

Nov. 24, 1953

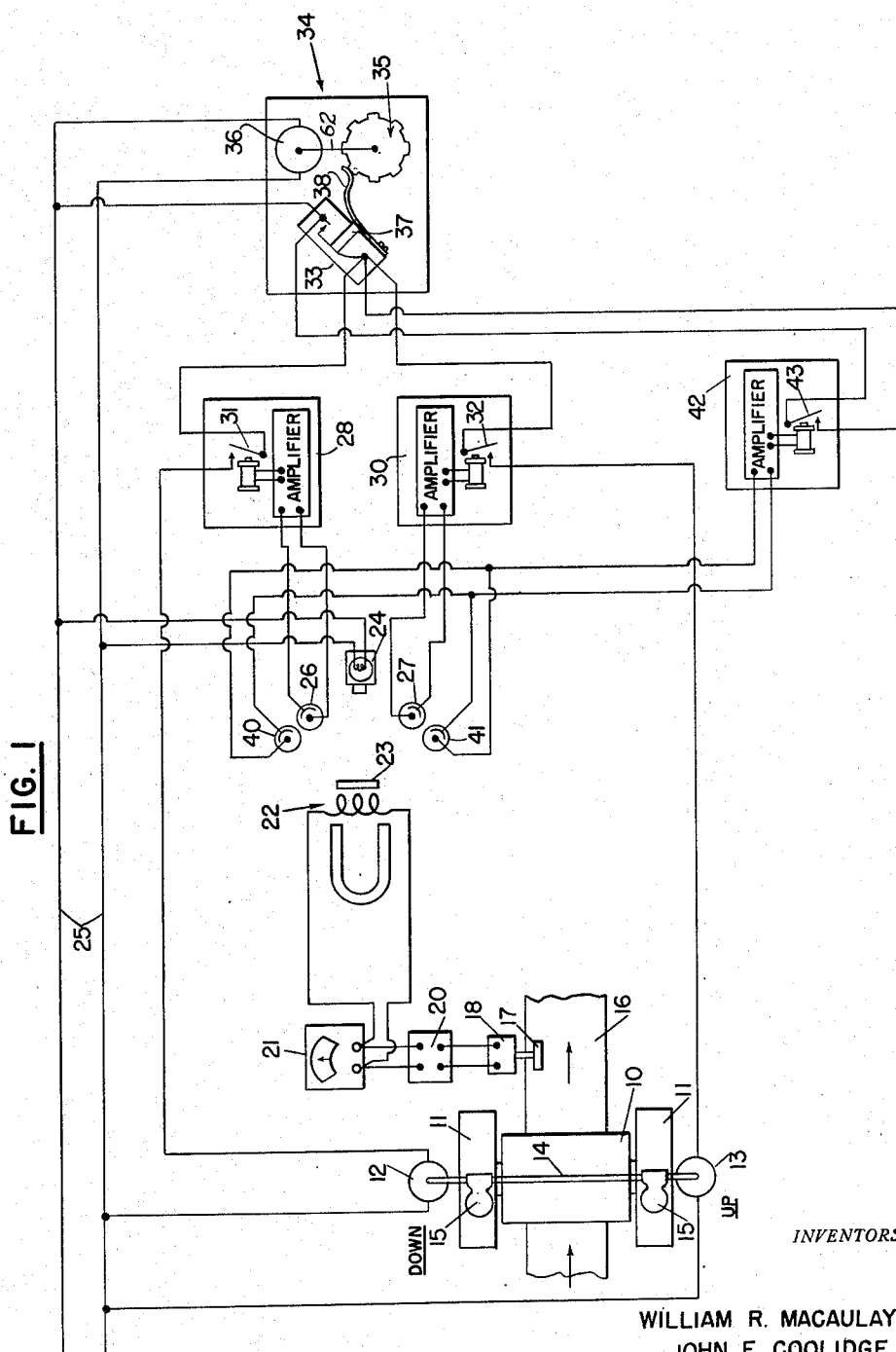
W. R. MACAULAY ET AL

2,660,077

APPARATUS FOR ROLLING SHEET METAL

Filed Feb. 2, 1946

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

FIG. 2

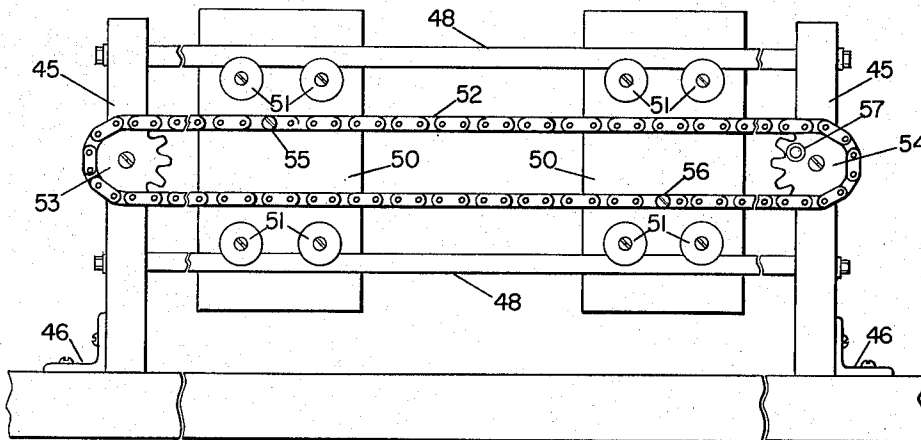


FIG. 3

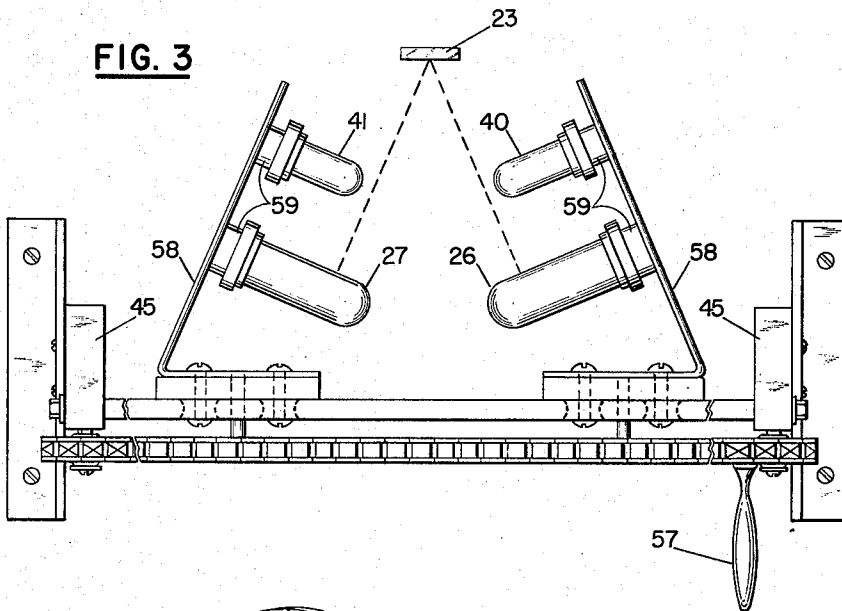
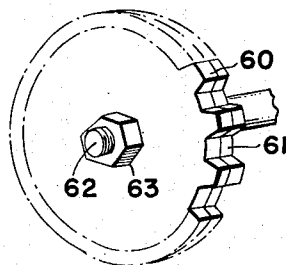


FIG. 4



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2,660,077

APPARATUS FOR ROLLING SHEET METAL

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Application February 2, 1946, Serial No. 645,204

12 Claims. (Cl. 80-56)

1

This invention relates to rolling sheet metal, and is concerned more particularly with controlling the rolling operation automatically so as to maintain essentially uniform thickness of the rolled sheet.

The invention is of especial value in the rolling of copper and copper-base alloys such as brasses. In the rolling of thin gauge sheets of such metals, it is customary to start with a heavy cast slab or bar of the metal and to pass it repeatedly through rolls which are successively closer spaced to reduce its thickness to the final gauge desired. The rolling operation subjects the metal to severe mechanical working, and it becomes increasingly work-hardened with successive passes through the rolls. Because of this work-hardening, it is necessary to anneal the metal periodically between successive series of passes through the rolls. For convenience in handling the metal between rolling operations, it is coiled as it emerges from the rolls, and it is in the coiled form that the metal is usually annealed in the annealing furnace. It is not always commercially feasible to conduct the annealing operation in such manner that absolutely uniform annealing of the metal throughout the coil is achieved. Consequently a coil of metal after annealing is likely to have sections that are relatively less well annealed and consequently relatively harder than other sections in the same coil. These relatively harder sections require greater rolling pressure to effect a given reduction in thickness than the softer sections. Consequently, unless the rolling pressure is varied during passage of the annealed strip through the rolls, so as to increase the pressure while rolling the harder sections and to decrease the rolling pressure on the softer sections, a rolled strip of uneven thickness will be produced. This unevenness in the thickness of the roll is particularly troublesome in producing sheet or strip of thin gauge, because in thin-gauge metal, a thickness variation of given absolute value represents a greater percentage variation than in the case of heavy gauge sheet or strip. In addition, variation in thickness due to uneven annealing is to some extent cumulative over a series of anneals and reductions in thickness by rolling, unless considerable care is exercised to maintain even thickness during each rolling operation. In extreme cases, thickness variations as great as 0.008 inch in rolled strip nominally 0.030 inch in thickness have been noted. This corresponds to a thickness variation amounting to over 25 per cent of the nominal thickness.

