

April 6, 1965

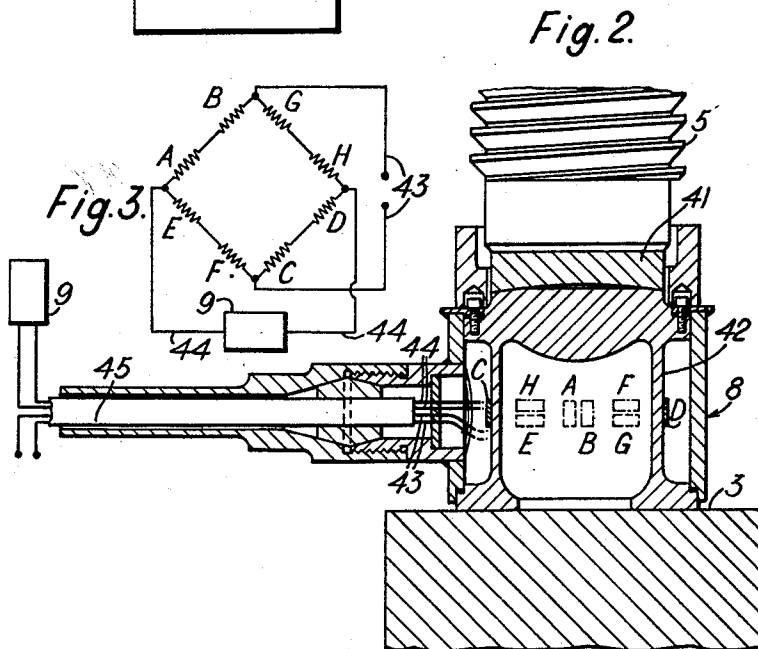
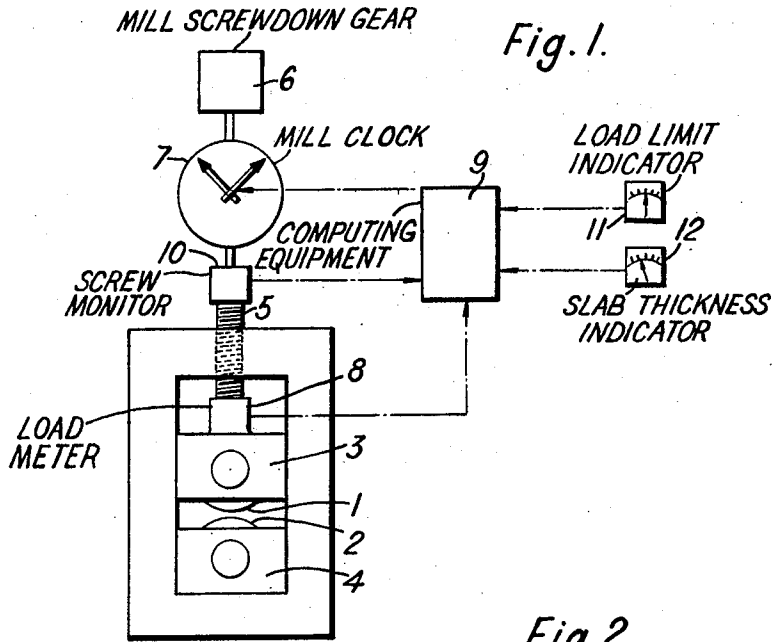
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3,177,346

