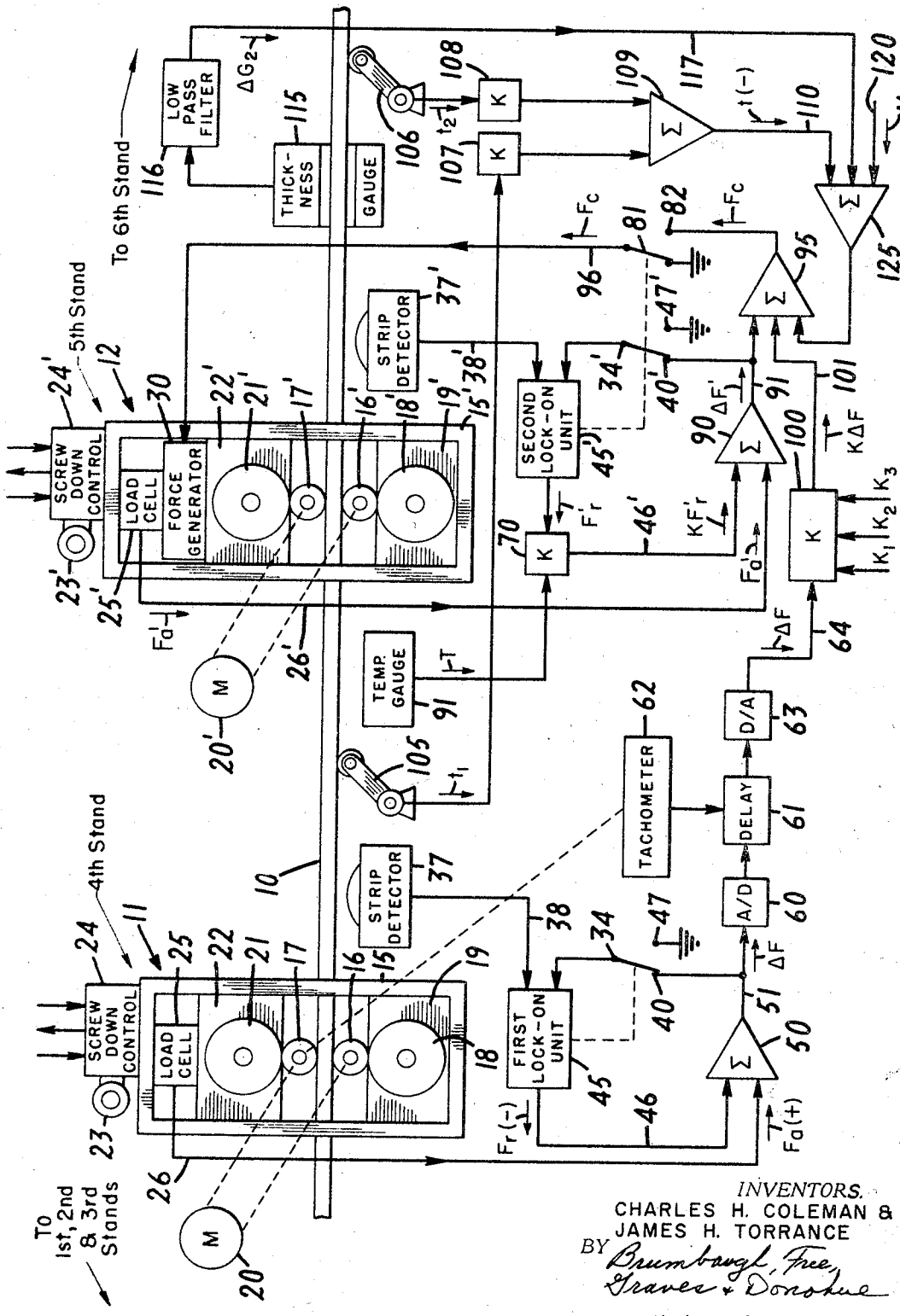
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THICKNESS REDUCTION CONTROL SYSTEM