Heretofore the skill of the man performing the rolling operations has been a major factor in coping with this problem. The roller manually endeavors to continuously adjust the rolling pressure as the strip passes between the

2

rolls to maintain even thickness of the rolled product. A high degree of skill is necessary to accomplish this successfully.

Various types of continuously indicating thickness gauges have been developed to provide visual indication of the thickness of the strip emerging from the rolls. These instruments have been of substantial benefit in helping to maintain the strip within commercial thickness tolerances but they have not eliminated the problem nor appreciably reduced the skill required on the part of the roller.

Various efforts have been made to devise automatic means for controlling the rolling pressure in response to thickness indications given by a continuously acting thickness measuring instrument. So far as we are aware, however, these automatic controls have never been applied successfully to the rolling of copper and copper alloys. We attribute this lack of success to the tendency of automatic controls to hunt, that is, to cause the rolling pressure to oscillate above and below the value that should be maintained. In extreme cases, this hunting effect may be so serious as actually to result in a rolled strip of even more varying thickness than if no control is employed.

The present invention provides an improved apparatus for automatically controlling the rolling pressure exerted by a rolling mill in response to thickness variations in the rolled sheet. The invention contemplates provision for minimizing the effect of over-control and hunting, so that rolled sheet or strip may be produced within very close thickness tolerances.

In accordance with the invention, the extent to which the thickness of the sheet emerging from the rolls varies from a desired standard thickness is measured by means which produce electrical currents of intensity related in magnitude to the magnitude of such variations. These currents are utilized as control currents for automatically adjusting the rolling pressure, but the control action of the currents is repeatedly interrupted so as to minimize over-control and hunting, and so to maintain the thickness of the rolled sheet substantially uniform within preselected limits.

The improved control provided by the invention comprises a relay circuit having its output connected to the controls operating the electric motor or other means for adjusting the rolling pressure. The output of the relay is controlled by gauging means which produce an electric current of magnitude related to the thickness of the metal emerging from the rolls. A repeating timer repeatedly interrupts the output of the relay, thereby minimizing over-control and hunting.

In one advantageous embodiment of the in-

3

vention, the output current from the gauging means operates a galvanometer carrying a mirror, or other device, for directing a beam of light back and forth between a pair of photoelectric cells. The output currents of the photoelectric cells actuate relays, which in turn actuate, through the repeating timer, the motors or other means by which the rolling pressure is controlled. The thickness tolerance to be maintained is set by appropriately adjusting the spacing between these photoelectric cells.

In a further embodiment of the invention, a second pair of photoelectric cells is arranged so as to be energized by the light beam in case the thickness of the rolled sheet departs materially from the preselected tolerance initially established. These additional photoelectric cells are arranged to cut out the repeating timer and so cause the rolling pressure to be changed rapidly to restore the thickness of the rolled sheet to within the desired tolerance.

The invention will be better understood from the following description of a specific embodiment shown in the accompanying drawings, in which

Fig. 1 is a diagrammatic representation of the new control;

Fig. 2 is an elevation of a form of mount for the photoelectric cells;

Fig. 3 is a plan of the mount shown in Fig. 2; and

Fig. 4 shows in perspective the cam represented in Fig. 1.

In Fig. 1, a rolling mill comprising rolls (only the upper roll 10 is shown) mounted between roll frames 11 is diagrammatically illustrated. The rolling mill is schematically shown as provided with screw-down motors 12 and 13, each driving a shaft 14 through which roll screw-downs 15 are operated. The first motor 12 rotates in a direction to bring the rolls closer together, and the other motor 13 rotates in the opposite direction to separate the rolls.

A strip of metal 16 is shown passing through the rolls. The thickness of the strip as it emerges from the rolls is measured by a continuously acting measuring instrument, such as a flying micrometer, having rollers (only one roller 17 is shown) bearing against opposite sides of the sheet. The rollers 17 are urged toward one another against the sheet by spring means and so are always separated by a distance equal to the thickness of the sheet passing between them. If the sheet is of varying thickness, there will be slight movement of the rollers toward and away from each other. A minute electrical current of magnitude related to and measured by the spacing of the rollers, and hence to the thickness of the sheet, is produced in the micrometer head 18. This head is electrically connected to an amplifier unit 20, and the amplified current registers on a microammeter 21. The current registered by the microammeter is proportional to, or otherwise a function of, the thickness of the sheet passing between the rollers 17, and hence the microammeter reading indicates the thickness of the strip. One form of thickness measuring instrument of this character which may be used in accordance with the invention is the Electrolimit continuous thickness gauge, Model D, manufactured by Pratt & Whitney Company, of Hartford, Connecticut. It is understood, however, that this particular gauge is named only by way of example, and that any thickness measuring instrument which produces

4

an electrical current related in magnitude to the thickness of the sheet being measured may be used.