APPARATUS FOR USE IN CONTROLLING A ROLLING MILL

Filed Nov. 6, 1959

3 Sheets-Sheet 1



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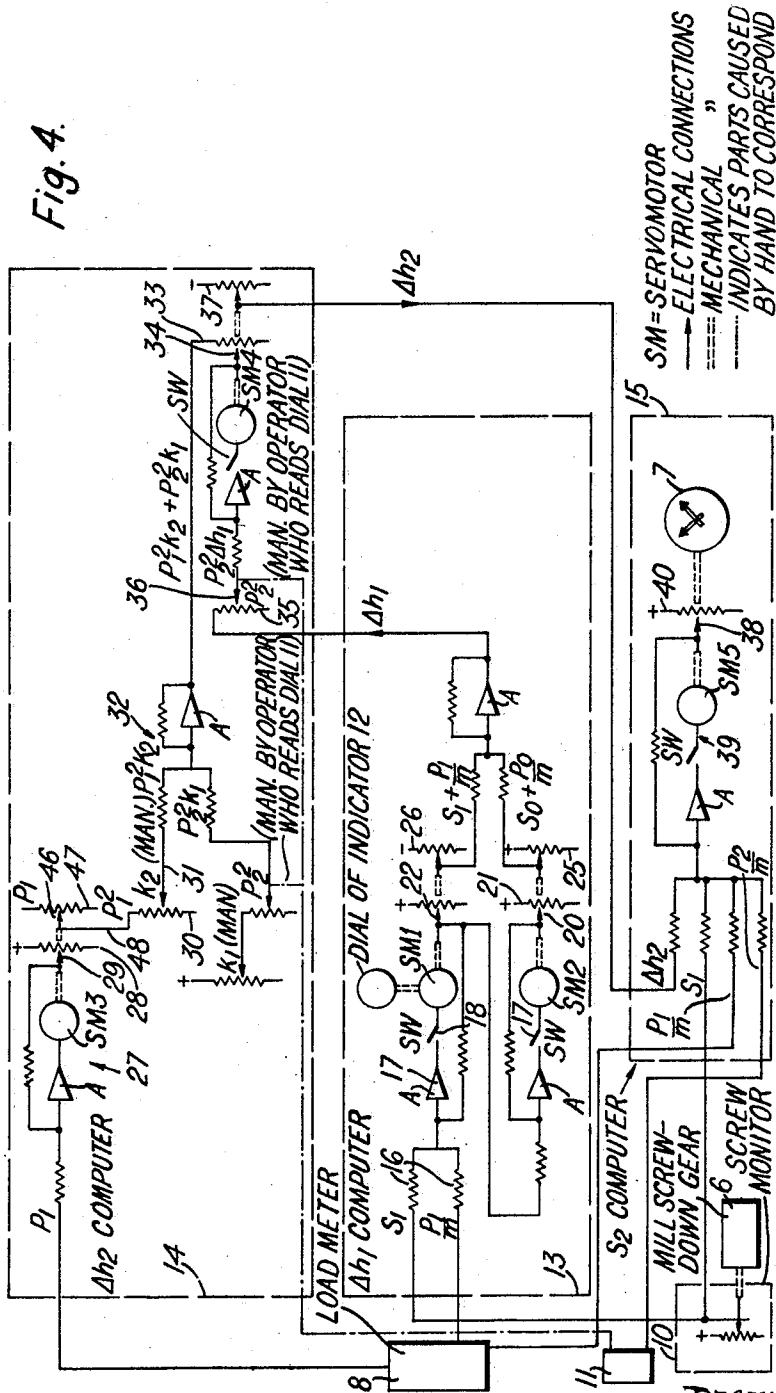
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APPARATUS FOR USE IN CONTROLLING A ROLLING MILL

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Fig. 4.



