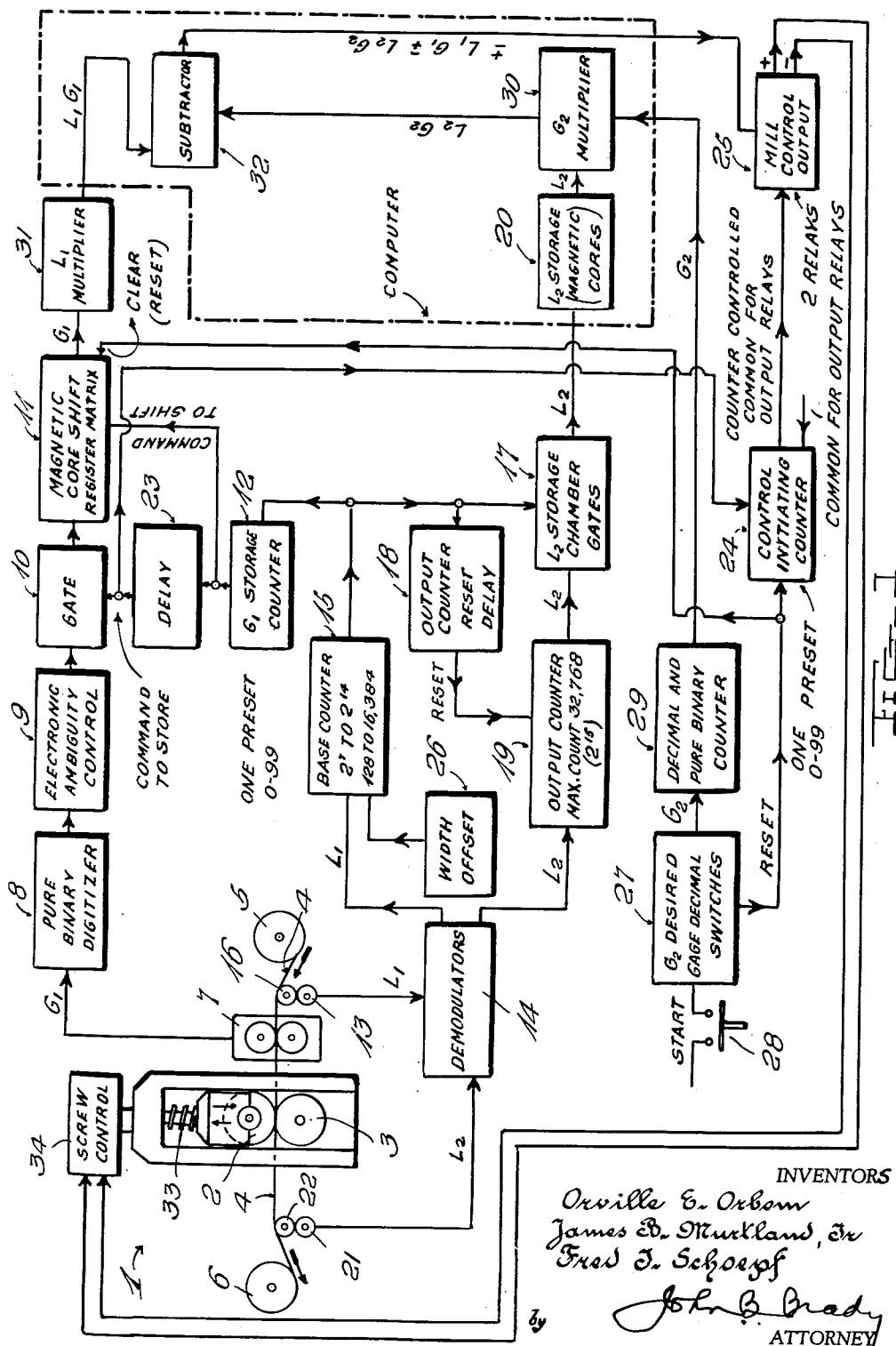


O. E. ORBOM ET AL
AUTOMATIC CONTROL SYSTEM FOR ROLLING
MILLS AND ADJUSTABLE DIES

3 Sheets-Sheet 1



Jan. 9, 1962

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3 Sheets-Sheet 2

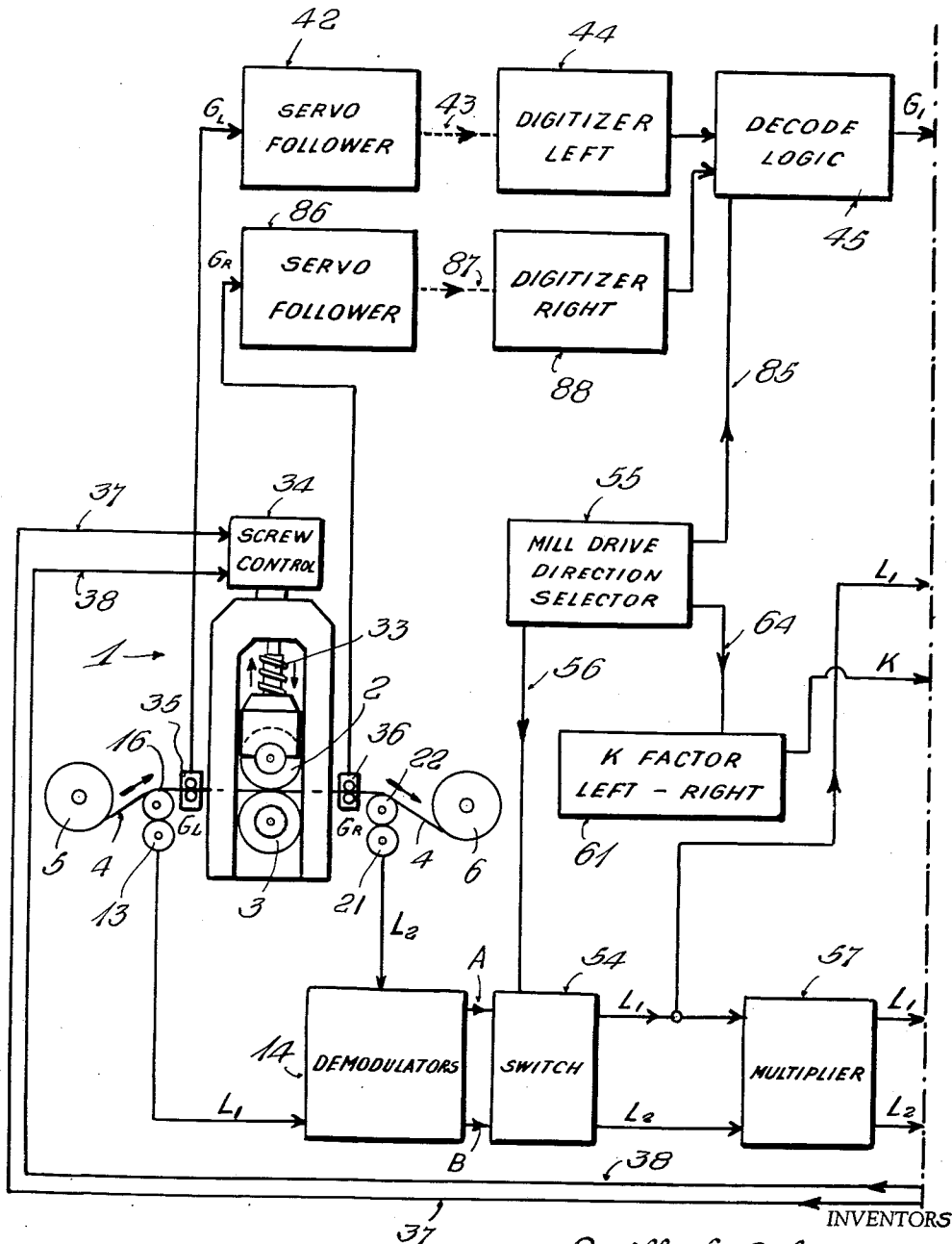


FIG. 2

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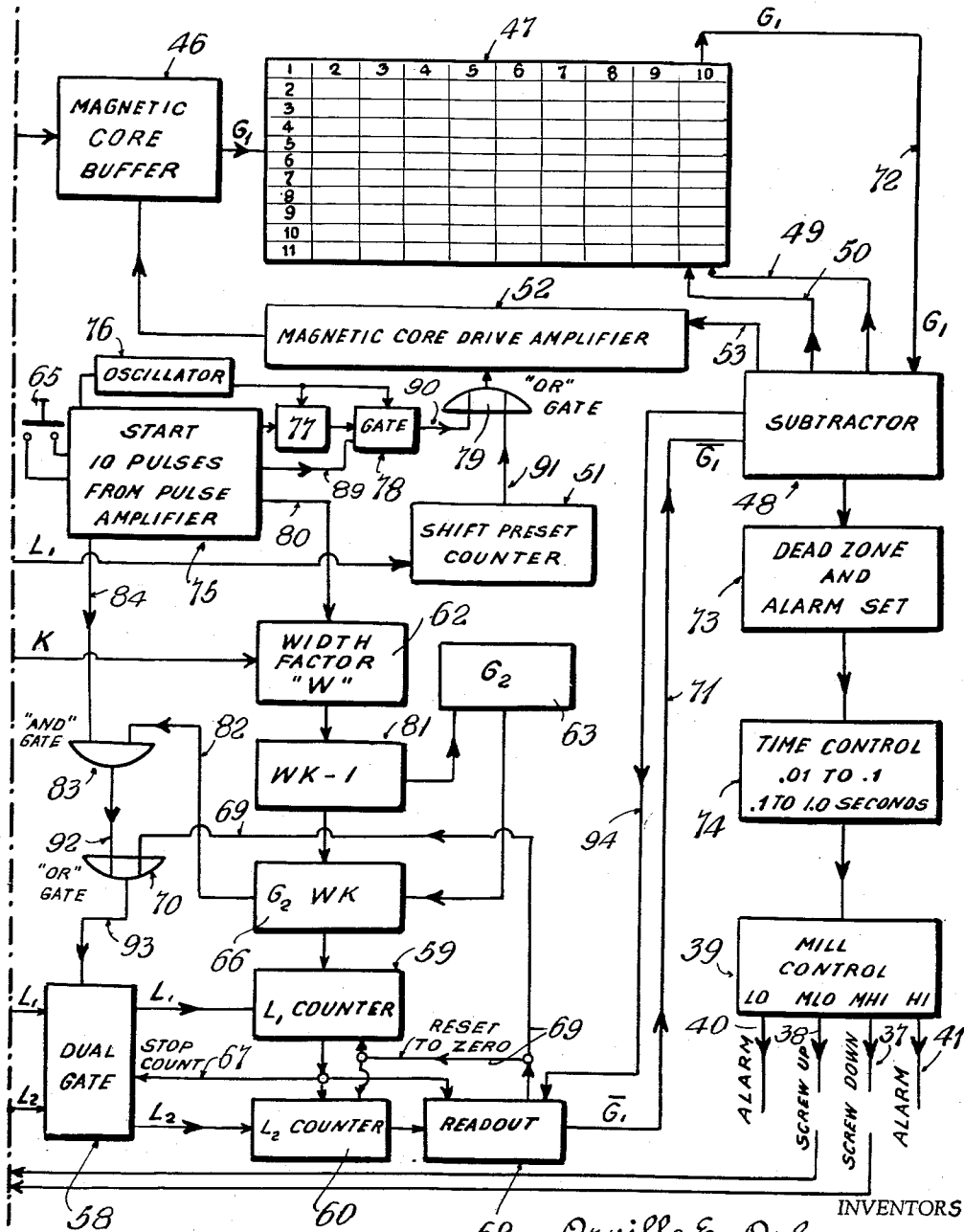


FIG. 3

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3,015,974

AUTOMATIC CONTROL SYSTEM FOR ROLLING MILLS AND ADJUSTABLE DIES

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Filed Sept. 18, 1958, Ser. No. 761,818
3 Claims. (Cl. 80—56)

Our invention relates broadly to the production of material by rolling through single or multiple stand rolling mills or by drawing through single or multiple dies of the kind having opposing die surfaces whose separation is adjustable and more particularly to an automatic system for controlling such mills or dies so as to produce material of a predetermined desired uniform gage thickness.

One of the objects of our invention is to provide an automatic control system for rolling mills or systems employing adjustable dies which measures gage and controls the mill or dies at the bite of the mill.

Another object of our invention is to provide a control system for rolling mills which greatly reduces the amount of waste material on the ends of a work piece.

Still another object of our invention is to provide an automatic control system for rolling mills which operates on the concept that the volume of material leaving the mill is equal to the volume of material entering the mill.

A further object of our invention is to provide an automatic control system for rolling mills which measures gage of an increment of work before the bite of the mill and stores this information in a memory unit until the same increment of work enters the bite of the mill, at which time the previous gage measurement is used for instantaneous mill control.

Still a further object of our invention is to provide an automatic control system for rolling mills which produces material to much stricter and more even tolerances throughout the length of the workpiece.

Other and further objects of our invention reside in the application of our control system to bidirectional rolling mills and also in the methods by which the mill correction signals are derived as set forth more fully in the specification hereinafter following by reference to the accompanying drawings in which:

FIG. 1 is a schematic diagram showing in block form a simplified control system for solving and executing the teachings of our invention; and

FIGS. 2 and 3 form a composite schematic diagram when the right edge of FIG. 2 is disposed adjacent the left edge of FIG. 3, the composite diagram showing in block form a modified and more complex control system for solving and executing the teachings of our invention.

Our invention is directed to the controlled production of material by rolling through single or multiple stand rolling mills or by drawing through single or multiple dies of the kind having opposing die surfaces whose separation is adjustable. More accurate dimensional control is an objective of automatic controls for the aforementioned equipment. For simplicity of description, this disclosure will concern itself with the description as applied to single stand rolling mills. Those skilled in the art can obviously see the correlation of the hereafter described systems to other rolling or drawing operations. In the majority of existing control systems for mills or dies, the system is controlled from a gage measurement taken several feet beyond the exit side of the rolling mill, by an elongation or percent reduction measurement, or by a roll pressure measurement. In a system employing gage measurement, the material after reduction progresses to the gage, which may be several feet beyond the bite of the mill, before any error present in material thickness can