A moving-coil galvanometer 22 carrying a mirror 23 is connected to the terminals of the microammeter 21. A light source 24 connected to a power supply line 25 projects a beam of light against the mirror 23. As the coil of the galvanometer moves back and forth in response to changes in the magnitude of the current supplied to it through its connection to the microammeter, the light beam reflected by the mirror 23 is deflected from its normal, central position and moves back and forth between two photoelectric cells 26 and 27. These photoelectric cells are connected respectively to photoelectric relay units 28 and 30. Each of relay units includes an amplifier circuit for magnifying the current which passes between the electrodes of the photoelectric cells when they are illuminated sufficiently to actuate relay switches 31 and 32 in the respective relay units 28 and 30. Various types of photoelectric relay units, such, for example, as the Photoelectric Relay Unit Catalogue No. CR7505-K108 G12, manufactured by the General Electric Company, of Schenectady, New York, are available for use in our control equipment. This particular relay is mentioned only by way of example, as any suitable relay may be used.

One terminal of each of the relay switches 31 and 32 is connected to a terminal of a timing switch 33 forming a part of a repeating timer 34. The repeating timer also comprises a timing cam 35 rotated by a motor 36 which is connected to the power supply line 25. The switch 33 is of the normally closed type, but may be opened by depressing a plunger 37. A lever 38 bearing on the plunger 37 and also on the timing cam 35 causes the plunger to be alternately depressed and released as the timing cam rotates and alternately raises and lowers the lever 38. The timing mechanism thus serves repeatedly to open and close the circuit through the switch 33.

The timing cam 35 advantageously is of the type consisting of two or more similar cam wheels 60, 61 (Fig. 4) which may be adjusted angularly with respect to one another and then may be clamped together on the drive shaft 62 by locknut 63. This angular adjustment of two or more cam wheels changes the length of the cam surface and permits adjusting the proportion of the time the lever 38 is depressed (or released) out of each full cycle of its motion, viz., per interruption cycle. Several pairs of cams may be provided so that various ranges of timing may be obtained.

The rate at which the timing cam should make and break the circuit through the switch 33 depends on many factors such as size of the rolling mill and electrical characteristics of the screw-down motors, but in general the full cycle of make and break should be of the order of one second or less time in length.

The timer shown in the drawings and described above is a mechanical timer and is entirely satisfactory for use in accordance with the invention. However, electronic timers, such as a pair of type T15U Cycle Timers, manufactured by Photo-switch, Inc., of Cambridge, Massachusetts, may be used equally well. The particular form of timer employed is optional so far as the present invention is concerned, so long as it is capable of repeatedly and continuously interrupting the control circuit in which it is connected, independ-

5

ently of the operation of the rolls. By this is meant that actuation of the timer which produces the interruptions is not controlled or even influenced by the screw-down motors, or by the control thereof, or by the rotation or rate of rotation of the rolls.

The terminal of the timing switch 33 opposite that to which the relay switches 31 and 32 are connected, is connected to one (upper) side of the supply line 25. The terminal of the first relay switch 31 opposite that connected to the timer is connected to one terminal of the first screw-down motor 12, and the other terminal of the motor is connected to the other (lower) side of the supply line 25. Similarly, a terminal of the second relay switch 32 is connected to one terminal of the second screw-down motor 13, and the other terminal of this motor also is connected to the supply line 25. Thus the first motor 12, through which the rolls of the rolling mill are brought closer together, is connected across the supply line 25 through the first relay switch 31 and the timing switch 33, and the second motor 13, through which the rolls are separated, is connected across the supply line through the second relay switch 32 and the timing switch 33.

So long as the thickness of the strip being rolled is within the preselected tolerance (which is determined by the physical spacing of the photoelectric cells 26 and 27), the current supplied to the galvanometer 22 is of such magnitude that the light beam reflected by the mirror 23 oscillates between the photoelectric cells but does not fall upon either of them. These cells therefore are not actuated, the relay switches 31 and 32 remain open, and the motors 12 and 13 do not operate. Consequently the spacing and pressure between the rolls of the rolling mill remain essentially constant. If, however, a hard section occurs in the strip and the thickness of the emerging strip increases beyond the preselected tolerance, the current input to the galvanometer 22 is changed sufficiently to deflect the moving coil and mirror enough to reflect the light beam on to the active surface of the first photoelectric cell 26, which, in turn, actuates the relay unit 28 to effect closing of the switch 31. As a result, the motor 12 is operated to bring the rolls of the rolling mill closer together and increase the rolling pressure during the intervals that the timing switch 33 is closed. With the relay switch 31 closed, the effect of the timing switch is to permit a series of current pulses, rather than a steady current flow, to pass through the motor 12, thus causing it to operate interruptedly. This interrupted operation of the motor enables it to increase the rolling pressure by increments of the amount required, without overincreasing it, and so minimizes any tendency toward over-control and hunting.