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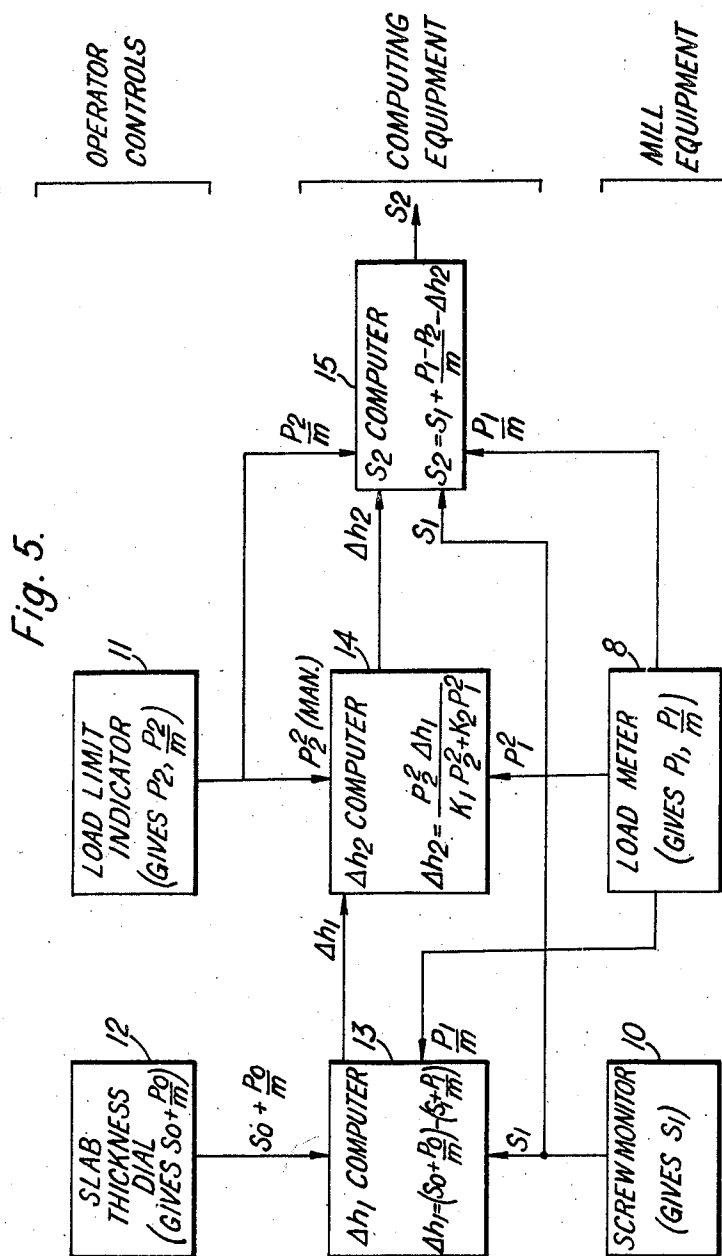
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APPARATUS FOR USE IN CONTROLLING A ROLLING MILL

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3 Sheets-Sheet 3



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3,177,346 APPARATUS FOR USE IN CONTROLLING A ROLLING MILL

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6 Claims. (Cl. 235-151)

When a single-stand reversing mill is used for rolling an ingot to a slab or a slab to a plate so as to reduce the thickness of the rolled material from pass to pass with little or no increase in the width, the gap between the mill rolls is reduced after each pass to give a draft, i.e. a specific reduction in thickness, to the material. The degree of draft is determined at present by the operator (who relies upon his experience) and it is necessary to vary the draft as the rolling conditions change. In present rolling practice there is very little equipment to assist the operator in the assessment of draft, and the loading on the mill in terms of roll-separating force or driving motor torque can vary over wide limits if the materials to be rolled vary in composition, width and working temperature from piece to piece, as commonly happens. For each pass there is an optimum draft, namely that which will give the maximum tenable mill load, i.e. roll-separating force, and this depends on the composition of the material, the width and the temperature.

It is an object of this invention to provide means whereby a mill may be set so that it will automatically work at the maximum tenable mill load on every pass. The ingot or slab being worked will therefore be rolled at optimum draft so that the number of passes required in a rolling schedule can be kept to a minimum and the mill capacity fully utilised. The invention is based on a relationship we have determined between the roll-separating force P in consecutive passes and the draft Δh in those passes. The draft Δh for a given pass is the difference between the thicknesses of the ingot or slab before and after the pass. The roll gap during rolling is greater than that actually set because of elastic stretch of the mill under load, and the extension of the gap under load is proportional to the load. Therefore, if the suffixes 0, 1 and 2 denote successive passes, m is the mill modulus and S is the set gap, the actual gap during rolling is

$$S + \frac{P}{m}$$

and the values of Δh are

$$\Delta h_1 = \left(S_0 + \frac{P_0}{m} \right) - \left(S_1 + \frac{P_1}{m} \right) \quad (i)$$

$$\Delta h_2 = \left(S_1 + \frac{P_1}{m} \right) - \left(S_2 + \frac{P_2}{m} \right)$$

In effect,

$$S_0 + \frac{P_0}{m}$$

represents the initial slab thickness or entering slab thickness as rolling proceeds.