be detected. This distance from the bite of the rolls to the gage is commonly referred to as "transport distance." The time required for the material to reach the exit gage is denoted as "Transport Time." Time required to measure the strip gage is referred to as "Sensing Time." Transport time and sensing time are major elements in developing error commands. Transport distances of five (5) feet or more are common in most of the commercial rolling equipment available at present. A system having a transport distance of five (5) feet would not be capable of detecting an error signal until five (5) or more feet of material had passed from the bite of the mill rolls. The corrective signal would then be transmitted to the mill screwdown; but, the measuring gage would not detect the result of this action until five (5) or more feet of material had passed through the mill. From this discussion, it is seen that a system of this sort has a natural frequency of oscillation. If this oscillation were left to exist without any attempt to control it, the results would be undesirable. For a material entering the mill with fairly noticeable changes in gage, the system described would cause such wide variations in output gage that in most probability would eventually result in tearing of the strip. In an attempt to control the natural frequency of oscillation, some designers have damped their system so as to allow only a certain portion of the requested corrective signal after each measurement to be transmitted to the screws. Other designers have provided damping in the screws in order to slow down the response to any corrective signals. In any case, damping considerably reduces the efficiency and effectiveness of these control systems. In a highly damped system, the result is a number of ensuing measurements before the material is brought within gage limits resulting in the waste of material which has progressed from the mill before the desired gage could be attained. In present day commercial mills, this loss is considerable.

A system employing elongation measurements as a means of control has one basic advantage; the transport distance of such a system is zero if the strip is under tension. Two basic types of measuring systems may be employed, an instantaneous rate measuring device such as a D.C. tachometer as described in other patents or a sampling type of device as described in Orville E. Orbom's copending patent application "Elongation Control System," Serial No. 680,349, filed August 26, 1957. The strip length-measuring devices may be placed at any distance from the roll bite of the mill. In the sampling type system, for a certain increment of length passing through the entering length-measuring device, there will be an equal or greater increment of length measured at the exit device. The exit length is dependent on reduction. Since the transport time (with the strip in tension) is zero, the only time delay in the system will be the time involved in sensing sample lengths at the entrance and exit of the mill. These increments can be made so short as to be ignored. Although it would appear that an elongation type of system control would be desirable, further analysis shows a serious shortcoming of this system. An elongation system will only reduce the material a given percentage. This system does not control to a given gage unless the entering strip gage is constant. Since the gage of the entering strip varies, this type of control is an inaccurate means of gage control. To illustrate, let us assume that an increment of material .040 inch thick enters a mill followed by an increment .080 inch thick. It is further supposed that the opening between the mill rolls is such as to reduce the first increment to a thickness or gage of .020 inch. In doing so, the material must then have been elongated to twice its original length. When the second increment of material (.080 inch thick) enters the mill, it will also be reduced to a gage of .020

3

inch. However, the elongation in this case is four times the original length; therefore corrective mill action will be requested by the system in the second case. But, corrective mill action is not desired since the exit gage or thickness is in both cases alike. Thus, it can be seen that a system employing elongation measuring methods alone is not feasible for gage control.

Systems utilizing roll pressure measurements as a means of control leave much to be desired when precision control of strip gage is required. First, an inherent factor in a pressure measuring system is the natural spring of the mill housing. There is no reasonable means of keeping the mill housing rigid under the extreme forces encountered in rolling. Compensating for this housing spring is possible; however, a second disadvantage would still exist in a roll pressure measuring system. This appears as a result of differences in material hardness at different points in a strip. Hard materials will not be reduced as much as soft materials under certain roll pressure conditions.