In a similar fashion, if the emerging strip should be of a thickness below the desired tolerance, the galvanometer 22 is deflected in the opposite direction and the light beam is reflected on to the active surface of the second photoelectric cell 27. The relay switch 32 thereupon is closed and the motor 13 is operated through the timing switch 33 to decrease the rolling pressure.

Occasionally, because of an exceptionally hard section in the strip being rolled, or for some other reason, the thickness of the emerging strip may depart substantially from the preselected tolerance limits. If this occurs, the appropriate screw-down motor 12 or 13 should be operated rapidly to compensate for this extreme thickness variation. For this purpose, a second pair

6

of outer photoelectric cells 40 and 41 may be provided. Each of these photoelectric cells is connected to a photoelectric relay unit 42 including an amplifier and a relay switch 43. This switch 43 is connected across the terminals of the timing switch 33, so that when the switch 43 is closed the timing switch is short-circuited. The outer photoelectric cells 40 and 41 are somewhat more widely separated than the inner pair of photoelectric cells 26 and 27, and light reflected from the mirror 23 falls upon them only when the galvanometer is deflected beyond the limits through which it normally oscillates. The outer cells 40 and 41, however, are located with respect to the inner cells 26 and 27 so that when the reflected beam of light falls upon either of these outer cells 40 or 41, it also will fall upon the adjacent inner cell 26 or 27.

If the thickness of the emerging sheet increases enough so that the galvanometer 22 is deflected to the point where light is reflected from the mirror 23 on to the active surface of the outer photoelectric cell 40, the result is that both of the photoelectric cells 26 and 40 are activated and both of the relay switches 31 and 43 are closed. The circuit through the motor 12 is thereby completed, as the timing switch 33 is shorted out by the closed relay switch 43, and the motor 12 operates without interruption until the rolling pressure has increased sufficiently to reduce the thickness of the emerging strip to a value within the tolerance range in which no light is reflected on to the photocell 40. When the photocell 40 is no longer activated, the relay switch 43 opens and the timing switch is again effective for interrupting the circuit in which it is connected.

In a similar manner, if the thickness of the sheet decreases much below the preselected tolerance, the galvanometer 22 is deflected enough so that light reflected from the mirror 23 impinges on the outer photoelectric cell 41 as well as on its adjacent inner photoelectric cell 27. Here again, the relay switch 43 is closed, shorting out the timing switch 33, and the circuit through the motor 13 that is closed in consequence of closure of the relay switch 32. The motor 13 therefore operates rapidly without interruption to reduce the rolling pressure, until the thickness of the emerging strip has increased to within the preselected tolerance limits.

It is apparent from the foregoing that the physical spacing of the photoelectric cells 26 and 27 determines the thickness tolerance that will normally be maintained by the control hereinafter described. Different tolerance limits are commercially established for different metals and for different thicknesses, widths, and grades of the same metal. Accordingly, we contemplate mounting the photoelectric cells so that the spacing between them may be readily adjusted by unit control means to correspond to whatever thickness tolerance is to be maintained. A suitable mounting of this character is shown in Figs. 2 and 3. The mounting unit shown comprises a pair of upright side frames 45 fastened by angle irons 46 or other suitable means to a base board 47. A spaced pair of rods 48 extends between the two side frames. A pair of tube carriages 50 are supported on the rods 48 by grooved rolls 51. The rods thus provide ways along which the carriages 50 may be moved toward or away from each other. A sprocket chain 52 passes around a pair of sprocket wheels 53 and 54, one of which is mounted on each side frame. The upper loop

of the sprocket chain 52 is connected by a screw 55 to one of the carriages 50, and the other loop of the sprocket chain is connected by a screw 56 to the other carriage. One of the sprocket wheels 54 is provided with a crank handle 57 for conveniently turning it. As the crank handle is turned clockwise, the carriages 50 are moved toward each other, and as it is turned counterclockwise, the carriages are moved away from each other.

On each carriage 50 is mounted a tube support bracket 58, on which sockets 59 for the photoelectric cells are fastened. The photoelectric cells 26, 27, 40 and 41 are mounted in these sockets. As shown in the drawings, it is advantageous to configure the tube supporting brackets 58 so that light reflected from the galvanometer mirror 23 impinges on the cells substantially perpendicularly to their longitudinal axes.