The relationship I have established is expressed by the equation

$$\Delta h_2 = \frac{P_2^2 \times \Delta h_1}{K^2 \times P_1^2} \quad (ii)$$

where K is a function which varies from mill to mill but can be found experimentally in any mill with fixed rolling

practice and which is defined in terms of P_1 and P_2 by the equation

$$K^2 = \frac{k_1 P_2^2}{P_1^2} + k_2$$

k_1 and k_2 being constants for the mill while its rolling practice is fixed. Equation (ii) thus gives Δh_2 in terms of the function K , of Δh_1 the draft on pass 1, of P_1 the roll-separating force on that pass which can be measured by a load meter and P_2 the roll-separating force it is desired to use for pass 2 and subsequent passes. P_2 , as already mentioned, is usually as large as possible and can be determined for a given mill.

The draft Δh_2 on pass 2 is related to the set gap S_2 for that pass by the equation

$$S_2 = S_1 + \frac{(P_1 - P_2)}{m} - \Delta h_2 \quad (iii)$$

Once this equation is solved, therefore, all the information has been obtained whereby the mill may be set to work to the best advantage on its next pass.

Now computing equipment can be designed or set to solve the Equations (i), (ii) and (iii) continuously, and will do so on being fed with appropriate signals. There must be means by which the signals are fed to the equipment, and these means may be an instrument or device responsive to the roll-separating force, whereby the computer may be fed with a corresponding signal; an instrument or device responsive to the roll gap as set, whereby the computer may be fed with a corresponding signal; an instrument or device set by the operator to feed a signal corresponding to the desired roll-separating force, and an instrument or device to feed a signal corresponding to the thickness of the material either before or after but preferably before the first pass; this will be called the starting thickness, and before the first pass it is given by

$$S_0 + \frac{P_0}{m}$$

The apparatus will not determine the draft in the first pass, because signals produced during one pass are needed to determine the draft in the next. During the one pass the computer is fed with signals representing the roll gap set for that pass, the roll-separating force developed in it, the desired load during the next pass and the function K , and usually with the starting thickness. The computer then gives a response corresponding to the optimum draft for the next pass. This response may either be transmitted to an indicator with the aid of which the operator sets the roll gap for the next pass or be employed to effect the setting of this gap automatically.

During the next pass, new measurements of mill load and roll gap are made, and together with the measurement of the roll gap in the previous pass are fed to the computing equipment so that the optimum draft for a third pass may be found and so on. In this way the drafting from pass to pass is computed automatically at values to load the mill to the pre-set limit.

This limit can be changed either during the rolling of a product or from one product to another. During the rolling of a product such a change may be desirable to allow roughing passes to be performed at a high load and finishing passes at a lower load. This is an asset in the rolling of plates, as a specific roll-separating force is commonly required on finishing passes to preserve plate shape.

The computing equipment may be composed of conventional electro-mechanical servo-mechanisms or a combination of these with electronic elements.

Of course, if with any particular mill it is preferred for any reason to work according to some variations of

the equation given above, the computing equipment may be adjusted to solve this other equation.

The combined effects of the composition of the material, the width, and the temperature all influence the roll-separating force, which is measured by the instrument or device responsive to it. These effects are therefore assessed automatically in each pass and accordingly variations in the yield stress of a material due to gradual changes in temperature and deformation rate are detected pass by pass.

The roll-separating force may be measured by a load meter interposed between the screw and the top chock of the mill.