In the following disclosure we will described a control system based on an entirely new basic concept of mill control, applied in such a manner that the transport time is zero and the measuring time is essentially zero. One of the greatest advantages of the control system of our invention is that it measures and controls a rolling mill at the bite of the mill. Basically, the system is designed on the concept that the volume of material coming out of the mill must be equal to the volume entering the mill. Thus:

$$V_1 = V_2$$

and

$$(1) \quad L_1 W_1 G_1 = L_2 W_2 G_2$$

where

L_1 = length of material entering mill

L_2 = length of material leaving mill

G_1 = gage of material entering mill

G_2 = gage of material leaving mill

W_1 = width of material entering mill

W_2 = width of material leaving mill

If X = the error control signal:

We can see that $X = \pm L_1 W_1 G_1 \mp L_2 W_2 G_2$.

The broad concept of our invention is any system or combination of systems viz., hydraulic, pneumatic, electrical, mechanical, etc. that will perform the necessary measuring and computations of the above formula so as to measure, compute, and/or control any material output from any single or multiple stand rolling mill, or measure, compute and/or control any material output from any drawing through single or multiple dies of the kind having adjustable opposing die surfaces.

In those cases where the lengths, widths, or thicknesses may remain constant, this formula may be simplified into several simplified versions.

In cold rolling, width of strip usually remains constant even though the material is being passed through the mill. Some materials to be rolled will be encountered wherein the exit width will not equal the entering width because of rolling forces. If it is found that there is no difference in exit and entering widths, then $W_1 = W_2$ and Formula 1 can be simplified to:

$$(2) \quad L_1 G_1 = L_2 G_2$$

$$X = \pm L_1 G_1 \mp L_2 G_2$$

For the case where the exit width differs from the entering width by a known constant amount, a constant correction can be applied to any system designed on the basis of Equation 2 to compensate for this difference in widths. In systems where the width is continually varying, width measuring devices can also be added to reflect the variation to equation solving equipment. In claiming a system capable of measuring and controlling at the bite of the mill and eliminating transport distance, it is

4

our intention to apply the above equation in a manner wherein the input gage (G_1) will be calculated on the basis of the other two or three variables (L_1 , L_2 , and G_2), then compared against the actual measured value of G_1 . Equation-wise, this may be written:

$$\bar{G}_1 = \frac{L_2 G_2}{L_1}$$

where $\bar{G}_1$ represents calculated input gage.

$$X = G_1 - \bar{G}_1 = G_1 - \frac{L_2 G_2}{L_1}$$

where

15 G_1 represents measured input gage
 G_{2d} represents desired exit gage

As discussed previously in the description of the elongation type of control system, transport time is zero, and the incremental sampling length can be made so short as to allow the elongation or length sensing time to be ignored. This feature is an integral part of the system of our invention due to the elongation or length measuring means (L_1 , L_2) which we employ. In addition, the desired exit gage (G_{2d}) is used in the calculation of desirable input gage, rather than actual output gage (G_2); thus, the control system of our invention is capable of control "before the fact" rather than "after the fact." In other words, the system will not need to wait until the material has progressed beyond the bite of the mill before recognizing and deciding on the necessary control operation. Our system anticipates and recognizes the necessary mill screw action as the material approaches the mill.

It should be remembered that any number of solutions to the above equations are possible; and this disclosure will therefore only attempt to illustrate a few in the following examples. The inventors desire that it be understood that the following examples be considered in the illustrative sense rather than in the limiting sense and that our invention lies in the following basic concepts:

(1) Control of a system based on constant volume.

(2) Control of a system based on constant volume, and elimination of transport distance and transport time by calculation of desirable entrance gage ($\bar{G}_1$) from the variables of entering strip length (L_1), exit strip length (L_2), and desired exit gage (G_{2d}).

(3) Control of a mill based on $L_1 W_1 = L_2 W_2$, where $G_1 = G_2$.

(4) Control of a mill based on $L_1 G_1 = L_2 G_2$, where $W_1 = W_2$.

(5) Control of a mill based on $W_1 G_1 = W_2 G_2$, where $L_1 = L_2$.

(6) It is possible to control thickness of product by this system, as set forth in the following examples.

(7) It is possible to control width by this system.

(8) It is possible to control length by this system.

The following will be two specific solutions to control a rolling mill and will serve as firm examples of types of equipment that might be used to solve the above equations and control the mill.

The discussion following is based on the example system shown in FIG. 1. In applying a digital solution to Equation 2, the equation will be used as written. However, the factor G_2 (mill exit gage) will now represent the desired exit gage rather than the calculated gage. This is permissible in our constant volume control system since the exit length (L_2) when used with the entrance length (L_1) and entrance gage (G_1) actually reflects exit gage. The digital system will not only compare the terms of Equation 2, but will actually solve for the amount of error in the comparison. In other words, the digital system will solve the constant volume Equation 2 in the form:

$$0 = L_1 G_1 - L_2 G_2$$

5

Of course this equation would always have zero as a final result if the exit gage (G_2) was the actual measured or calculated quantity (as long as there was no deviation in width or as long as a correction was applied for width change). Since in our case, we inject the desired exit gage (constant quantity) into the system to represent " G_2 ," an error factor will appear in the final solution of Equation 2 at any time when the factors L_1 , G_1 and L_2 do not appear in proper proportion to combine with G_2 .

Thus the system solution of Equation 2 can be written in the form

$$\text{Error} = L_1 G_1 - L_2 G_2$$

or

$$\text{Error} = L_2 G_2 - L_1 G_1$$

A simplified schematic diagram of a typical system illustrating the equipment necessary for digital solution of our "error" equation is shown in FIG. 1.

Reference character 1 represents a conventional rolling mill having pressure rolls 2 and 3 between which pass the material 4 being acted upon or processed in the mill which feeds off of payoff reel 5 and is coiled onto take-up reel 6. Entrance gage is measured by a digital type displacement gage 7 with an attached binary digitizer 8 to convert gage information into switch closures; thus, a coded readout of entrance strip thickness will be procured. The "electronic ambiguity control" 9 is a device for removing ambiguity common to the two brush binary digitizer. This ambiguity is such that in a case of an output progressing from a count of 63 to 64, any combination of the 2^6 - 2^5 - 2^4 - 2^3 - 2^2 - 2^1 relays may be received, whereas only the 2^6 relay should be energized. Therefore an ambiguity control unit is necessary. The ambiguity control unit 9 need not be a relay unit as ordinarily accompanies most commercial binary digitizers but can be an electronic type of ambiguity control which gives faster response than relay type controls. It should be noted that the output of the binary digitizer and ambiguity control approaches 2^{11} binary units or actually the maximum is 2047 decimal units. This output is necessary since it is desired to measure entrance gage to a maximum of 0.2000 inch. The binary digitizer 8 and electronic ambiguity control 9 together perform the function of converting the analog output from displacement gage 7 to a binary representation of the analog output. The book Digital Computer Components and Circuits, by R. K. Richards, published in 1957 by D. Van Nostrand Company, Inc., contains an extensive chapter 11, from page 459 to 501, on Analog-to-Digital and Digital-to-Analog Computers plus an extensive bibliography on pages 501-503. A suitable two brush binary digitizer plus an ambiguity control is described in detail starting on page 471 of Richards.

The gate 10 acts as a switch controlling the storage of the measured entrance gage (G_1) in the magnetic memory 11 designated as "Magnetic Core Shift Register Matrix." Normally the gate 10 is closed and only at predetermined intervals preset in the " G_1 Storage Counter" 12 will the gate open. A suitable gate is described on pages 107-111 of Richards.

As mentioned before, the "magnetic core shift register matrix" 11 is the memory or storage point for the measured entrance gage (G_1). Primarily the memory is composed of ten storage chambers; each storage chamber having eleven magnetic cores to represent the progressive binary digits which must be combined to represent a certain measured gage. Automatic shifting is provided to remove a stored gage measurement once the information has been used and is no longer necessary or desired. The automatic shift circuitry also shifts the stored information in one chamber to the next succeeding chamber. Thus the entrance gage information in the storage chamber most distant from the gate 10 is the gage measurement for the incremental strip length about to enter the mill rolls. Perhaps it should be explained why

6

ten storage chambers are provided. Ordinarily, the entrance strip gage must be mounted about five feet from the bite of the mill. Since extreme variations in gage are not normally encountered, a measurement of strip gage six inches of strip length will be sufficient to reveal deviation in gage. On the basis of a measurement over each six inches of length and a distance of five feet between the mill and the gage, a magnetic core storage system with ten chambers will be necessary. More memories can be added if closer control is desired; for example, 20 memories and 5 feet from gage to roll bite would give new values every 3 inches. A suitable magnetic core shift register matrix is shown in U.S. Patent 2,946,047 to Morgan. The memory shown in this patent has only two storage chambers but it is well within the skill of one skilled in the art to enlarge the memory to ten storage chambers as called for herein. In the patent each storage chamber has only eight magnetic cores but again it is well within the skill of one skilled in the art to enlarge each storage chamber to ten magnetic cores. In the patent the information is shifted into the first storage chamber serially and transferred to subsequent storage chambers in parallel.