The particular form of mount shown in Fig. 3 is designed for use of physically large photoelectric cells 26 and 27 for main control purposes, and physically small photoelectric cells 40 and 41 for shorting out the timer. It is evident, however, that four photoelectric cells all of the same physical size may be employed by suitably changing the shape of the brackets 58, or by mounting the sockets for the main control photoelectric cells 26 and 27 relatively farther out from the surface of the brackets than the sockets for the other pair of photoelectric cells.

By turning the crank 57 and thus moving the carriages 50 toward or away from each other, the photoelectric cells may be spaced apart any desired distance within the limits of travel of the carriages 50. The tube mounting structure described above may be calibrated in conjunction with the sheet metal thickness measuring instrument employed, and such calibration may be noted by markings indicating the position of the carriages 50. After such calibration, it is a simple matter to set the photoelectric cells at a distance apart corresponding to whatever thickness tolerance it is desired to maintain in rolling sheet metal in a rolling mill equipped with the new control.

We have found the control herein described to be highly effective in maintaining very close thickness tolerances in rolling non-ferrous alloy strip to thin gauges. The tolerances which we have maintained automatically in accordance with the invention are very much closer than standard commercial tolerances for sheet metal, and in fact are very much closer than can be maintained commercially either manually or by controls heretofore proposed or available.

It is understood that the invention is not confined to the embodiments specifically described herein in conjunction with the drawings. For example, it is not necessary that two separate motors be employed to operate the roll screw-downs. It is equally possible to use a single reversible motor, and connect the relays so that actuation of one relay causes the motor to operate in one direction to bring the rolls closer together and actuation of the other relay operates the motor in the opposite direction to separate the rolls. Or two reversible motors may be used, one operating on each side of the rolls, so that either side may be screwed down or up independently of the other. In this latter case, the two motors should be positively connected mechanically, as by a clutch, so as to operate as a single unit when an automatic control employing only a single gauging means and one relay system is

used. The use of reversible motors to control roll screw-downs is common practice in the art.

Similarly, it is not necessary to employ a measuring instrument which actually bears against the metal emerging from the rolls. Measuring instruments including elements between which the strip passes without actually coming in contact with them are available and may be used equally as well as an instrument of the type particularly described herein. For example, gauging means using X-rays to compare the thickness of the rolled strip with that of a standard specimen, and having an electric current output related in magnitude to the difference in thickness between the rolled strip and the specimen, are available and may be used successfully. It is only necessary that the thickness gauging instrument and its associated elements have a current output which is related in magnitude to the desired thickness of the strip and is therefore capable of serving as an initial control current.

Particular reference has been made herein to gauging instruments that produce a current related in magnitude to the thickness of the sheet, but instruments that produce a voltage, rather than a current, so related to the sheet thickness may be used equally well. In stating that the gauging instrument "produces" a current (or voltage) related in magnitude to the sheet thickness, it is understood that the instrument may actually generate such current (or voltage), or it may simply modify a current or voltage supplied from an external source so that the magnitude thereof becomes related to the sheet thickness.

We claim:

1. In apparatus for rolling sheet metal comprising a set of rolls, electrically operated pressure adjusting means for adjusting the pressure between said rolls, and gauging means producing electrical currents of magnitude related to the thickness of sheet metal emerging from the rolls, the improvement which comprises a pair of spaced photoelectric cells, a light source, optical means for deflecting a beam of light from the source from a normal line to one of said cells whenever the current produced by said gauging means corresponds to sheet thickness below the desired tolerance and to the other of said cells whenever such current corresponds to sheet thickness above the desired tolerance, a relay connected to the first photoelectric cell and actuating the pressure adjusting means to decrease the rolling pressure when light from the source is directed to said first cell, a second relay connected to the second photoelectric cell and actuating the pressure adjusting means to increase the rolling pressure when light from the source is directed to said second cell, repeating timer means for repeatedly and continuously interrupting actuation by the relays of the pressure adjusting means, and means independent of the electrically operated pressure adjusting means, and independent of the operation of said set of rolls for continuously operating said repeating timer means to minimize overcontrol and hunting, and means for adjusting the spacing of said photoelectric cells from said normal line, whereby to effect the adjustment of the sheet thickness tolerance which is to be automatically maintained.