The roll gap as set by the operator may be signalled to the computer by an instrument responsive to the position of the mill screws. This instrument may be a Selsyn repeater with its rotor directly coupled to a screw, the repeater giving a signal which corresponds to the angular position of the screw and which does not change with the loading. The extension of the roll gap when the mill is loaded is determined by the computer from the signals from the load meter.

The signal which gives the computer the desirable roll-separating force is transmitted by any convenient instrument having a visible scale with the aid of which the operator can set the instrument. He must know the maximum load which the mill or the driving motors can safely stand and normally will set the instrument to this, though as explained above a lesser load may be desirable in the later stages of the rolling.

If the operator is told the starting thickness of the material, the signal giving this thickness to the computer may be transmitted by an instrument having a visible scale and similar to that which transmits the signal indicating the roll-separating force. Alternatively the starting thickness may be measured by an instrument that cooperates automatically with the transmitting instrument.

The preferred construction will now be described by way of example with reference to the accompanying drawings, in which:

FIGURE 1 is a diagrammatic representation of a single stand reversing mill equipped for automatic operation according to this invention;

FIGURE 2 is a partly diagrammatic sectioned elevation of part of the mill;

FIGURE 3 is a diagram showing part of the electrical circuit used in this part of the mill;

FIGURE 4 is a block schematic representation of the computing equipment and associated parts; and

FIGURE 5 is a diagrammatic representation of the electrical circuits in the computing equipment.

In FIGURE 1 the two rolls of the mill are shown at 1 and 2 and the top and bottom chocks at one end at 3 and 4, the top chock being forced downwards by a screw 5, driven by mill screw-down gear 6 and whose angular position is indicated by a mill clock 7. A load meter 8 is interposed between the screw 5 and the top chock 3, and feeds a signal to the computing equipment shown at 9. A screw monitor 10 of the Selsyn repeater type feeds a signal corresponding to the angular position of the screw 5; the screw monitor comprises an electrical potentiometer connected directly to the screw-down gearing. An instrument to indicate the desirable roll-separating force, so that the computing equipment may be fed with signals corresponding thereto, is shown at 11; this instrument comprises a dial which can be set manually to correspond to the desired load and which is connected directly to an electrical potentiometer which gives a corresponding electrical signal. This instrument will be called the "load limit indicator." A similar instrument giving a reading from which the computing equipment may be supplied with a signal corresponding to the starting thickness of the slab of material is shown at 12. This device will be called the "slab thickness indicator."

After many observations had been made on the mill now

being described, it was found that the function K^2 could be described approximately in terms of P_2^2/P_1^2 by the equation

$$K^2 = k_1 \frac{P_2^2}{P_1^2} + k_2$$

k_1 and k_2 being constant for the mill in question provided its rolling practice remains fixed. Graphed results actually showed k_1 and k_2 to be approximately equal to 0.38 and 0.75 respectively. Substituting

$$k_1 \frac{P_2^2}{P_1^2} + k_2$$

for K^2 in Equation (ii), we find

$$\begin{aligned} \Delta h_2 &= \frac{P_2^2 \cdot \Delta h_1}{P_1^2 \cdot \left(k_1 \frac{P_2^2}{P_1^2} + k_2 \right)} \\ &= \frac{P_2^2 \cdot \Delta h_1}{k_1 P_2^2 + k_2 P_1^2} \end{aligned} \quad (iv)$$

The computing equipment of the mill being described was used to solve Equations (i), (iv) and (iii) continuously.

FIGURE 4 indicates that the computing equipment 9 comprises three computers. First the computer 13 or "Δh₁ Computer," which solves the equation

$$\Delta h_1 = \left(S_0 + \frac{P_0}{m} \right) - \left(S_1 + \frac{P_1}{m} \right)$$

given

$$\left(S_0 + \frac{P_0}{m} \right)$$

from the slab thickness indicator 12, S_1 from the screw monitor 10 and P_1/m from the load meter 8. Second, the computer 14 or "Δh₂ Computer," solves the equation

$$\Delta h_2 = \frac{P_2^2 \times \Delta h_1}{k_1 P_2^2 + k_2 P_1^2}$$

given Δh_1 from the computer 13, P_1 from the load meter 8 and P_2 from the load limit indicator 11. Thirdly, the computer 15 or "S₂ Computer," which solves the equation

$$S_2 = S_1 + \frac{(P_1 - P_2)}{m} - \Delta h_2$$

given P_2/m from the indicator 11, Δh_2 from the computer 14, S_1 from the screw monitor 10 and P_1 from the load meter 8.