Input strip length (L_1) is sensed by equipment similar to that described in the copending application "Elongation Control System," Serial No. 680,349, O. E. Orborn, filed August 26, 1957, namely a pulse generator 13 and demodulator unit 14, and a pulse counter 15. The pulse generator 13 is coupled to idler roll 16 on the entrance side of the mill, and produces five hundred electrical pulses per generator revolution. Each generator revolution will represent a certain length of strip. The entrance strip length will be preset into the base counter 15. As shown in FIG. 1, the base counter can be preset to count in strip intervals between 128 and 16,384 pulse counts. When the pulse count at the base counter 15 reaches the preset value, a pulse of electrical energy will be transmitted to the " L_2 Storage Chamber Gates" 17, to the "Output Counter Reset Delay Chamber" 18, and to the " G_1 Storage Counter" 12. A book, Pulse and Digital Circuits, by Jacob Millman, published by McGraw-Hill Book Company, Inc., in 1956, describes on page 345 a commercially available preset counter which may be used as the preset counter base counter 15. Also see reference note 9 on page 353. In supplying a pulse of energy to the " L_2 Storage Chamber Gates" 17, a command is initiated for the count of exit strip length (L_2) to be stored. This is accomplished by opening the " L_2 Storage Chamber Gates" 17, and allowing the count from output counter 19 to pass into the computer " L_2 Storage" 20, which is primarily a magnetic core memory. Patent 2,946,047 to Morgan again describes a magnetic core storage register. It is well within the skill of one skilled in the art to adapt the magnetic core storage register disclosed in Patent 2,946,047 to the required number of magnetic cores. Exit strip length (L_2) is sensed by pulse generator 21 coupled to idler roll 22 on the exit side of the mill and produces a series of pulses with the aid of demodulator unit 14 in the same manner as the L_1 pulses were produced, and transmits them to output pulse counter unit 19. Patent 2,848,166 to Wagner describes a suitable counter and associated gates for output counter 19 and L_2 storage chamber gates 17. At the same time, the same energy pulse transmitted from the base counter 15 to the "Output Counter Reset Delay Chamber" 18 triggers a delay circuit which after a specific elapsed time will reset the "Output Counter" 19 to zero. Suitable delay circuits for delay circuit 18 are described on pages 101-103 of Richards, Digital Computer Components and Circuits. The " G_1 Storage Counter" 12 will also receive one pulse of energy from the base counter for each unit length of entrance strip. " G_1 Storage Counter" 12 is preset to allow only one storage of entrance gage G_1 for several measurements of entrance and exit length. Again, a suitable preset count-

er is referred to on page 345 of Millman, Pulse and Digital Circuits. Entrance gage (G_1) would not show any appreciable deviation if it were measured and stored during the same short intervals that entrance length is measured over. Therefore, it is only necessary to store one entrance length measures. It should be remembered, however, that the gage is being measured continually even though it is only stored at preset intervals. In a typical case, entrance length may be measured in terms of one inch increments whereas entrance gage measurement and storage may only be desirable for each six inches of strip. Therefore, the " G_1 Storage Counter" 12 will be preset to count six pulses before initiating a command for storage of entrance gage. As can be seen in FIG. 1, when the pulse count at the " G_1 Storage Counter" reaches the preset value a pulse of energy will be directed to the "magnetic core shift register matrix" 11 to cause the entrance gage value in the last storage chamber (closest to computer) to be destroyed, and then to cause the information in the ensuing chambers to be shifted by one chamber. While this is occurring, energy from the " G_1 Storage Counter" is also delivered to the "delay" unit 23 and after a specific time interval, the delay circuitry will allow energy to flow to the "gate" 10 to open the gate and allow the measurement of entrance gage G_1 to be stored in the magnetic core shift register matrix 11. A suitable delay circuit for delay circuit 23 is described on pages 101-103 of Richards, Digital Computer Components and Circuits. Pulses flowing to the gate 10 also flow to the "Control Initiating Counter" 24. The purpose of this one preset counter is to delay control of the mill at start up until the magnetic core shift register matrix has been completely filled with entrance gage measurements. This is necessary since the entrance gage information entering the magnetic core shift register matrix is stored in the first chamber and shifts one chamber at each ensuing length measurement; thus, a particular entrance gage measurement is not used until it has reached the tenth and final storage chamber in the magnetic core shift register matrix. It can be seen that this arrangement also insures that the proper entrance gage information is associated with a particular increment of strip length when the calculation for the increment is made immediately prior to its entrance into the bite of the mill. In our case, it was assumed that ten increments of strip length would be measured before the first increment entered the bite of the mill. This would mean that the "control initiating counter" 24 would be preset for ten counts at which time it would close relay contacts and connect the common side of the power source to the output relays in the "mill control output" unit 25. Since the output relays in unit 25 must be energized when a mill correction is desired, no mill control will be initiated until the "control initiating counter" 24 has counted to the preset number. Again a suitable preset counter is referred to on page 345 of Millman, Pulse and Digital Circuits.

The "width offset" 26 is provided for correction of the system to compensate for any deviation of the strip width from the initial assumed constant value. The correction is injected into the "base counter" 15 by triggering the base counter to a certain count value at the beginning of each entrance strip measurement. In other words, a typical correction for an entering strip increment of 100 counts with a 10% deviation in width would be 10 counts. Thus the base counter would be reset to -10 at the time that each new entrance increment was begun to be measured. This is accomplished with a series of switches in the "width offset" unit 26. The switches when closed will supply bias voltage to certain tubes in the base counter, and force the tubes to a count 10 condition at reset. The switches can be set manually or if width measuring devices are used, the switches will be electrical in nature and can be controlled from the width measuring devices.

Desired exit gage (G_2) is injected into the system with

the " G_2 desired gage decimal switches" 27. The apparatus 27 consists of a single preset decimal counter, an oscillator and a series of pushbuttons. The operator selects the desired gage on the push-buttons. Circuitry on the pushbutton contacts is so arranged that the complement of the desired gage is actually reflector to the single preset decimal counter; in other words, if the operator inserts a pushbutton gage selection of .0200 and the maximum gage that can ever be attained is .2000, the pushbutton circuitry actually reflects the complement of the desired gage (.1800). Thus the single preset decimal counter is triggered by the pushbutton circuitry to a count of 1800. After inserting the desired gage, the operator then pushes the "start button" 28, at which time the oscillator in the " G_2 desired gage decimal switches" unit 27 will begin to oscillate and send pulses of energy to the single preset decimal counter, as well as to the "pure binary counter" 29. The single preset decimal counter is arranged to stop the oscillator when the single preset decimal count reaches the maximum of 2000 units. Since, in our assumed case, the single preset decimal counter was initially triggered to an 1800 count, the oscillator will send out pulses until the single preset decimal counter reaches a count of 2000, at which time the oscillator cutoff will occur. Since the initial single preset decimal counter count was 1800, and the final count was 2000, only 200 pulses of energy were received. These 200 pulses of energy were also transmitted to the "pure binary counter" 29, but this counter had started at zero, therefore, it will display a count of 200 at shutoff. This was the initial gage set into the pushbutton. At shutoff, the count attained in the "pure binary counter" 29 will be transmitted to the " G_2 multiplier" 30 in the computer. This count will be in binary form. Patent 2,848,166 to Wagner again shows and describes a suitable binary counter for pure binary counter 29.

Each time the operator inserts the desired exit gage and pushes the "start button" 28, a pulse of energy will be sent to the "Control Initiating Counter" 24 to reset it. Once the individual functions of Equation 2 have accumulated in the system, the following actions occur:

(1) The entrance strip gage (G_1) associated with the first increment of strip length, and stored in the magnetic core shift register matrix 11 tenth chamber, is multiplied by the length of incremental strip (L_1). This is accomplished in the " L_1 Multiplier" unit 31 and the final result is a product ($L_1 G_1$). It should be mentioned that the " L_1 Multiplier" unit 31 is equipped for manual insertion of the L_1 value. A series of rotary switches is provided with which this adjustment can be made. As described on page 11, base counter 15 is preset to the number representing the strip interval L_1 which is to be multiplied in L_1 multiplier 31. When the counter 15 has counted a one strip interval L_1 the base counter 15 transmits a pulse to G_1 storage counter 12 indicating that one increment L_1 has been measured. Storage counter G_1 has been preset to six and after six increment lengths L_1 have been measured and base counter 15 has transmitted six pulses to G_1 storage counter 12, G_1 storage counter 12 counts to the preset number of six and transmits a pulse to the magnetic core shift register matrix 11 to cause the entrance gage in the last or tenth storage chamber to be transferred to L_1 multiplier 31 and the entrance gage in the other storage chambers to be shifted to the next succeeding storage chamber. As the input gage G_1 was measured at six inch intervals with the measurement made five feet from the rolls as described on page 11, the entrance gage stored in the last or tenth storage chamber is the gage of the increment length L_1 which was counted in base counter 15 six times to cause the shift in the magnetic core shift register matrix 11 and the transfer of the gage to L_1 multiplier 31. The incremental length L_1 has been manually inserted into L_1 multiplier 31. Thus the transfer of the entrance gage G_1 into the L_1 multiplier 31 results from the measurement of an

increment length six times and the entrance gage G_1 is automatically multiplied by the increment length L_1 in the L_1 multiplier 31.