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INVENTORS.
CHARLES H. COLEMAN &
JAMES H. TORRANCE
BY Brumbaugh, Free, Graves & Donohue
their ATTORNEYS

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THICKNESS REDUCTION CONTROL SYSTEM

Charles H. Coleman, Groton, and James H. Torrance, Uncasville, Conn., assignors to General Dynamics Corporation, New York, N.Y., a corporation of Delaware

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ABSTRACT OF THE DISCLOSURE

Six stand rolling mills for strip in which the thickness-reducing action of the fifth stand is controlled by applying to the work rolls thereof a variable force computed as a function of the force of the strip on the fourth stand and of other operating parameters. As the leading portion of the strip passes through the fourth and fifth stands, lock-on devices convert signals of the forces of the strip on those stands into reference levels for subsequently obtained values of such signals.

This invention relates to systems for controlling installations which reduce the thickness of material passing therethrough. The invention is applicable to various sorts of such installations (as, say, bar mills, tube mills, and die drawing installations) which are employed to effect a reduction in thickness in one or more dimensions of lengths of materials of various compositions and shapes. For the purpose, however, of making clear the character of the invention, it is disclosed herein as being specifically embodied in a control system for a multi-stand rolling mill for metal sheet or strip.

In such a mill, the strip is reduced in thickness by the work rolls of each stand in accordance with the size of the gap between those rolls. Because variations in thickness of the input strip to the rolls tends to a variable forcing apart of the rolls and because of other factors, it is necessary to adjust the relative spacing between the rolls (i.e., adjust the size of the roll gap) in order to avoid undesirably large variations in thickness of the output strip from the rolls. To that end, numerous closed loop control systems have been proposed in which one or more signals of a condition of the moving strip (e.g., the instantaneous input thickness of the strip) are utilized to provide an output signal indicative of the instantaneous relative position the rolls should have to minimize the variation in thickness of the output strip from a desired thickness. Such output signal is then used to actuate roll adjusting means (e.g., a screw-down motor) to adjust the rolls to assume the relative position indicated by that signal. Such proposed position-determining systems usually have, however, the disadvantage, that they have too slow a response to compensate adequately for rapid variations in the input thickness of the strip.

U.S. Patent 3,197,986 to Freedman et al. discloses how to overcome such disadvantage by replacing the usual position-computing closed loop system by a closed loop control system which (a) computes the force the rolls should exert on the strip to obtain a desired output thickness, and (b) applies to the rolls an actual force corresponding to such computed force by a fast acting force generating device such as a wedge actuator. Wedge actuators of such sort are disclosed for example, in the Freedman et al. patent and in copending application Ser. No.

405,749 filed Oct. 22, 1964, now Patent No. 3,355,925, and owned by the assignee hereof.

In the system of the Freedman et al. patent, the input thickness signal for the force-computing closed loop is derived from a conventional thickness gauge on the input side of the stand controlled by the system. Such thickness signal does not, however, reflect in its value various other gross changes in the condition of the moving strip as, for example, the chemistry, hardness, and temperature of the material of the strip and the width of the strip. In addition the thickness signal inherently contains low frequency noise due to internal and external sources (e.g., random nature of the gauge and fluids on the strip).

In U.S. Patent 3,111,046 to Koss et al. for a rolling mill, it is proposed to employ a signal derived from a load cell for the first stand as an error signal for a closed loop system controlling the thickness reduction effected by the rolls of the second stand. Because, however, the Koss et al. closed loop system is a position-computing system rather than a force-computing system of the sort described, the Koss et al. system is too slow to respond adequately to rapid fluctuations in the mentioned error signal. Hence, in the Koss et al. system, a rapid variation in the input thickness of strip to the second stand will cause a corresponding variation in thickness to appear in the output strip from that stand.

It is accordingly an object of this invention to control the thickness reducing action on material of the working means at least one stand of a multi-stand thickness-reducing installation by controlling the adjustment of such working means by force-generator means responsive to a signal of the force from such material on the working means of a preceding stand, said force-generator means being responsive to rapid fluctuations in such signal to correspondingly control said action.