Referring now to FIGURE 4, it may be seen that the signals corresponding to S_1 and P_1/m fed to the computer 13 from the screw monitor 10 and load meter 8 respectively pass through a summing circuit including input resistors 16 and an amplifier 17. The dial of the slab thickness indicator 12 is mechanically connected to a positioning servomotor SM1. Consequently when the operator records the thickness on the dial of the indicator 12 the motor SM2 turns and a cooperating potentiometer tapping key 20, mounted on the shaft of the motor SM2 so as to slide as the shaft rotates, slides to a position on the feedback potentiometer 21 corresponding to the thickness, i.e. to

$$S_0 + \frac{P_0}{m}$$

As soon as a pass begins switch 18 is caused to close and switch 19 to open. The tapping key 22, mounted on the shaft of the motor SM1 just like the key 20 is mounted on the shaft of the motor SM2, is therefore caused to slide along the wire of the feedback potentiometer 23 to a position corresponding to

$$S_1 + \frac{P_1}{m}$$

Consequently the summing circuit 24 will receive from

the output potentiometers 25 and 26 signals corresponding to

$$\left(S_0 + \frac{P_0}{m}\right) \text{ and to } -\left(S_1 + \frac{P_1}{m}\right)$$

and will sum them to give a signal corresponding to Δh_1 .

At the same time the computer 14 is fed from the load meter 8 with a signal of voltage corresponding to P_1 . This signal passes by way of a positioning servo-mechanism 27 to a feedback potentiometer 28; the tapping key 29 of this potentiometer is mounted on the shaft of the servomotor SM3 in the mechanism 27, as is the tapping key 46 of an output potentiometer 47. The latter potentiometer is supplied with a voltage corresponding to P_1 , and therefore a signal of voltage corresponding to P_1^2 is created in a lead 48, which leads to a potentiometer 30. This signal is converted to one corresponding to $P_1^2 \times k_2$ by means of the potentiometer 30, the position of the tapping key 31 being set manually to correspond with k_2 . A summing circuit 32 now combines this signal with one corresponding to $k_1 \times P_2^2$, the components of this latter signal having been fed manually, the latter component by the operator after reading the indicator 11.

A signal of voltage corresponding to $P_1^2 \cdot k_2 + P_2^2 \cdot k_1$ is thus produced, and this voltage is supplied to one end of the wire of a feedback potentiometer 33, the tapping key 34 of which is mounted on the shaft of a servomotor SM4 so as to slide as the motor rotates. The key is supplied with a signal of voltage corresponding to $P_2^2 \Delta h_1$, this signal having been produced by supplying the Δh_1 voltage produced by computer 13 to a potentiometer 35, the tapping key 36 of which is set manually to correspond to P_2^2 . An output potentiometer 37 cooperates with the potentiometer 33 to issue a voltage corresponding to

$$\frac{P_2^2 \times \Delta h_1}{P_2^2 \cdot k_1 + P_1^2 \cdot k_2}$$

i.e. to Δh_2 . This signal, together with signals corresponding to S_1 , P_1/m and P_2/m deriving from the screw monitor 10, load meter 8 and load limit indicator 11 respectively are fed to the S_2 computer 15, where they are summed and the key 38 of a positioning servo-mechanism 39 is mounted on the shaft of a servomotor SM5 to take up a position, on an output potentiometer 40, related to the value of S_2 .