(2) Exit strip length (L_2), as stored in the " L_2 Storage" magnetic core memory 20, is multiplied by the desired exit gage G_2 and a product (L_2G_2) is obtained. This multiplication is accomplished in the " G_2 Multiplier" 30. This unit is similar to the " L_1 Multiplier" 31, except that multiplier insertion is not manual but automatic. The multiplier value is adjusted as a result of switch closures in the "Decimal and Pure Binary Counter" 29. The L_1 multiplier 31 and G_2 multiplier 30 may consist of digital-to-analog converters for converting the digital data into analog form and analog multipliers. In L_1 multiplier 31 the insertion of the L_1 value may be directly in analog form. Richards, Digital Computer Components and Circuits, in chapter 11, pages 459-501, describes digital-to-analog converters that may be used to convert the digital information into analog form. Analog multipliers suitable for multiplying the analog values are well known to those skilled in the art with such an analog multiplier described in Patent 2,735,616 to Hoadley.

(3) Once the products " L_1G_1 " and " L_2G_2 " are obtained, the smallest value must be subtracted from the largest value to obtain the difference. This is done in the "Subtractor" 32. Millman, Pulse and Digital Circuits, in chapter 15, pages 459-485, describes voltage comparators in detail which may be used as the Subtractor 32. Perhaps it should be mentioned that the product " L_1G_1 " will be represented by a voltage of certain polarity and magnitude while the product " L_2G_2 " will be represented by a voltage of opposite polarity but substantially the same magnitude. Thus the products can be compared to determine which is the larger of the two. When a difference in value exists between the two products, we have then detected that an error in exit gage will occur if the mill is not adjusted for the strip increment about to enter the bite of the mill. Since it is advantageous in most cases to tolerate a small amount of error, allowance is made in the subtractor to provide a manual control for adjusting the amount of error that can be detected without any ensuing adjustment to the mill.

(4) Once a significant error has been detected in the "Subtractor," an adjustment request will be transmitted to the mill via the "Mill Control Output" unit 25. The "Mill Control Output" unit 25 consists of two relays. One relay will upon energization start the mill screws represented at 33 upward, while the other relay will cause the mill screws 33 to move downward. The particular relay energized will be determined by the polarity of the error detected in the "Subtractor" unit 32. Screw-up or screw-down operation which is controlled through "Screw Control" unit 34 will continue as long as a significant error is detected at each calculation and transmitted to "Screw Control" unit 34 from "Mill Control Output" 25.

FIGS. 2 and 3 illustrate a second method of rolling mill control based on the previously mentioned Equations 1 and 2. As can be seen from the diagram, many of the component parts are the same parts as appeared in FIG. 1. For purposes of further identification, each major component will be briefly discussed below before attempting an overall system performance description.

Reference characters 35 and 36 represent thickness or gage sensing devices of the displacement, X-ray, gamma ray, beta ray, etc., type. FIG. 2 shows the gage sensing devices, also labelled G_L and G_R for the reason that the direction of rolling will determine whether the left gage (G_L) or the right gage (G_R) output should be used to represent the input gage G_1 of the mill.

Reference characters 42 and 86 represent servo type followers which accept the gage readings (usually in electrical form) of components 35 and 36 and converts them into mechanical shaft rotations represented at 43 and 87 respectively.

Shaft position digitizers 44 and 88 convert the shaft rotations 43 and 87 representing material thickness (as reflected in components 42 and 86) into a mathematical form suitable for computer input. The mathematical readout may be either of the decimal or binary class. However, in this case, the binary type of digitizer will be assumed as being used herein.

Decode Logic unit 45 is an electronic repeater of the digitizers as well as a device which removes the ambiguity common to most two brush commercial binary digitizers. The unit also includes means for switching outputs of digitizers 44 and 88 in and out of the output channel connecting to the magnetic core buffer 46. Depending on the direction of rolling of the mill one of the digitizer readings (and only one) will be submitted to the magnetic storage chamber 47 via the magnetic core buffer 46. The direction of rolling will be selected by the mill operator at the "mill drive direction selector" unit 55, and a reflector of this selection will be relayed to the "decode logic" unit 45 over circuit 85. The decode logic unit will then make the proper switch contact closures to insure that the proper digitizer output is supplied as an indication of mill input gage to the magnetic storage memory.

The magnetic core buffer unit 46 is simply a buffer amplifier inserted for attaining better impedance match between the magnetic core load (of the magnetic core memory) and the transistor repeaters of the "decode logic" unit 45. Gain in stability is procured by this design since the buffer amplifier is usually designed to draw no grid current. Also, included in this unit is an electronic gate or latch which only allows the input strip gage measurement to be stored at certain intervals.

The magnetic core memory 47 is the storage point wherein the measured material entrance gage G_1 is contained until compared with calculated value. Primarily the memory is composed of ten storage chambers; nine of these chambers each have eleven magnetic cores to represent the progressive binary digits which must be combined to represent a certain measured gage. The tenth storage chamber is constructed of transistors rather than magnetic cores, since it is necessary to read-out the information from this chamber in serial fashion. Magnetic core memories do not lend themselves to serial fashion readout conveniently.

The strip length sensing means are the pulse generators 13 and 21 coupled to the idler rolls 16 and 22 respectively of the mill. These pulse generators receive an R.F. signal from the demodulator units 14 and modulate it according to strip length passing each length sensing element.

Demodulator units 14 are a source of R.F. energy for the pulse generators 13 and 21, as well as a means of reconvert (or demodulating) the modulated signal into pulses of D.C. energy representing strip length. Thus the combination of a pulse generator and its respective demodulator unit will produce either 500, 1000 or 2000 electrical pulses per revolution of the pulse generator, each revolution of the pulse generator in turn will represent a certain strip length of material entering the mill.

The system of this disclosure concerns a control means not only for unidirectional rolling mills, but also for reversible mills, therefore, the electrical pulses representing strip length from the entrance and exit sides of the mill must be directed to the proper pulse counting equipment at each reversal of the mill. In other words, the mill entering strip length pulses must always be recorded in the L_1 counter 59 and the mill exit length pulses in the L_2 counter 60. To do this the switch 54 is supplied. Each time that the mill operator changes the mill drive direction selector 55 it will relay this information to the switch 54 (over circuit 56) and cause it to reverse lines "A" and "B" from the demodulators 14.

Multiplier 57 serves as a sensitivity selecting means. By use of it, selection can be made as to whether each

revolution of the pulse generators 13 and 21 will result in 500, 1000 or 2000 electrical pulses being produced. This is accomplished by the use of only one of the etched patterns in the pulse generator (of the type, for example, as produced by Telecomputing Co.), by the use of both of the etched patterns or by the utilization of both the negative and positive pulses produced in both etched patterns

As mentioned before, the equipment of this invention is not limited to unidirectional mill control. But each time that the controlled mill is reversed, certain control system components must be preselected to take care of this reversal. It is the prime duty of the mill drive direction selector, unit 55, to perform this function. This unit supplies a direction signal to cause contact closures in units 45, 54, and 61 by means of circuits 85, 56 and 64, respectively.

In discussing Equation 2, described previously in column 3, mention was made that correction can be applied to this type of solution if it was noticed that some of the supposed constant factors were found to be in error. One of these errors may be encountered due to slight physical and operational differences in the pulse generators 13 and 21. An error constant in magnitude, and quite significant in value is encountered when the pulse generators 13 and 21 are driven from discs designed to ride on the mill idler rolls 16 and 22. After some time, the discs will show wear or differences in diameter, such that if the mill were to be opened to produce no reduction and a certain pulse count increment submitted from one side of the mill, the pulse generator on the opposite side of the mill would not produce an exact same pulse count increment. Unit 61 is the means for manually setting in this correction. Since the correction is dependent on mill direction, two adjustments, "left" and "right," are provided.

Error caused by a change in width of strip can be compensated for by means of component 62. The "W" factor is introduced by rotary selector switches into the Width Factor Unit 62.