2. In apparatus for rolling sheet metal comprising a set of rolls, electrically operated pressure adjusting means for adjusting the pressure between said rolls, and gauging means producing electrical currents of magnitude related to the

thickness of sheet metal emerging from the rolls, the improvement which comprises photoelectric means through which said pressure adjusting means are actuated, means for energizing said photoelectric means in response to currents produced by said gauging means, and means operating independently of said pressure adjusting means and independently of the operation of said set of rolls for repeatedly and continuously interrupting the actuation by the photoelectric means of said pressure adjusting means, thereby actuating said pressure adjusting means as required to maintain the thickness of the rolled sheet metal within preselected tolerances with minimization of overcontrol and hunting of said pressure adjusting means.

3. In apparatus for rolling sheet metal comprising a set of rolls, electrically operated pressure adjusting means for adjusting the pressure between said rolls, a power source for energizing said pressure adjusting means, and gauging means producing electrical currents of magnitude related to the thickness of sheet metal emerging from the rolls, the improvement which comprises a pair of spaced photoelectric cells, a light source, means for directing light from the source to one or the other of said cells to energize the same whenever the current produced by said gauging means corresponds to sheet thickness outside a preselected tolerance, relay means actuated in response to said photoelectric cells and connected to said power source and to said pressure adjusting means for actuating said pressure adjusting means in response to energization of the photoelectric cells as required to maintain the thickness of the rolled sheet metal substantially within the preselected tolerance, and means operating independently of said pressure adjusting means and independently of the operation of said set of rolls for repeatedly and continuously interrupting the actuation by said relay means of said pressure adjusting means to minimize overcontrol and hunting thereof.

4. In apparatus for rolling sheet metal comprising a set of rolls, electrically operated pressure adjusting means for adjusting the pressure between said rolls, and gauging means producing electrical currents of magnitude related to the thickness of sheet metal emerging from the rolls, the improvement which comprises first photoelectric means connected to control the actuation of said pressure adjusting means in response to the currents produced by said gauging means as required to maintain thickness of the rolled sheet substantially within a preselected tolerance, repeating timer means connected to said pressure adjusting means and disposed to repeatedly interrupt the energization of the pressure adjusting means so as to minimize over-control and hunting, and second photoelectric means responsive to currents produced by said gauging means of magnitude greater than that of the first-named currents, for cutting out the effect of said repeating timer means so as to operate said pressure adjusting means continuously whenever thickness of the rolled sheet departs substantially from within the preselected tolerance.

5. In apparatus for rolling sheet metal comprising a set of rolls, electrically operated pressure adjusting means for adjusting the pressure between said rolls, and gauging means producing electrical currents of magnitude related to the thickness of sheet metal emerging from the rolls, the improvement which comprises a pair of spaced photoelectric cells, a pair of mounts mov-

able toward and away from each other on which said cells are supported, means for adjusting the spacing of said mounts and thus of said photoelectric cells, with respect to each other, to a distance corresponding to a preselected sheet thickness tolerance which it is desired to maintain, a light source, means for directing light from the source to one or the other of said cells to energize the same whenever the current produced by said gauging means corresponds to sheet thickness outside a preselected tolerance, and relay means connected to said photoelectric cells and actuating said pressure adjusting means in response to energization of the photoelectric cells as required to maintain the thickness of the rolled sheet metal substantially within the preselected tolerance.

6. In apparatus for rolling sheet metal comprising a set of rolls, electrically operated pressure adjusting means for adjusting the pressure between said rolls, and gauging means producing electrical currents of magnitude related to the thickness of sheet metal emerging from the rolls, the improvement which comprises, a pair of spaced photoelectric cells, a light source, means for directing an undeflected beam of light from the source along a normal line, means for deflecting said beam to impinge on a first of said cells whenever the current produced by said gauging means corresponds to sheet thickness below the desired tolerance and to impinge on a second of said cells whenever said current corresponds to sheet thickness above the desired tolerance, a relay connected to be actuated by the first photoelectric cell and connected to actuate the pressure adjusting means to decrease the rolling pressure when light from the source impinges on said first cell, and a second relay connected to be actuated by the second photoelectric cell and connected to actuate the pressure adjusting means to increase the rolling pressure when light from the source is directed to said second cell, repeating timer means connected in the output circuits of said relay for repeatedly interrupting actuation by the relays of the pressure adjusting means to minimize over-control and hunting thereof, a second pair of photoelectric cells comprising third and fourth cells spaced further from said normal line than are said first and second cells, respectively, both of said pairs of cells being so disposed with respect to said light source that a small deflection of said light source from said normal line activates only the first or second cell of said first pair of cells and a larger deflection thereof activates both said first and third cells, only, or said second and fourth cells, only, and a third relay connected to be actuated by said third and fourth photoelectric cells and connected to the repeating timer means in such manner as to short-out said timer when said third relay is actuated, whereby the effect of said repeating timer means is cut out whenever the thickness of the rolled sheet departs sufficiently from the preselected tolerance so that light from said source is directed to impinge on either said third or fourth photoelectric cell, and whereby the effect of said repeating timer means is cut in again when the thickness of said rolled sheet closely approaches said tolerance.