Another object of this invention is to control the thickness reducing action on material of a thickness-reducing installation by means which compares a force signal derived from the thickness reducing action with a reference level for that signal, and which means then utilizes the result of the comparison to compute and apply to the working means a force which should yield a desired thickness reduction.

Still another object of this invention is to establish the mentioned reference level by passage of an initial portion of such material through the mentioned working means.

These and other objects are realized in accordance with the invention by providing for a multistand installation a control system wherein force-computation means responds to separate signals of the force from the material on the working means of one stand and of the force from the material on the working means of a preceding stand to derived an output representative of a computed force value which should yield a desired thickness of the strip emerging from the one stand. That output is then utilized to actuate a fast acting force generator means which applies to the working means of the one stand a force in accordance with said computed force value. Both the force computation means and the force-generator means have a fast enough response to follow accurately any rapid variations in the value of the mentioned force signals.

As another aspect of the invention, the force signal from the one stand is compared with a reference level established for that signal to derive from such comparison

an error signal representative of the difference between such signal and level. That error signal then controls the force-computation means to actuate the force-generator means as a function of that error signal.

As still another aspect of the invention, a reference level of such sort is established for either one or both of the force signal from the one stand and the force signal from the said preceding stand by passage of an initial portion of the material through those stands.

For a better understanding of the invention, reference is made to the following description of an exemplary embodiment thereof and to the accompanying figure which is a schematic diagram of a portion of a six stand strip rolling mill and of a control system associated with that portion.

In the description which follows, elements which are counterparts of each other are identified as such by using the same reference numeral for each element, but are distinguished from each other by using a prime (') suffix for the reference numeral of one of the counterpart elements. It is to be understood that, unless the context otherwise requires, a description of any one element is to be taken as equally applicable to a counterpart thereof.

Referring now to the figure, the reference numeral **10** designates a hot strip or sheet of iron or steel being reduced in thickness by being passed through the fourth stand **11** and the fifth stand **12** of a six stand rolling mill which may be similar to that disclosed in copending U.S. application 564,817 filed July 13, 1966, now abandoned and owned by the assignee hereof. Since the control system to be discussed is associated only with the fourth and fifth stands, the remaining stands of the six stand mill are not shown in the figure.

Stand **11** is a conventional stand comprised of a frame **15** and working means in the form of lower and upper work rolls **16** and **17** between which the strip **10** passes. The work rolls **16** and **17** are dirven by a motor **20** which may be controlled as disclosed in U.S. application Ser. No. 564,817. The lower work roll **16** is contacted by a lower back-up roll **18** while the upper work roll **17** is contacted by a back-up roll **21**, both disposed in roll chocks **19** and **22** supported within frame **15** to be vertically slidable therein. Roll chock **22** is subjected to pressure from a screw-down mechanism including a screw-down motor **23** and a screw-down control unit **24**. A load sensing means in the form of a load cell **25** is disposed above roll chock **22** between the chock and frame **15**. Load cell **25** produces on a lead **26** a sensed force F_a signal, i.e., an electrical signal which varies in amplitude in accordance with the force exerted by the strip **10** on the work rolls **16** and **17**.

The fifth stand **12** is like stand **11** in that stand **12** is comprised of frame **15'**, lower and upper work rolls **16'** and **17'**, and driven by motor **20'**, a lower back-up roll **18'** in chock **19'**, and upper back-up roll **21'** in vertically slidable chock **22'**, a screw-down motor **23'** controlled by screw-down control unit **24'** for exerting adjustable pressure on chock **22'**, and a load-cell **25'** productive on lead **26'** of an electrical F'_a signal representative in amplitude of the force exerted on rolls **16'** and **17'** from the strip **10**. As distinct from stand **11**, however, stand **12** also includes a fast-acting force-generator means **30** interposed between chock **22'** and the screw-down mechanism for that chock. Device **30** is preferably a wedge actuator such as is disclosed in U.S. Patent 3,197,986 (Freedman et al.) or in copending application Ser. No. 405,749 filed Oct. 22, 1964 and owned by the assignee hereof.

