# United States Patent

[11] 3,628,358



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[21] Appl. No. **864,414**
[22] Filed **Oct. 7, 1969**
[45] Patented **Dec. 21, 1971**
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## [54] METHOD OF REVISING WORKPIECE TEMPERATURE ESTIMATES OR MEASUREMENTS USING WORKPIECE DEFORMATION BEHAVIOR

**4 Claims, 4 Drawing Figs.**


[52] U.S. Cl. ..... 72/8, 72/19
[51] Int. Cl. ..... B21b 37/00
[50] Field of Search ..... 72/8–13



[56] **References Cited**

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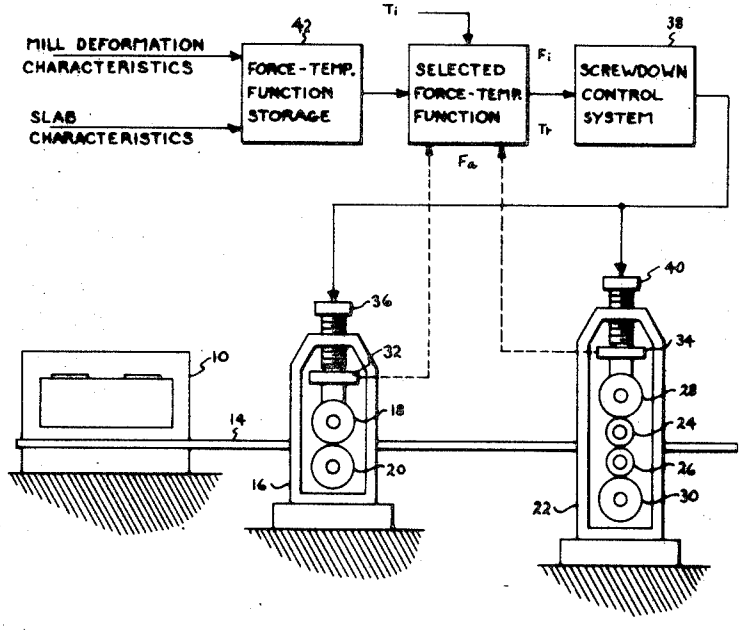
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**ABSTRACT:** For use in setting up a rolling mill, a method of revising an estimate or measurement of workpiece temperature based on prior deformation behavior of the workpiece. According to the method, roll forces are expressed as functions of workpiece temperatures for different rolling conditions. Prior to a rolling pass during which a revised temperature is to be established, one of these functions is selected on the basis of anticipated rolling conditions. Using an initially established temperature, the selected function yields a predicted roll force value. When the rolling pass is executed, a measured roll force value is used with the selected function to establish an apparent workpiece temperature. The revised temperature, taken for purposes of stability to be an average of the initially established temperature and the apparent temperature, is used in force and draft calculations needed for setting up the rolling mill for upcoming rolling passes.