7. In apparatus according to claim 6, a pair of carriages movable toward and away from each other, said first and third photoelectric cells being mounted on one of said carriages and said second and fourth photoelectric cells being mounted on the other of said carriages, and uni-

control means for simultaneously moving said carriages toward and away from each other to the same extent so as to adjust the spacing between said first and second cells, respectively, and between said third and fourth cells, respectively.

8. In a mill for rolling sheet metal which includes rolling pressure means and means for continuously determining the extent to which the thickness of the sheet emerging from the rolls varies from a desired standard thickness, the improvement which comprises means for producing, in response to variations in thickness of the sheet, electrical current of intensity related in magnitude to the magnitude of the variations, means for controlling the adjustment of the rolling pressure in accordance with variations in intensity of said current, and means independent of the adjustment of said rolling pressure for repeatedly and continuously interrupting the control action of said current at a rate independent of the operation of said rolls, thereby to minimize overcontrol and hunting and to maintain the thickness of the rolled sheet substantially uniform within preselected limits.

9. In a mill for rolling sheet metal which includes rolling pressure means and means for continuously determining the extent to which the thickness of the sheet emerging from the rolls varies from a desired standard thickness, the improvement which comprises means for producing, in response to variations in thickness of the sheet, electrical currents of intensity related in magnitude to the magnitude of the variations, electric means for controlling the rolling pressure, means for controlling the adjustment of said electric means in accordance with variations in intensity of said current including electric contacts connected to actuate and deactuate said electric means by repeatedly and continuously interrupting the control action of said current at a rate independent of said adjustment of the rolling pressure and independent of the operation of said rolls, thereby to minimize overcontrol and hunting and to maintain the thickness of the rolled sheet substantially uniformly within preselected limits, and means operable independently of the means which controls the adjustment of the rolls for adjusting the ratio of open to closed periods of said contacts per interruption cycle.

10. In apparatus for rolling sheet metal comprising a set of rolls, electrically operated pressure adjusting means for adjusting the pressure between said rolls, an electrical power source for operating said means, and gauging means producing electrical currents of magnitude related to the thickness of sheet metal emerging from the rolls, the improvement which comprises, light deflecting means operable in response to said electrical currents, first and second photoelectric means actuated in response to light from said light deflecting means, relay means, connections between said first photoelectric means and said relay means, and between said relay means, said power source and said pressure adjusting means through which actuation of said pressure adjusting means is controlled in response to the currents produced by said gauging means as required to maintain thickness of the rolled sheet substantially within a preselected tolerance, repeating timer means operated independently of operation of said rolls and including circuit-interrupting means connected be-

tween said power source and said pressure adjusting means operable to repeatedly interrupt the power to said pressure adjusting means so as to minimize over-control and hunting thereof, and switching means responsive to said second photoelectric means connected to cut out the circuit-interrupting effect of said circuit-interrupting means so as to operate said pressure adjusting means continuously whenever the thickness of the rolled sheet departs substantially from said preselected tolerance.

11. In apparatus for rolling sheet metal comprising a set of rolls, electrically operated pressure adjusting means for adjusting the pressure between said rolls, gauging means producing electrical current of magnitude related to the thickness of sheet metal emerging from said rolls, a relay having an output circuit connected to control the operation of said pressure adjusting means, and means for actuating said relay in response to a predetermined magnitude of current produced by said gauging means and in such manner that the pressure adjusting means is operated to change the rolling pressure as required to maintain the thickness of the rolled sheet substantially uniform, the improvement which comprises means independent of said pressure adjusting means for repeatedly and continuously interrupting the output of said relay at a constant rate which is independent of the pressure adjustment of the rolls, and means responsive to current of magnitude different from said predetermined magnitude, independent of the electrically operated pressure adjusting means and independent of the operation of the rolls for annulling the interruptions of the output of said relay.

12. In a mill for rolling sheet metal which includes rolling pressure means and means for continuously determining the extent to which the thickness of the sheet emerging from the rolls varies from a desired standard thickness, the improvement which comprises means for producing, in response to variations in thickness of the sheet, electrical current of intensity related in magnitude to the magnitude of the variations, means for controlling the adjustment of the rolling pressure in accordance with variations in intensity of said current, and means independent of the adjustment of said rolling pressure for repeatedly and continuously interrupting the control action of said current at a rate independent of the operation of said rolls, said rate being of the order of one second or less per interruption cycle, thereby to minimize overcontrol and hunting and to maintain the thickness of the rolled sheet substantially uniform within preselected limits.

WILLIAM R. MACAULAY.
JOHN E. COOLIDGE.

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