In the operation of the shown installation, the work rolls **16** and **17** of stand **11** reduce the thickness of strip **10**, and a further reduction in strip thickness is effected by the work rolls **16'** and **17'** of stand **12**. In stand **11**, the thickness of the emerging strip depends upon the load on the stand and the initial position setting of the screw-down mechanism for that stand. Over the long term, the load on stand **12** is determined by the positional setting of the screw-down mechanism for the latter stand. The short term loading on stand **12** and the output thickness of the strip from that stand are, however, primarily determined by a control system of which the device **30** forms a part, and which control system will now be described in detail.

While the sensed force or F_a signal from load cell **25** is representative of the force exerted from the strip on the work rolls **16** and **17** of stand **11**, that signal is also representative of the output thickness of the strip emerging from that stand. Hence, such F_a signal is also representative of the input thickness of strip **10** in relation to stand **12**.

Conventionally, the input thickness signal for stand **12** would be derived from an X-ray thickness gauge and should be corrected for gross changes in one or more of the parameters of the rolling operation such as the chemistry (i.e., composition) of the strip and its hardness and temperature. The F_a signal from load cell **25** is, however inherently sensitive to the changes in the aforementioned variables, and, accordingly, is superior to a signal derived from an X-ray gauge as an input thickness signal for stand **12**.

Moreover, load cell **25** has a very fast response to changes in the force exerted from strip **10** on work rolls **16** and **17**. Accordingly, the F_a signal from load cell **25** is adapted to manifest rapid changes in thickness of the input strip to stand **12** as rapid fluctuations in the amplitude of the load cell signal F_a.

The F_a signal from load cell **25** is fed via lead **26** to the summing amplifier **50**. Another input to amplifier **50** is a signal F_r from lead **46** which is opposite in polarity to F_a. The F_r signal is obtained from the lock-on device **45** and works as follows. As the leading edge of the strip **10** is sensed by strip detector **37**, which may be, for example, a photocell, the blade **34** of a switching means contacts a contact **40** and connects one output of amplifier **50** to the lock-on device **45**. This signal is integrated until a small predetermined error exists at the output of amplifier **50**, at which time the blade **34** is switched to contact **47** which is at ground reference, and the integrated signal F_r is held at the output of unit **45** at that point until the tail end of the strip leaves the stand.

Because the input signals F_a and F_r to amplifier **50** are of opposite polarity, the amplifier provides as an output on lead **51** a signal ΔF which is representative in magnitude and polarity of the deviation of the F_a signal from the F_r signal. Hence, the F_r signal acts as a reference signal for the F_a signal. While the F_r signal is indicative of a reference level for the force from strip **10** on the work rolls of stand **11**, the F_r signal is also representative of a reference level for the thickness of the input strip to stand **12** in the same way as the F_a signal is representative of the instantaneous variations in thickness of such input strip. Note, moreover, that the F_r signal represents a thickness reference level which is automatically set by the leading portion of strip **10** itself rather than a reference thickness level set in accordance with the judgment of the operator of the mill. Hence, the ΔF signal is representative of the instantaneous deviation in thickness of the input strip to stand **12** from a reference thickness level set for that particular strip by the measured average thickness of the leading portion of such strip.

The analog ΔF signal on lead **51** is converted by analog-to-digital converter **60** to digital form and is then passed through a delay device **61** which may be, say, a digital shift register. Device **61** is controlled by shift pulses from a tachometer **62** driven by work roll **17** so as to cause the ΔF signal to be delayed in device **61** for a time just equal to that required for the strip portion whose thickness is then represented by the ΔF signal to pass from the bite between the work rolls of stand **11** to the bite between the work rolls of stand **12**. However, due to the fact the back-up rolls **18** and **21** may be eccen-

tric and cause fluctuation 180 degrees out of phase with the ΔF signal, the delay may be adjusted so that the delay is advanced one half of the circumference of the back-up roll, thus putting this signal in phase with actual thickness variation and the roll gap of stand **12**. Hence, the ΔF signal at the output of device **61** represents at any instant the thickness value of the portion of strip which is just entering the bite between the work rolls of stand **12**. To make that output ΔF signal more convenient to operate on, it is reconverted by a digital-to-analog converter **63** into analog form. From converter **63**, the analog ΔF signal is fed by lead **64** as a correction signal to a closed loop system which provides the primary thickness control for stand **12**, and which is as follows.