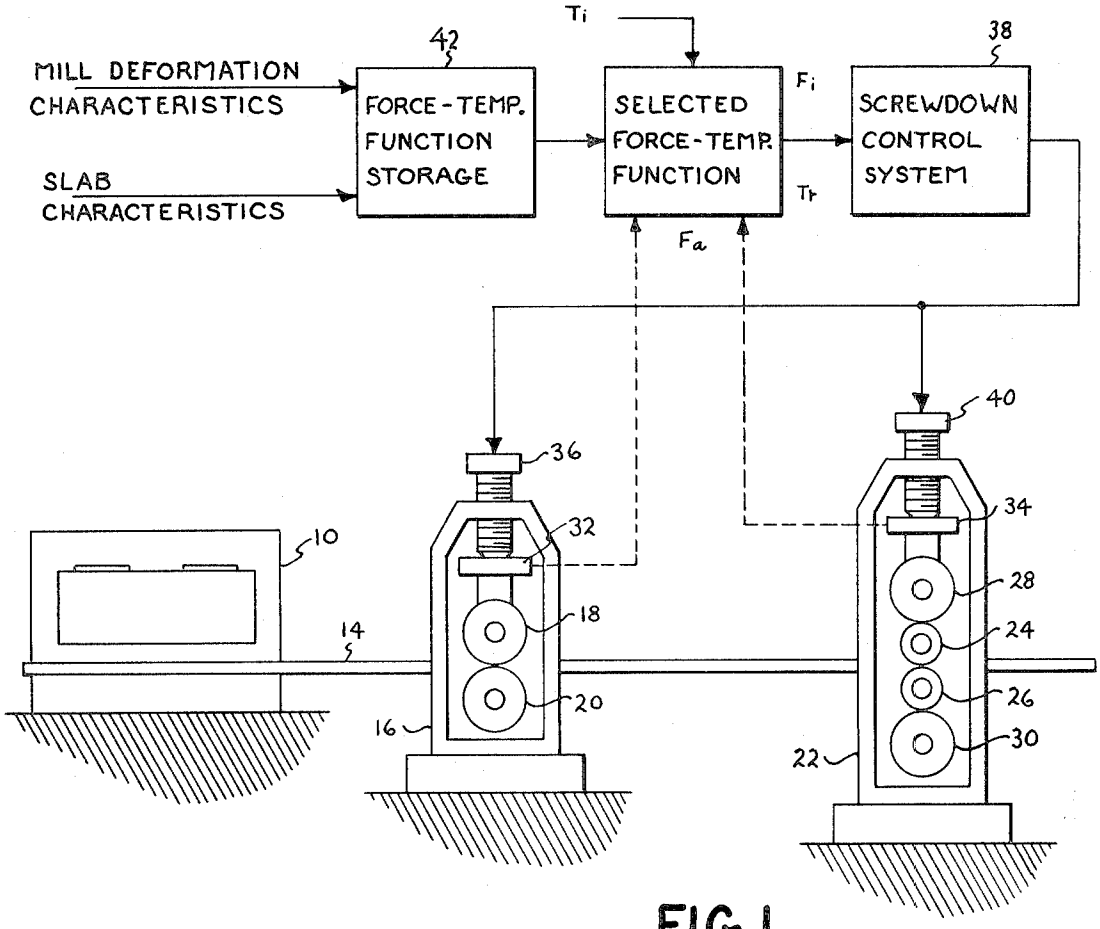
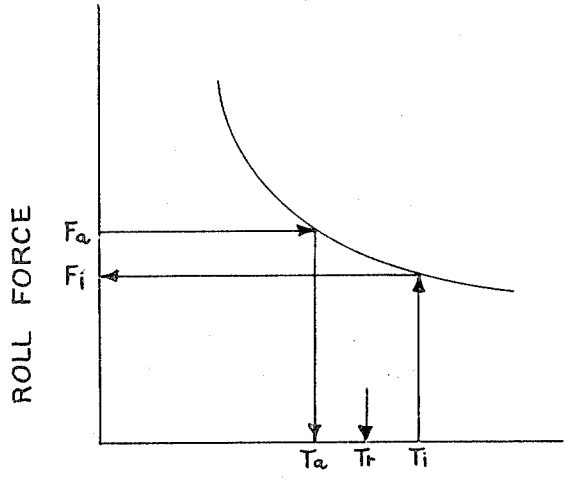