The error constants K and W, as discussed under components 61 and 62 must be multiplied and then applied to the desired output gage G_2 and elongation ratio in order to calculate the desired value of G_1 . Mathematically, we say:

$$\bar{G}_1 = \frac{L_2}{L_1} G_2 WK$$

The multiplications shown above can be performed in a number of ways, and it is not intended to limit this invention by specifying only one means of doing this; any number of solutions are possible. As an example, a series of summations could be utilized to attain the final product. However, in this instance, the multiplication of "W" and "K" is determined via another standard computer practice, in order to save computation time. To do this, we vary our mathematics somewhat. Originally we said that

$$WK = W \times K$$

We will now alter the form and say

$$\begin{aligned} K &= 1 + \Delta P \\ W &= 1 + \Delta W \end{aligned}$$

therefore

$$\begin{aligned} \Delta K &= K - 1 \\ \Delta W &= W - 1 \end{aligned}$$

then

$$\begin{aligned} WK &= (1 + \Delta K)(1 + \Delta W) \\ WK &= 1 + \Delta K + \Delta W + \Delta K \times \Delta W \\ WK - 1 &= \Delta K + \Delta W + \Delta K \times \Delta W \end{aligned}$$

The last equation is of the form utilized in component 81. This form saves computation time since the factors on the right hand side of the equation deals with fewer significant digits than the W and K factors originally contained. Thus with a case where $K=1.018$ and $W=1.050$, the

multiplying equipment uses only the digits 18 and 50, rather than 1018 and 1050. This also results in a saving of equipment. The equipment contained in component 81 includes an oscillator, several electronic gates and a number of pulse counters. Equipment arrangement to effect this multiplication will not be discussed here since the technique utilized is a standard computer technique.

The desired output gage selector, unit 63, consists of a manual selecting means (such as rotary switches), oscillator and a counter. Mill operators can inject the desired output gage into the unit, wherein it is registered as a pulse count on the counter.

Unit 66 is very similar to unit 62 since a multiplication type function is desired. The desired output gage G_2 and the product of the correction factors (in the form $WK-1$) is multiplied in this unit. As can be seen from FIG. 3, the result is G_2WK , which is then relayed to the L_1 counter unit 59, to serve as a preset for this counter.

Reference character 65 designates a pushbutton with which the mill operator initiates the solution of the product WKG_2 , clears old information from the memory and starts introduction of new G_1 values into the memory unit.

The pushbutton closure (component 65) is taken as a notice by command unit 75 to clear or reset counter 77 and to trigger oscillator 76 into a pulse conducting state. At the same time gate 78 is commanded (over circuit 89) to open and transmit pulses from oscillator 76 (via units 78, 79, 52 and 46) for the purpose of clearing (by stepping) the magnetic memory of any old information that may be present, as well as supplying the memory with control signals for the storage of ten new readings of material gage. It may be noteworthy to mention that the strip increments over which this gage information is accumulated will not necessarily be of the same length as the gage measuring increments later determined by the shift preset counter unit 51. For start up, however, this condition is found to be satisfactory.

A further duty of unit 75 is to hold dual gate unit 58 in the closed state until the magnetic memory is filled with input gage information. This is accomplished by not allowing electrical energy to flow to the "end gate" unit 83 (via circuit 84) until the magnetic memory has reached the full state, and also the G_2WK multiplication has been completed.

Unit 76 consists of a standard electronic oscillator, controlled from unit 75, and transmitting pulses to units 77 and 78.

The counter 77 is also a standard unit of the preset counter nature. In this application, the counter is preset to ten counts, at which time, it closes the gate 78 to announce the completion of the input gage storage in the magnetic memory.

Gate unit 78 is of the electronic type also, and serves as a controlling and transmitting means of oscillator pulses used to step or command the magnetic memory storage circuits. As previously mentioned, this gate is opened (allowed to transmit pulses) by a signal from unit 75 via circuit 89 and the gate is closed by a signal from the ten-count counter 77.

Shift preset counter unit 51 is the means of commanding the magnetic memory 47 to make a gage storage, as well as, commanding the memory to shift all gage information forward one chamber. The shift preset counter is only used in this capacity after the initial start-up of the automatic control system. As mentioned before, at start-up the units 75, 76, 77 and 78 control the magnetic memory 47. After the initial start, those units are no longer used, and the shift preset counter unit 57 controls all storage in the magnetic memory.

Previous discussions brought out the fact that extreme variations in gage are not normally encountered and that normally one reading of gage is stored in approximately six inches of strip. This length is adjustable in the preset means of unit 51. Since the storage command is re-

lated to certain increments of entering strip length, the shift preset counter unit 51 receives its input information from the mill entrance length sensing line L_1 . This information is in the form of pulses, which are then counted in the shift preset counter. The existing relationship between the number of pulses generated by the pulse generators 13 and 21 as compared to the actual length of strip passing into the mill during the pulse generating time, as well as the length increment over which gage is to be measured, will determine the count at which the unit 51 should be preset. When the count reaches this value, a command (pulse) is given to store another reading of input gage G_1 . This command is routed through the components 79, 52 and into component 46.

The "or gate" unit 79 is a transistor circuit arranged in standard electronic fashion so that output energy will be supplied to the magnetic core drive amplifier unit 52 at any time that input energy appears on either circuit 90 or circuit 91.

A magnetic core drive amplifier 52 primarily of the buffer amplifier type, is necessary in order to supply a low impedance pulse for driving the magnetic storage equipment. Unit 52 makes this low impedance pulse possible. In addition, this unit furnishes a lock circuit which serves to delay any read-in (storage) signals during a subtraction operation. This is necessary, otherwise a shift of gage information from one chamber to the following chamber may occur, and thus the information in the tenth and final chamber (being used in the subtraction operation) may be destroyed. The signal to lock is given by the subtractor unit 48 over the circuit 53.

"And gate" unit 83 is of the standard transistor variety described under "or gate" unit 79. The prime function of this unit is to act as a gate in controlling electrical energy flow to the dual gate unit 58 to allow it to open (via the "or gate" unit 70). Since this unit is of the "and gate" type, energy will only be delivered to unit 70 when the two input circuits 84 and 82 have signals appear on them simultaneously. The significance is that the automatic control system has been put into operation, ten storages of input gage have occurred, and that the multiplication of the desired output gage G_2 , width factor W , and correction factor K has also been completed.

"Or gate" unit 70 is also a standard transistor circuit arrangement as discussed under "or gate" unit 79 and "and gate" unit 83, however, it will produce an output suitable for opening dual gate (unit 58) when a signal appears on either of its two inputs, circuit 92, or circuit 69. The signal controlling conditions of circuit 92 have been discussed under unit 83. As to circuit 69 a signal will appear on this circuit after each transfer of $\bar{G}_1$, from unit 60 to unit 68.

Dual channel gate 58 is a vacuum tube unit so constructed that an electrical signal from circuit 93 will cause the tubes to conduct and pass the signals on the input channels. A signal on circuit 67 will cause the gate to close and stop passing of the input channel information. The signal controlling factors of circuit 67 will be discussed in the description of component 59.

L_1 counter unit 59 consists of a binary single preset counter. The value to which this counter is preset is determined by the product G_2WK multiplied by a binary shift point constant (some power of two). The L_1 counter receives electrical pulses (representing strip length) from the dual gate unit 58. When the pulse count reaches the preset value, coincidence circuits respond to close dual gate unit 58 (to block all length measurement pulses from proceeding to the L_1 and L_2 counters), to notify L_2 counter unit 60 to stop counting and transfer this final count to the readout unit 68 and to notify the readout unit 68 to store the count reading of the L_2 counter unit 60. As soon as the L_2 count has been transferred and stored in the readout unit 68, a signal will be transmitted from the readout unit 68 to the L_1 and L_2 counter units 59 and 60 to cause the counters

to reset to zero, also the same signal will be conveyed to the dual gate unit 58 via circuits 69 and 93 to cause the gate to open and again allow pulses to flow to the counters.

In the opening statement of this explanation of L_1 counter unit 59, brief mention was made that the value G_2WK was multiplied by a binary shift point constant before being used as a preset for L_1 counter. This binary shift point mechanism (considered part of the L_1 and L_2 counter hardware arrangement of FIG. 3) consists of a stepping switch home-seeking device, in conjunction with a manual selector, the combination of which operates to multiply G_2WK by some power of two (as selected with the manual selector). The manual selector in this case is of the three position type, and reflects multiplications by a factor of 2^0 , 2^1 , or 2^2 . Gain in accuracy is the main advantage of this device. This may be accomplished in two ways. First of all, it is common knowledge that the count of L_1 counter unit 59 is more significant and accurate if this count is within the one-half to full scale range of the counter. Thus, multiplying a small value of G_2WK by 2^1 or 2^2 to bring the present value of the L_1 counter within the above mentioned range would be advisable. Secondly, the increased preset value of L_1 counter will bring about a longer measuring time and possibly a better measurement of L_2 .