Load cell **25'** of stand **12** generates on lead **26'**, a sensed force signal F'_a representative of the force exerted from strip **10** on the work roll **16'**, **17'** of that stand. The F'_a signal is led to the input of amplifier **90** where another input signal from lead **46'** KF'_r is opposite in polarity to F'_a. The KF'_r signal is obtained from modifying the F'_r signal by the temperature of the strip entering stand **12** sensed by temperature gauge **91**. This process is accomplished in block **70** where the F'_r signal is weighted as a function of the temperature of the strip. The second lock-on device works the same as the first except for the fact that temperature is also included. Amplifier **90** sums the F'_a and KF'_r signals of opposite polarity, as a differential amplifier which produces on its output lead **91** a ΔF' signal representative of the magnitude and polarity of the deviation in amplitude of the F'_a signal from a reference force level represented by the KF'_r signal and established by the leading portion of strip **10**. Because the KF'_r component of the ΔF' signal is provided as described by lock-on unit **45'**, the force deviation represented by the ΔF' signal is a deviation from a reference level of force which is automatically set by the strip itself rather than being set in accordance with the judgment of the operator of the mill.

The ΔF' signal on lead **91** is supplied to the input of a summing amplifier **95** providing an output error signal F_c. During the period when lock-on unit **45'** is building up signal F'_r, error signal F_c is disconnected. When blade **40'** disconnects ΔF' from unit **45**, a second blade **81** connects to point **82**, thereby coupling F_c by lead **96** to force-generator device **30** to control the force exerted by that device on chock **22'** and load cell **25'**. Elements **25'**, **90**, **95**, and **30** thus form a closed loop servo system providing the main thickness control loop for stand **12**.

If that control loop were to be energized only by the signals F'_a and KF'_r, the loop would operate to actuate device **30** to equalize the force F'_a exerted thereby to the reference force level FK'_r. That is, the operation of the loop would be such that if constant thickness but varying temp strip were entering the stand the system would produce constant thickness strip leaving the stand.

However, due to the fact that the entering strip will not only vary in temperature, but thickness, the system makes use of the ΔF signal to command the force exerted by device **30** to reduce the thickness of the strip passing through work rolls **16'** and **17'** to a desired output thickness value.

As stated, the ΔF signal on lead **64** represents the instantaneous deviation in thickness of the input strip to stand **12** from a nominal or reference thickness set for that whole strip by the leading portion of said strip. That ΔF signal is passed through a signal-mixing network **100** where it is modified to become a KΔF signal by exteriorly introduced constant correction signals K_1, K_2, K_3 which may, for example, be representative of, respectively, (a) the type of material of which strip **10** is formed, (b) a nominal thickness for the strip between the stands **11** and **12**, and (c) the width of the strip material. The KΔF signal is then supplied via lead **101** (and with a polarity opposite to that of the ΔF' signal) to an input of summing amplifier **95** separate from the amplifier input for the ΔF' signal.

For the purpose of using the tension of the strip as a factor in the computation of the control signal F_c, loopers **105** and **106** develop respectively corresponding signals t_1 and t_2 which are representative of, respectively, the tension of the strip between stands **11** and **12** and the tension of the strip on the output side of stand **12**. The t_1 and t_2 signals are passed through respective signal weighting networks **107**, **108** (e.g., potentiometers) and are then combined in a summing amplifier **109** to produce on an output lead **110** for that amplifier an instantaneous tension signal $t(-)$. If constant tension loopers are employed, this signal may be omitted from the control.