FIG. 1

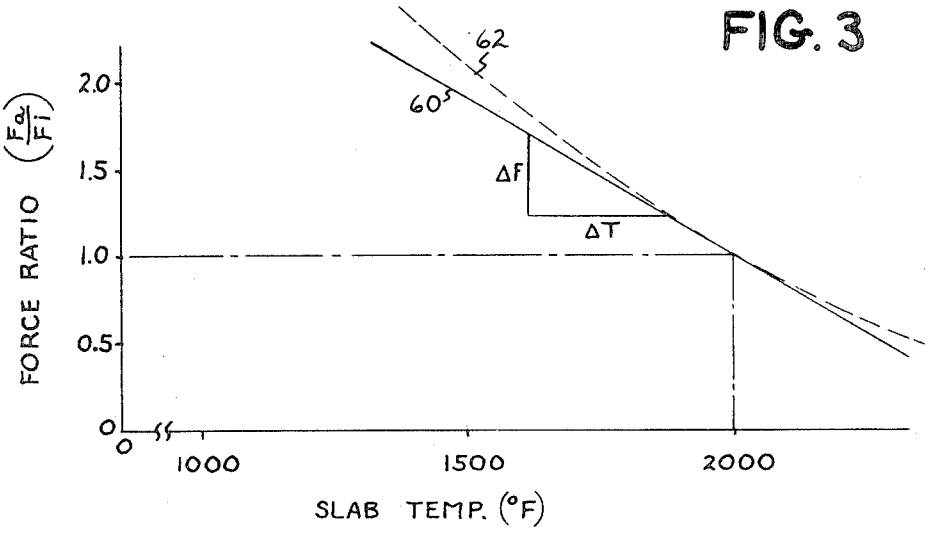



$$T_r = \frac{T_a + T_i}{2}$$

FIG. 2

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FIG. 3


62
60
ΔF
ΔT
2.0
1.5
1.0
0.5
0
FORCE RATIO (Fa/Fi)
0
1000
1500
2000
SLAB TEMP. (°F)

