$$r=\frac{l_2-l_1}{l_2}$$

The slab thickness after a pass may be obtained from Equation 2 thus

$$t_2=\frac{l_1 t_1}{l_2}$$

where l_2 is the slab length after the pass and l_1,t_1 are the corresponding length and thickness of the slab before or after one of the earlier cross-rolling passes. Alternatively the slab thickness may be calculated from the formula

$$t=\frac{w}{l.d.g}$$

where:

w=total weight of slab
l=slab length
d=slab width
g=density of steel comprising the slab.

Effects of errors in the calculated value of aM on the prediction of required screwdown setting may be minimized by adopting a drafting policy which gives nearly equal slab length extensions on the last two cross-rolling passes so that

$$l_1-l_0 \simeq w-i_1$$

or

$$2l_1-l_0-w \simeq 0$$

and the effect of the term in Equation 13 which involves aM is small.

In a mill with a known stretch curve $f(L)$ which is fitted with loadcells, values of r or c on any pass may be obtained from the slab thicknesses before and after the pass calculated from Equations 3 and 7. If in such a mill the cross-rolling is always finished on the same side of the mill, only one slab length measuring device need be fitted, on the side remote from the finishing side, to furnish the value l_1 in Equation 9. If the cross-rolling may be finished on either side of the mill length measuring devices are required on both sides of the mill. If loadcells are not fitted to the mill, length measuring devices are required on both sides of the mill.

The rolling load L in a pass may be obtained by averaging an analogue or digital representation of the load obtained from commercially available loadcells already in use on steel rolling mills.

In order that the invention may be well understood two embodiments, given by way of example only are shown in the accompanying drawing in which each of FIGURES 1 and 2 is a schematic diagram of a millstand.

FIGURE 1 shows a millstand having work rolls **2** the lower of which is bottomed against a load cell **3**. The upper roll is actuated by a screwdown motor and screwdown indication is provided by a position transducer **4** which may give an analogue or digital representation of the rotation of the screwdown motor or of the screwdown screw itself, such a transducer being well known. Over the work table **5** is a length measuring device **6** e.g. an English Electric Slab Length Measurer.

The signals derived from the load cell, position transducer and length measurer are fed to a computer which also receives the constants $f(L)$, w and k. The resultant signal is fed back to the screwdown motor.

In FIGURE 2 is shown a similar arrangement but for the elimination of the load cell and the provision of two length measurers. In place of the constant $f(L)$ the computer is fed either the measured thickness on a proceeding pass or the slab width weight and density.

In FIGURE 1 rolling must always finish at the right side of the millstand, the device operating on the basic expression:

$$s_2=\frac{l_1 s_1}{w}+\frac{l_1 f(L)}{w}-f(L_2)-r_2 k$$

and l_2 is not required, while the arrangement of FIGURE 2, working according to the expression

$$s_2=\frac{l}{w}[l_1 s_1+aM[2l_1-l_0-w]-k(w-l_1)]$$

requires two length measurers to provide both l_1 and l_2 (l_0 and l).

For the measurement of slab thickness (t_1) a known thickness measurement device may be used, for example a rocker arm rotated by the slab and operative to set a potentiometer or a visual indicator.

It will, of course, be appreciated that, apart perhaps for any calculations to be made before a complete rolling program with a particular mill arrangement, all of the above representations and calculations can be effected automatically by the use of known equipment which will normally be of an electrical form. Also, it should be understood that although the present invention has been described above in relation to a particular operation, namely plate rolling from slab, and concerning control apparatus therefor, the invention is of broader application in the control of any rolling operation where a particular as-rolled workpiece dimension is required.

I claim:

1. Apparatus for controlling the setting of the roll of the last broadside pass in the rolling sequence of a roughing stand of a plate mill to produce a predetermined length (w) for the rolled material, comprising means for generating an electrical signal representing the actual roll gap setting (s_1) corresponding to the last-but-one pass, means for generating an electrical signal representing rolling load (L_1) corresponding to the last-but-one pass, means for generating an electrical signal representing the material length (l_1) before said last pass, and calculating apparatus for providing an electrical signal for controlling the roll gap setting (s_2) for said last pass calculated in accordance with the relationship

$$\frac{l_1 s_1}{w}+\frac{l_1 f(L_1)}{w}-f(L_2)-r_2 k$$

where k is a predetermined constant characteristic of the mill, f(L) is the total mill stretch calculated in predetermined manner from the respective rolling load (L_1 or L_2), and r_2 is the predicted reduction ratio for the pass to be controlled.

2. Apparatus as claimed in claim **1** in which said calculating apparatus comprises means for deriving r_2 from the relationship

$$r_2=\frac{w-l_1}{w}$$

3. Apparatus as claimed in claim **2** in which said calculating apparatus comprises means for deriving L_2 from r_2, l_1 and r_1 by the relationship

$$\frac{L}{r}=\text{constant}$$

with r_1 representing the reduction ratio for the preceding pass.

4. Apparatus for controlling the setting of the roll of the last broadside pass in the rolling sequence of a roughing stand of a plate mill to produce a predetermined length (w) for the rolled material, comprising means for generating an electrical signal representing the actual roll gap setting (s_1) corresponding to the last-but-one pass, means for generating an electrical signal representing rolling load (L_1) corresponding to the last-but-one pass, means for generating an electrical signal representing the material length (l_1) before said last pass, and calculating apparatus for providing an electrical signal for controlling the roll gap setting (s_2) for said last pass calculated in accordance with the relationship

$$\frac{l}{w}[(l_1 s_1+aM(2xl_1-l_0-w)-k(w-l_1)]$$

where k is a predetermined constant characteristic of the mill,

$$a=\frac{L}{r}$$

and M is the modulus of elasticity of the millstand, and l_0 is the workpiece length before the next to the last pass.

5. Apparatus as claimed in claim **4** in which said calculating means comprises means for deriving aM according to the expression

$$t-s-k=ML=aMr$$

in which t represents the thickness of the workpiece and means to determine r according to the expression

$$r=\frac{l_2-l_1}{l_2}$$

in which l_2 represents the predetermined workpiece length.

6. Apparatus according to claim **5** in which said calculating means comprises means to determine t according to the expression

$$t_2=\frac{l_1 t_1}{l_2}$$

in which t_1 and t_2 represent the thickness of the workpiece before and after the last pass.

7. Apparatus according to claim **5** in which said calculating means comprises means to determine t according to the expression

$$t=\frac{W}{l.d.g}$$

in which l represents the length and d the width of the workpiece after any given pass, W represents the weight of the workpiece and g represents the density of the workpiece.

8. Apparatus for rolling plate from slab comprising means for controlling the setting of the roll of the last broadside pass in the rolling sequence of a roughing stand of the plate mill to produce a predetermined length (w) for the rolled material, means for turning the rolled material through 90°, and then rolling the material to the required plate thickness, the means for controlling the setting of the roll of the last broadside pass including means for generating an electrical signal representing the actual roll gap setting (s_1) corresponding to the last-but-one pass, means for generating an electrical signal representing rolling load (L_1) corresponding to the last-but-one pass, means for generating an electrical signal representing the material length (l_1) before said last pass, calculating apparatus for providing an electrical signal for controlling the roll gap setting (s_2) for said last pas calculated in accordance with the relationship

$$\frac{l_1 s_1}{w}+\frac{l_1 f(L_1)}{w}-f(L_2)-r_2 k$$

where k is a predetermined constant characteristic of the mill, f(L) is the total mill stretch calculated in predetermined manner from the respective rolling load (L_1 or L_2) and r_2 is the predicted reduction ratio for the pass to be controlled.

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