The thickness of strip **10** on the output side of the last stand (not shown) is monitored by a follow-on thickness gauge **115**, for example, an X-ray gauge, developing a ΔG_2 signal which is representative of the deviation, if any, of the output thickness of the strip from a desired output thickness therefor. High frequency variations in the ΔG_2 signal are removed by a low pass filter **116**. Hence, on the output lead **117** from the filter, the ΔG_2 signal is representative only of long term variations in the output thickness of the strip. As disclosed in application Ser. No. 565,526 filed July 15, 1966 and owned by the assignee hereof, such ΔG_2 signal from the follow-on gauge is adapted to correct for steady state errors produced by the control system because of drift in the gain of the summing amplifiers or similar long term changes in the other operating parameters of the system.

Finally, the described control system provides for the introduction thereinto on a lead **120** of a manually set M signal adapted to be set to a value which will compensate for any residual inaccuracy in the operation of the control system.

The *t* signal on lead **110**, the ΔG_2 signal on lead **117** and M signal on lead **120** are supplied to separate inputs of a summing amplifier **125** to provide on an output lead **126** for that amplifier an S signal representative of the combined inputs to that amplifier. The S signal is supplied to amplifier **95** as an input in addition to the ΔF' and KΔF signals applied thereto. By virtue of its summing action, that amplifier renders the F_c error signal on lead **96** a function of each of the input signals supplied to that amplifier.

Thus, the shown system computes the force to be applied by device **30** as a function of all the signals which have been described. The computed force value is the force value represented by the error signal F_c, and is the whole force value calculated as being required to be exerted by force generator **30** in order to minimize variations in thickness in the strip emerging from stand **12**. Roughly speaking:

$$F'_a = KF'_r + \sum_{i=1}^{i=j} C_i$$

where the term C_i represents the correction effect in the closed loop of the *i*th one of the desecribed correction signals.

The overall operation for one run of the shown installation is as follows. The strip **10** to be reduced in thickness during that run is advanced through the stands of the installation. When the front end of the strip passes strip detector **37**, the resulting signal actuates the first lock-on unit **45**. That unit develops from the F_a signal a held reference F_r signal representative of the average force in the stand for the leading portion of the strip. Once the lock-on is complete, the output of summing amplifier **50** produces a ΔF signal representative of the deviation of the F_a signal from the F_r signal. After being delayed by unit **61** for the time required for the strip portion whose thickness deviation is represented by ΔF to move from the bite between the work rolls of stand **11** to

the bite between the work rolls of stand **12**, the ΔF signal is applied to the force-computing closed-loop thickness control system of stand **12** as one of the major correction signals for that system.

In the closed loop system for stand **12**, the signal from strip detector **37'** causes the second lock-on unit **45'** to activate. The second lock-on unit **45'** develops from the F'_a signal a reference signal KF'_r representative of the average force in the stand for the leading portion of the strip modified by the instantaneous temperature changes in the strip. At the end of the second lock-on, summing amplifier **90** produces the $\Delta F'$ force signal for closed loop computation.

Also included in that loop is summing amplifier **95** by which the correction signal ΔF is injected into the loop after being weighted by the factor K determined by three "trimming" or correction signals K_1, K_2 and K_3. Other correction signals directly or indirectly introduced into the loop are the previously described signals T, t_1, t_2, G_2 and M.

In response to all the mentioned signals, the control system computes a force error signal F_c which controls directly the amount of force exerted by force generator **30** on elements **22'** and **25'**, and, indirectly, the thickness reduction instantaneously effected on strip **10** by the work rolls **16'** and **17'** of stand **12.**

The above-described embodiments being exemplary only, it is to be understood that additions thereto, modifications thereof and omissions therefrom can be made without departing from the spirit of the invention and, that the invention comprehends embodiments differing in form and/or detail from that embodiment which has been specifically described. For example, the invention is applicable to installations having more or less than six stands and to installations wherein the control system is associated with stands other than the two stands which have been specifically described. Accordingly, the invention is not to be considered as limited save as is consonant with the recitals of the following claims.