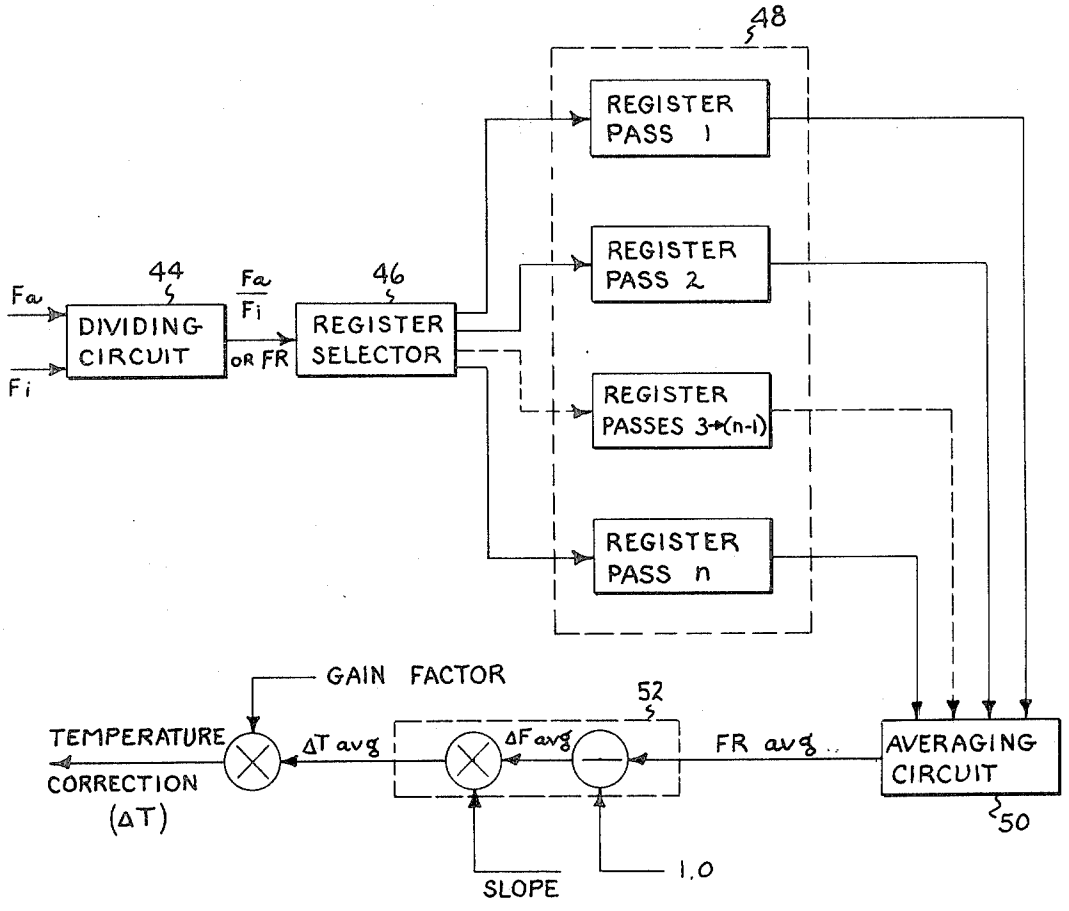

48
REGISTER PASS 1
REGISTER PASS 2
REGISTER PASSES 3→(n-1)
REGISTER PASS n
Fa
Fi
44
DIVIDING CIRCUIT
Fa/Fi
OR FR
46
REGISTER SELECTOR
GAIN FACTOR
52
TEMPERATURE CORRECTION (ΔT)
ΔT avg
ΔF avg
FR avg
AVERAGING CIRCUIT
50
SLOPE
1.0

FIG. 4

# METHOD OF REVISING WORKPIECE TEMPERATURE ESTIMATES OR MEASUREMENTS USING WORKPIECE DEFORMATION BEHAVIOR

## BACKGROUND OF THE INVENTION

The present invention relates to the art of metal deforming and more particularly to the art of revising workpiece temperatures for use in setting up a metal rolling mill.

One of the first steps in the rolling of metal plates or strips is the reheating of previously produced slabs to a temperature of around 2,200° F. by passing them through an oil- or gas-fired furnace known as a reheat furnace. In nearly all existing installations the reheat furnace, which may hold 20 or more slabs at a single time, is controlled by a furnace operator who manipulates fuel and airflow rates and, to some extent, slab movement rates in an attempt to heat each slab to a predetermined target temperature by the time the slab leaves the furnace on its way to the rolling mill. While skilled furnace operators can do an excellent job on the average, unexpected delays often occur which prevent even skilled operators from reheating each and every slab to the target temperature.

For this reason, the actual temperature of the workpiece to be rolled may be quite important in setting up the rolling mill, particularly during final reductions. The effects of workpiece temperature on the rolling process are twofold. First, the workpiece temperature influences the resistance to deformation of the workpiece. That is, a hotter workpiece has a lower resistance to deformation (requires less roll force before it will be deformed by a given amount) than a colder workpiece of similar composition and dimensions. The workpiece temperature must, therefore, be considered in determining the roll force which will be required to deform a workpiece by a given amount. Second, the cold physical properties of a workpiece are influenced by the temperature pattern during the final reductions of the workpiece. If the temperature is known, the temperature pattern may be more accurately controlled during final reductions to impart desired physical properties to the finished workpiece.

There are, of course, known methods for measuring or estimating the actual temperature of a workpiece although these methods are known to have drawbacks which make it necessary to revise slab temperature estimates once rolling has begun. One widely used technique is to place a pyrometer at the exit from the reheat furnace to measure the temperature of an emerging slab. It is believed desirable to be able to revise pyrometer measurements of the actual temperature of a workpiece since a pyrometer output may deteriorate in the rugged and pernicious environment of a rolling mill. Another method of obtaining an initial slab temperature is to estimate the temperature based on knowledge of fuel flow to the reheat furnace, slab movement rates through the reheat furnace, and slab dimensions. It should be recognized that such an estimate may require subsequent revision since it is based on several measured quantities and does not necessarily take into account the thermal energy supplied to individual slabs, but only to groups of slabs reheated at the same time.