Circuitry from a second contact bank on the stepping switches is used to automatically shift the binary set point in the reverse direction on the count attained in the L_2 counter unit 60. As an example, if the G_2WK value is initially multiplied (with the binary shift point selector) by a value of 2^1 , then the count of L_2 counter unit 60 will also automatically be divided by 2^1 .

Unit 60 is an electronic binary counter unit similar to that of unit 59, except that it does not include any preset control. The output material length pulses are counted and upon command are submitted to the readout unit 68 for storage; the acceptance of the information at the readout unit then being followed by a reset signal to the L_2 counter unit 60, and the unit then again being ready to count pulses.

It is desirable at this time to explain how the division operation in our solution for the desirable input gage $\bar{G}_1$ has been performed. As previously written:

$$\bar{G}_1 = \frac{L_2 G_2 K W}{L_1}$$

From FIG. 3 it can be seen that the value G_2WK was transmitted to the L_1 counter unit 59. In the L_1 counter unit 59, the G_2WK value was used to represent the preset value of L_1 counter, or in other words, L_1 was set equal to G_2WK units. Since

$$L_1 = G_2WK$$

then

$$\bar{G}_1 = \frac{L_2 G_2 WK}{G_2 WK} = L_2$$

Thus, the L_2 count is an absolute reflection of the calculated desirable input gage.

Readout unit 68 consists of a series of transistor flip-flops circuits so arranged as to store the L_2 count in binary form. Each flop-flop circuit represents a certain binary digit. Gating circuitry is provided to allow transfer of information in and out of the equipment only at proper intervals. This gating circuitry is controlled by circuits 67 and 94.

The subtractor unit 48 is constructed of standard transistorized logic circuits which serially (one bit at a time) compare the measured value of input gage G_1 (as stored in the tenth chamber of unit 47) against the calculated desired value of input gage $\bar{G}_1$ (as stored in unit 68). Here again, transistor flip-flop circuitry is utilized to store the difference between corresponding bits. This information (magnitude of difference between G_1 and $\bar{G}_1$,

as well as the sign of the difference) is then sent to the mill control unit 39 (via units 73 and 74), where it is set into flip-flop circuits controlling the alarm and screw operations.

In order to synchronize all operations, the subtractor unit 48 has a built in distributor. The distributor provides the timed signal necessary to control the readout of G_1 , $\bar{G}_1$, also to control the subtractor and the dead zone and alarm set unit 73, and to reset unit 68 by means of circuit 94. The composite mechanism of this unit consists of a multivibrator transistor pulse gates and transistor flip-flop sequence circuit. As the gating circuits and flip-flop sequence circuit respond to the successive incoming pulses, signals are transmitted to the various components of the control system, viz., a signal is given for the first binary bit in the tenth chamber of unit 47 to be transferred into the subtractor by circuit 50. On the next flip-flop action, a signal is given to unit 68 (via circuit 94 to have the corresponding binary bit transferred to the subtractor, etc.).

Dead zone and alarm set unit 73 consists of a manual selecting means (2 sets of 8 pushbuttons each) for selecting the amount of deviation between G_1 and $\bar{G}_1$ that can occur before any mill control is initiated. This first set of pushbuttons is circuited to the "and" gates and flip-flop circuits of the mill control unit 39, and determines when and whether a screw-up or screw-down operation should occur. The second set of pushbuttons determines (over similar circuitry) the maximum deviation which can be tolerated. This means is used to energize alarm relays in unit 39 which in turn discontinue automatic control on the mill screws.

Although the relay controls can be energized once a significant error has been realized, the maximum time a relay may stay energized is controlled by the delay circuit of the time control unit 74. The delay circuit is simply an R-C circuit (with adjustable resistance) in which the charge rate of the timing capacitor determines the length of time that associated transistors pass current; this, in turn determining when a reset signal should be given to the relay control flip-flop circuits of unit 39.

As explained previously, the mill control unit 39 consists of several "and" gates, a series of transistor flip-flop circuits and four relays (LO, MLO, MHI, HI). The "and" gates upon receipt of simultaneous signals (at a time determined by the distributor) will set the flip-flop circuits if a difference equal to or greater than the preset values of unit 73 was obtained in the subtraction process. The state of the flip-flop circuits then determines which of the above mentioned relays is to be energized. Energization of the LO or HI relays signifies a difference greater than the permissible maximum has been obtained; an alarm is sounded and a mechanically latched relay is energized. The mechanical latch relay breaks all control circuits between the control system and the mill screws. The mill must then be manually controlled. Return to automatic control cannot be made until the mill operator removes the mechanical latch by pushing a reset button.

Energization of the MLO or MHI relays closes circuits to the solenoids on the mill screws in screw control unit 34. Depending on which relay (MLO or MHI) has been energized, the mill will respond with either screw-up or screw-down action to produce material on the output side of the mill with constant gage thickness. As stated previously, the length of the screw-down or screw-up operation is controlled from the time control unit 74.

System operation.—Reference character 1 schematically designates a conventional rolling mill having coacting pressure rolls 2 and 3 through which the material 4 being engaged passes from the coiled roll 5 to the coiled roll 6. For the purposes of this discussion we will consider that the material being rolled is passing from coiled roll 5 to coiled roll 6. Thus we find that

the gage G_L in position 35 is on the input side of this roll and G_R in position 36 refers to the gage on the exit side of the roll.

When the material is traversing the mill in one direction measurements are effected by one gage, whereby when the mill is reversing and operates in the opposite direction the measurements are effected by the other gage. The gage measurement G_1 in each case, which is used for purposes of control of the mill, is the gage measurement on the entry side of the mill, regardless of direction. It will be understood that the invention is applicable to both unidirectional and bidirectional mill operations and that in the instance of unidirectional mill operation gage measurement is effected only on the entry side of the mill.

The mill rolls 2 and 3 are controlled by various means which, in this instance, has been indicated as a screw 33 operated by screw control 34 through leads 37 and 38 from the mill control designated at 39. The mill control 39 has been shown as including the screw-up circuit 38 and the screw-down circuit 37 and separate alarm control circuits designated at 40 and 41. The alarm circuits include provisions for locking out automatic control of the mill screws and returning the mill to manual control.

The input gage head G_1 in position 35 is electrically connected to the servo-follower 42 which is a device for sensing thickness of material at position 35 and converting this thickness into mechanical shaft rotation at 43. This shaft rotation which is proportional to thickness operates a shaft position digitizer 44 with a binary output. This binary output is then fed electrically to the decode and logic unit 45 which serves to eliminate ambiguity to decide which gage (35 or 36) information is to be used, and then in turn feed this information into the magnetic core buffer 46, which then feeds this information into the memory assembly 47. The magnetic core buffer 46 serves to put the input gage information into a form which the memory assembly 47 can accept. This memory is needed because it is necessary to measure the thickness of the material 4 in advance of the bite of the mill. It therefore becomes apparent that the thickness information must be stored, and in effect transported with the flow of the material to the bite of the mill, so that the gage thickness leading the memory corresponds to the thickness of the material at the bite of the mill. The memory 47 comprises, in the example herein explained, an eleven binary bit device having ten cells to progressively store and advance gage readings of the material 4 for every six inches of length thereof. The eleven binary bits are required to gain reasonable decimal capacity, which in this application is 2,047.

The first nine cells of the memory are of magnetic storage arrangement where the tenth cell is transistorized. Information is read out in serial fashion from this tenth cell to the subtractor circuit represented at 48 and information returned to the tenth cell as indicated by the return path 49. A command circuit 50 extends from the subtractor 48 to the tenth cell of the magnetic memory for synchronizing the operation of this cell so that read-out occurs at the proper instant. Command circuit 50 delivers a pulse from the subtractor 61 when subtractor 61 is ready to perform a subtraction to read out the contents of the last register in the matrix 47 to the subtractor 61.

Since, as pointed out earlier, the gage information is measured before the bite of the mill and then introduced into a memory assembly, it is necessary that the gage information be advanced through the memory in direct relationship with the passage of the strip 4 through the mill. This function is performed by employing the pulses generated in the strip length-sensing unit 13 which is a pulse generator which gives an electrical measurement of the length of material L_1 entering the mill in our example. These pulses are counted on the shift preset

counter 51 which serves to advance the memory assembly 47 each time the pulses accumulated in this counter 51 reach the preset value. For example, if the input gage G_1 is at position 35 and is sixty inches from the bite of the mill, and the memory assembly is ten cells deep it becomes necessary to divide the total pulses which would represent sixty inches into ten equal parts. Thus, if sixty inches of strip represented 3,000 pulses, the shift preset counter 51 would have been set at 300. It is in this manner that the input gage information is correlated with the strip product. As the shift preset counter 51 commands the memory assembly 47 to advance, it is necessary, for proper operation and synchronization, to interpose the magnetic core drive amplifier 52 with the output thereof connected to magnetic core buffer 46 to the input of the memory 47. Register shift hold circuit 53 from subtractor 48 to magnetic core drive amplifier 52 delays the pulse output therefrom in the event that a command to shift the memory assembly has occurred while a subtraction was taking place. Upon completion of the subtraction the hold circuit releases, permitting the magnetic core drive amplifier 52 to perform its function.