The key 38 is mechanically connected to the hands of the mill clock 7 so that the latter move round as the key slides. The clock will thus show the roll gap desirable for the next pass and the operator can then adjust the gap to this value. Alternatively the read-out of S_2 can be used to adjust the roll gap automatically. Thus the read-out may be fed to any suitable controls by which motors turning the screws of the mill are set into motion and stopped. Moreover, these controls may be such that the motors are either started wholly automatically or only when the operator closes a switch. Suitable controls have already been used in conjunction with rolling mills; they are usually called remote position controls and are described for example in the Journal of the Iron and Steel Institute, vol. 191, part 11, February 1959, "Remote Position Control of Screw-Down Drives of Primary Rolling Mills" by L. N. Bramley, et al., and in the Trans. A.I.E.E. 1948, vol. 67, 58-63 "Improvements in Rolling Mill Screw-Down Controllers" by Leitch and Schurr.

FIGURE 2 shows how the load meter 8 is interposed between the top chock 3 and the mill screw 5. The screw and the load meter are separated by a thrust bearing 41, and strain gauges A-H, are bonded to the ground-finished wall of the cylindrical measuring element 42. The strain gauges are made from metal foil printed into a thin sheet of plastic. When the element is strained by the applied load these gauges will also be strained and their resistance altered. FIGURES 2 and 3 show both how these gauges are connected electrically to a source

of power and also the leads by which their signal passes on to the computing equipment 9. The leads 43 and 44 are carried in a cable 45.

The table below shows the result obtained when the mill described was used to roll a $\frac{1}{2}'' \times 5\frac{1}{2}'' \times 2'$ slab in 11 passes.

Data collected when rolling $\frac{1}{2}'' \times 5\frac{1}{2}'' \times 2'$ slab

Pass No.	Draft (.001")	Load (Long Tons)
1	59	26
2	51	31.3
3	36	30.5
4	31	31.5
5	23	28.8
6	20	30.5
7	19	30
8	17	31
9	13	31
10	12	33
11	9	31.8

I claim:

1. Apparatus for use in vertically positioning the rolls in a screw-down rolling mill comprising, in combination with the mill, computing equipment adapted to compute Δh_1 , Δh_2 and S_2 from the equations

$$\Delta h_1 = \left(S_0 + \frac{P_0}{m}\right) - \left(S_1 + \frac{P_1}{m}\right)$$

$$\Delta h_2 = \frac{P_2^2 \Delta h_1}{K^2 P_1^2}$$

and

$$S_2 = S_1 + \frac{P_1 - P_2}{m} - \Delta h_2$$

where the suffixes 0, 1 and 2 denote successive passes, m is the mill modulus, S is the set gap between the rolls, P is the roll-separating force in a pass, Δh the draft in that pass and K is a function given by

$$K^2 = k_1 \frac{P_2^2}{P_1^2} + k_2$$

k_1 and k_2 being constants for the mill; and means by which signals are fed to the computing equipment, said means comprising a device responsive to (and feeding the computing equipment with a signal corresponding to) the roll-separating force; a device responsive to (and feeding the computing equipment with a signal corresponding to) the set roll gap; a device to be set by the operator to feed a signal corresponding to a predetermined roll-separating force; and a device adapted to feed a signal corresponding to the initial thickness of the material, said computing equipment thereby being adapted to compute the proper position of the rolls for the next pass from the data determined during the preceding pass.

2. Apparatus according to claim 1 in which the device feeding a signal corresponding to the thickness has a visible scale with the aid of which the operator can set the instrument.

3. Apparatus according to claim 1 in which the device measuring the roll-separating force is a load meter interposed between the screw and the top chock of the mill.

4. Apparatus according to claim 1 in which the device signalling the roll gap as set to the computer is responsive to the position of the mill screw.

5. Apparatus according to claim 4 in which the device signalling the roll gap is a Selsyn repeater with its rotor directly coupled to the screw, the repeater being adapted to give a signal which corresponds to the angular position of the screw and which does not change with the loading.

6. Apparatus according to claim 1 in which the instrument feeding a signal corresponding to a predetermined roll-separating force has a visible scale with the aid of which the operator can set the instrument.

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