## SUMMARY OF THE INVENTION

The present invention is a method of revising initial estimates or measurements of workpiece temperatures for use in setting up the rolling mill for future rolling passes. Based on anticipated rolling conditions during an upcoming rolling pass, a roll force value is predicted. When the rolling pass is executed, the extant roll force is measured. A revised workpiece temperature is established as a function of the difference between the measured and the predicted roll forces. A revised workpiece temperature, in the range between the initial estimate or measurement and the apparent temperature, is used in setting up the rolling mill for upcoming rolling passes.

## DESCRIPTION OF THE DRAWINGS

While the specification concludes with claims particularly pointing out and distinctly claiming that which is regarded as the present invention, certain details of a preferred embodiment of the invention may be more readily ascertained from the following detailed description when read in conjunction with the accompanying drawing in which:

FIG. 1 shows in simplified form the components of a metals rolling mill in which the present invention may be practiced;

FIG. 2 is a representative curve expressing roll force as a function of workpiece temperature;

FIG. 3 is a linearized force ratio-workpiece temperature curve used in a particular embodiment of the invention; and

FIG. 4 is a block diagram of a circuit which may be used in a particular embodiment of the invention.

## DETAILED DESCRIPTION

Referring now to FIG. 1, a metal rolling mill in which the present invention is to be used includes a reheat furnace 10 for reheating slabs to a temperature in the range of 2,200° F. before they are discharged in succession from the furnace 10 onto a mill table 14. The initial reductions in the slab thickness may be taken in one or more rolling passes through a roughing mill stand 16 which may consist of an upper work roll 18 and a lower work roll 20. The roughing mill stand 16 is normally a reversing mill in which the slab passes back and forth between the successively more closely set rolls 18 and 20 until the desired reduction in thickness is accomplished. After the initial reductions have been made, the slab may be transferred to a finishing mill stand 22 including upper and lower work rolls 24 and 26, respectively, and upper and lower backup rolls 28 and 30, respectively. In a preferred embodiment, the roughing mill stand 16 includes a force transducer such as a load cell 32 for measuring the roll force produced as a slab passes between the work rolls 18 and 20 of the roughing mill 16. The finishing mill stand 22 may include a similar load cell 34. In roughing mill stand 16, load cell 32 is interposed between the upper work roll 18 and a roll-adjusting screw 36 which is operated by a screwdown control system 38 to regulate the opening between work rolls 18 and 20. In finishing mill stand 22, load cell 34 is interposed between upper backup roll 34 and a roll-adjusting screw 40 also operated by screwdown control system 38.

One of the initial steps in designing a control system for a mill such as the one shown in greatly simplified form in FIG. 1 is the accumulation of vast amounts of data during the rolling of slabs of different compositions to different final gages under various rolling conditions. The term rolling conditions is one which includes known factors such as planned drafts, mill deformation characteristics, and slab characteristics such as composition, dimensions and temperature. Analysis of this data shows that when all of the other conditions are held constant, the extant roll force during a rolling pass may be expressed as a function of the extant slab temperature. Referring to FIG. 2, the function is a generally inverse one as would be expected.

The curve shown in FIG. 2 is a representative curve in a family of curves in which each curve expresses the relationship between roll force and slab temperature for a different set of rolling conditions. The functions represented by these curves are used to revise initially established slab temperatures in accordance with the following method. When the proper force-temperature function for an upcoming rolling pass has been selected from a function storage means 42 through the specification of the planned draft, the mill deformation characteristics, and the slab characteristics other than slab temperature, that curve is entered with an initially established temperature $T_i$ to extract a value $F_i$ for the roll force which is expected during the rolling pass. The particular manner in which temperature $T_i$ is initially established is not critical to the present invention. Temperature $T_i$ may be obtained by pyrometer measurement, by estimates based on temperature drops during passes, or (as will be explained in more detail below) by repeated use of the present invention.