We claim:

1. In a mill control system in which material moves through successive stands and passes in each stand through adjustable working means to be reduced in thickness in accordance with the adjustment of such means, and in which force-computation means responds to a sensed force signal representative of force from said material on the working means of one of said stands to control force-generator means to apply to such working means a force which adjusts such means and is of a value computed as being that required to produce a desired thickness reducing action on said material by said working means, the improvement comprising, load-sensing means coupled to the working means of a stand preceding said one stand and responsive to force from said material on said latter working means to develop an additional signal representative of said last-named force, and means to supply a correction signal which is a function of said additional signal as an input to said force-computation means so as to render the control of said force-generator means a function of both said sensed force signal and said correction signal.

2. The improvement as in claim **1** further comprising, time-integrator lock-on means responsive to an input signal thereto to provide a held output which is a function of such signal as integrated over a time period during which said material is first passing through said one stand, signal-combining means responsive to two respective signal inputs thereto to supply to said force-computation means an output which is a function of the difference between such signal inputs, and switching means operable during said time period to connect said sensed force signal to said input of said lock-on means and operable thereafter to connect said sensed force signal and said output of said lock-on means in opposition as said respective inputs to said signal-combining means to thereby render said control of said force-generator means a function of said difference.

3. The improvement as in claim **2** further comprising, additional time integrator lock-on means responsive to an input signal thereto to provide a held output representative of such signal as integrated over a time interval during which said material is first passing through said preceding stand, additional signal combining means responsive to two respective signal inputs thereto to supply to said force-computation means an output which is a function of the difference between such two inputs, and switching means operable during said interval to connect said additional signal to the input of said additional lock-on means and operable thereafter to connect said additional signal and said output of such lock-on means in opposition as said respective inputs to said additional signal-combining means so as to render said output from said signal-combining means a function of the difference between said additional signal and said output from said additional lock-on means.

4. In a mill control system in which material moves through successive stands and passes in each stand through adjustable working means to be reduced in thickness in accordance with the adjustment of such means, and in which force-computation means responds to a sensed force signal representative of force from said material on the working means of one of said stands to control force-generator means to apply to such working means a force which adjusts such means and is of a value computed as being that required to produce a desired thickness reducing action on said material by said working means, the improvement comprising, time-integrator lock-on means responsive to an input signal thereto to provide a held output which is a function of such signal as integrated over a time period during which said material is first passed through said one stand, signal-combining means responsive to two respective signal inputs thereto to supply to said force computation means an output which is a function of the difference between such signal inputs to said signal-combining means, and switching means operable during said time period to connect said sensed force signal to said input of said lock-on means and operable thereafter to connect said sensed force signal and said output of said lock-on means in opposition as said respective signal inputs to said signal-combining means to thereby render said control of said force-generator means a function of the difference between said sensed force signal and said output of said lock-on means.

5. In a mill control system in which material moves through successive stands and passes in each stand through adjustable working means to be reduced in thickness in accordance with the adjustment of such means, the improvement comprising, first and second load-sensing means of which each is associated with a respective one of two of said stands, each of said load-sensing means being responsive to the force from said material on the working means of the corresponding stand to produce a sensed force signal which is a function of that force, first and second time-integrator lock-on means associated with, respectively, said first and second load sensing means and each responsive to an input to provide a held output which is representative of such input as integrated over a time period of operation for that lock-on means during which said material is passing through the stand corresponding to that lock-on means, first and second signal-combining means associated with, respectively, said first and second lock-on means and each being responsive to two respective signal inputs from said lock-on means and said load sensing means to provide an output which is a function of the difference between such inputs, first switching means operable at the start of the integrating time period for said first lock-on means to connect said output of said signal-combining means as said input to said first lock-on means, and operable after such time period to disconnect said

output from said input of said lock-on means, second switching means operable at the start of the integrating time period for said second lock-on means to connect said output of said signal-combining means as said input to said second lock-on means, and operable after such time period to disconnect said output from said input of said lock-on means and thickness control means responsive to the respective outputs of said two signal-combining means after each is receiving said respective signal inputs thereof to control the thickness reducing action of the working means of at least one of said two stands as a function of each of said two sensed force signals and each of the respective outputs of said two lock-on means.

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CHARLES W. LANHAM, *Primary Examiner.*

A. RUDERMAN, *Assistant Examiner.*

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