The circuit 53 therefore allows a binary number to be completely transferred from the last cell of the magnetic memory to the subtractor 48 before a new binary number is allowed to enter the last cell from the preceding cell. This overcomes the difficulty that a portion of a number being read-out in serial fashion from the last cell may be lost in part or in whole.

When a measured gage reading reaches the tenth cell of the magnetic memory 47, the tenth cell of the memory assembly has the input gage information of the increment of material about to enter the bite of the mill. At this time a calculation is made to determine what the input gage should be to produce the desired preset output gage of the mill.

As heretofore explained, the principle involved in this invention is set forth by the following equation:

$$\bar{G}_1 = \frac{L_2}{L_1} G_2 WK$$

$$G_1 - \bar{G}_1 = \text{error}$$

where:

$\bar{G}_1$ = calculated input gage.

L_2 = output length.

L_1 = input length.

G_2 = preset desired output gage.

W = width factor.

K = pick-up factor which is a constant derived from the difference in diameter of the pulse generator pick-up wheels which ride on idler rolls 16 and 22.

G_1 = measured input gage.

The input L_1 and output L_2 strip length sensing means are at positions 13 and 21 coupled to idler rolls 16 and 22. These pick-ups sample on a continuous basis the incremental length of the material entering the mill and leaving the mill by modulating an R.F. signal in direct relation to the incremental length. To utilize this information in this control system it is necessary to demodulate the signal in the demodulator unit 14. The respective outputs of this demodulator are a series of pulses; the number of pulses on each output line being exactly related to the number of revolutions of the pulse generators 13 and 21 and thus to the strip length. These outputs are fed into the switch unit 54 which establishes (according to mill direction information received from mill drive direction selector 55 over circuit 56) which pulse generator output should be used as input length reflection L_1 , as well as which of the two should be used as exit length reflection L_2 . As mentioned in the component description, the outputs of the pulse generators 13 and 21 per increment of strip length can be multiplied with multiplier 57 to effect ideal control. The pulses generated by the mill entrance side pick-up L_1 are then fed

through dual gate 58 to the L_1 binary counter 59, while the pulses generated by mill exit pick-up L_2 are fed through gate 58 and to the L_2 binary counter 60.

As referred to in the previous equation, it is necessary to determine the product of $K \times W \times G_2$. Since these factors are all considered constants on any given pass on the mill, they are introduced by rotary switches or push-buttons in the assembly 61, 62, or 63 as the occasion may be. The K factor which represents the relationship between the idler rolls 16 and 22 and the pick-up wheels 13 and 21, once established, is not changed; however, it should be understood that actually there are two distinct values of K and the value used is determined by mill direction (reflected from unit 55 over wire 64). The K factors are manually introduced into the assembly 61; the W factor is manually introduced into the assembly 62; and the G_2 desired output gage factor is manually introduced into the assembly 63. To satisfy the equation in which these factors are used the factors must be multiplied by each other. This is performed at start-up (when pushbutton 65 is operated) by multiplying first the K factor 61 by the W factor 62, and the resultant product then multiplied by G_2 as represented at 63. The final product is then stored at 66 and expressed as G_2WK . This product then provides the preset limit for the L_1 counter which means that upon the accumulation in the L_1 counter of this preset value, counter 59 will operate the dual gate circuit 58 (through the lead 67) which will block both the L_1 pulses and the L_2 pulses. In addition, a command to read-out of L_2 counter 60 is provided. Upon completion of the read-out into unit 68, both the L_1 and the L_2 counters are reset to zero, the dual gate 58 is re-opened (via circuit 69, gate 70, and circuit 93), and the process is repeated.

Read-out 68 now contains in binary form the solution of the desired input gage which the mill should have in order to produce the desired output gage G_2 . The output of read-out 68 provides the calculated value $\bar{G}_1$ which is applied through lead 71 to the subtractor 48 upon command thereof through lead 94. The actual measured gage G_1 is supplied through lead 72 from the output of the tenth cell of memory 47 to the subtractor 48. The difference between the calculated value and the actual value of G_1 as expressed in the foregoing equation constitutes the difference signal which is fed through the unit 73 (which we designate as the dead-zone and alarm set) to the unit 74 (designated as time-control .01 to .1 and .1 to 1.0 second) to the mill control 39 heretofore explained.

In order to start this automatic control system, the control button 65 of the start unit 75 is closed. This action provides for the following operation:

(1) Oscillator 76 is functioned to deliver pulses to the single preset counter unit 77 and to the gate circuit 78. The gate 78 in turn passes the pulses to the magnetic core drive amplifier 52 which serves through the "or" gate 79 to advance memory assembly 47, such as to clear the memory assembly of prior G_1 information and to introduce into each cell the new value of G_1 . Upon completion of the above, preset counter 77 operates to close the gate 78 and hence disable the circuit.

(2) A pulse is transmitted over lead 80 from the start unit 75 to the width factor W unit 62 which initiates the multiplication of $K \times W \times G_2$ through the unit 81 ($WK-1$). Upon solution of this product a pulse is provided from the G_2WK unit 66 through lead 82 to the "and" circuit 83.

(3) The pulse on lead 82 when simultaneously appearing at "and" gate 83 with the pulse through lead 84 (initiated from the start unit 75 when control button 65 is closed) causes a pulse to be passed from "and" gate 83 to gate 70 and thence to the dual gate 58. Gate 58 is forced to open by this pulse thus starting initially the L_1 and L_2 counters.

Oscillator 76 is disabled as soon as counter 77 has

reached its preset limit; thus signifying that the memory assembly 47 has been cleared of past information and refilled with new G_1 information (all ten calls).

We have constructed, adapted and tested the automatic control system of our invention on a cold rolling steel mill and have found the system of our invention to be very efficient, economical, practical, reliable and precise.

The applicants realize that there are many ways in which the principle of this invention may be carried out and the examples shown herein are to be considered in the illustrative sense and not in the limiting sense.

While we have described our invention in certain preferred embodiments, we realize that modifications may be made therein as well as in its application, as for example, instead of controlling screw action on a mill, the system may be utilized for controlling tension of the strip or a combination of tension and screw action, and we therefore desire that it be understood that no limitations upon our invention are intended other than may be imposed by the scope of the appended claims.

What we claim as new and desire to secure by Letters Patent of the United States is as follows:

1. In a system for performing work upon a moving strip by a pair of rolls through which said strip is advanced, means positioned along the path of said strip for measuring the gage of the strip before said strip enters said rolls and for producing data representative thereof, means for measuring the length of strip passing into said rolls and for producing data representative thereof, means for producing a data representation of the desired gage of said strip leaving said rolls, means for measuring the length of strip passing from said rolls and for producing data representative thereof, means for storing data representative of the gage of said strip before entering said rolls measured by the said measuring means, means for combining said data in respect to gage and length of strip before said strip enters said rolls to produce a first combination, means for combining said data in respect to length of strip after leaving said rolls with data representative of said desired gage to produce a second combination, means for comparing said first and said second combinations, and means controlled by said comparing means for adjusting said rolls.

2. In a system for performing work upon a moving strip by a pair of rolls through which said strip is advanced, means positioned along the path of said strip for measuring the gage of the strip before said strip enters said rolls and for producing data representative thereof, means for measuring the length of strip passing into said rolls and for producing data representative thereof, means for producing a data representation of the desired gage of said strip leaving said rolls, means for measuring the

length of strip passing from said rolls and for producing data representative thereof, means for storing data representative of the gage of said strip before entering said rolls measured by said measuring means, means for adding data representative of the initial width of said strip to data relating length of said strip in said storage means, means for combining said data in respect to gage and length of strip before said strip enters said rolls to produce a first combination, means for combining said data in respect to length of strip after leaving said rolls with data representative of said desired gage to produce a second combination, means for comparing said first and said second combinations, and means controlled by said comparing means for adjusting said rolls.

3. In a rolling mill control system for operating upon a strip of ductile material by a pair of rolls through which said strip is advanced, a thickness gage for measuring the gage of the strip entering said rolls for producing a single representative thereof, means for converting said signals produced by said thickness gage into entering gage data having a digital notation, a first counter for storing said entering gage data, a second counter capable of receiving data in digital notation representative of predetermined thickness for the exit strip from said rolls, a tachometer pulse generator coacting with the strip entering said rolls, a tachometer pulse generator coacting with said exit strip, an analog to digital converter for each said generator, a gate controlled by the first said generator to bring about synchronous operation of the second said generator, a first multiplier for combining data from first said counter and first said generator, a second multiplier for combining data from second said counter and second said generator, means for adjusting said rolls, and a differential amplifier having an input from each said multiplier for controlling the said adjusting means.

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