When the upcoming rolling pass is executed in mill stand 16 or 22, the appropriate load cell 32 or 34 is used to measure the actual, extant roll force $F_a$. Once $F_a$ is known, the curve originally used to predict $F_f$ is reentered with $F_a$ to extract a value $T_a$ for the apparent temperature of the slab.

While it would be possible to substitute the apparent temperature $T_a$ for the initially established temperature $T_f$, a stabilizing effect is introduced into the system by selecting a revised temperature $T_r$ somewhere in the range between the initially established temperature $T_f$ and the apparent temperature $T_a$. In a preferred embodiment of the invention, the revised temperature $T_r$ is established as the average of the initially established temperature $T_f$ and the apparent temperature $T_a$. The revised temperature $T_r$ made available by this method is then used in screwdown control system 38 in force and draft calculations needed in order to determine the proper position for the appropriate roll-adjusting screw 36 or 40 during upcoming rolling passes.

The details of screwdown control system 38 have been purposely omitted since the present invention is suitable for use with any system in which slab temperature is a necessary input.

The present invention lends itself to successive revision and refinement of estimated slab temperatures. For the first pass of a slab through a rolling mill, the initially established temperature $T_f$ may be derived from a pyrometer output or from an estimate based on the parameters of the reheating process. When the first pass is completed, the first revised temperature $T_r$ may be used as a preferred replacement for an initially established temperature for the second pass. The step of using the revised temperature from one pass as the initially established temperature for the succeeding pass may be repeated for each pass in an entire rolling schedule, including both initial and final reductions.

However, the slab temperature is not critical during the initial reductions since the resistance to deformation of a thick slab is relatively constant and the physical properties of a finished slab are altered very little by the pattern of the initial reductions. For this reason, a possible technique for using the present invention may be to determine a revised temperature $T_r$ only during the last pass of the slab through the roughing mill stand 16. In this manner the relationship between calculated and observed forces for all roughing passes can be reflected in the revised temperature $T_r$. Upon transferring the slab to the finishing mill stand 22, the revised temperature $T_r$ is used in future force and draft calculations.

A disadvantage of this particular technique is that it assumes the force measurement taken during the last pass is representative of the deformation behavior during all of the preceding passes. There is, however, no way of determining whether the deformation behavior during the last pass is characteristic of earlier behavior. To avoid reliance on a single force measurement, a temperature-averaging technique may be preferred.

According to the preferred technique, an apparent temperature $T_a$ is calculated in the described manner during each pass through the roughing mill stand. Following each pass, the difference between the initially established temperature $T_f$ and the apparent temperature $T_a$ is calculated and stored. Following the last pass through the roughing mill stand, the difference $(T_f-T_a)$ for all of the passes are averaged. The initially established transfer temperature (the temperature at which the slab is transferred to the finishing mill stand) is then modified by the average of the differences to obtain an apparent transfer temperature. While this apparent temperature might be used in the finishing mill stand force and draft calculations without modification, system stability may be enhanced by using a gain factor which would establish a revised temperature in the range between the apparent and the initially established transfer temperature.

The temperature difference averaging technique requires that an initially established temperature $T_f$ be available for each pass included in the averaging process. The temperature $T_f$ for the first pass may be taken from a pyrometer at the exit from the slab reheating furnace. Because of radiant and conductive heat losses in the roughing mill stand, the initially established temperature for the later passes will naturally be lower. The approximate temperature drops or thermal rundowns which may be expected during successive passes are well known to those skilled in the art, however, making it a simple matter to derive a temperature $T_f$ for each pass in a rolling schedule.

In still another embodiment of the invention, the number of calculations needed to carry out the invention is reduced by use of force ratio calculations which are performed for other purposes. This embodiment is based on the assumption that the force-temperature relationship may be considered to be a linear one in the region of the roughing temperatures, which typically range from 2,000° to 2,200° F. Referring to FIG. 3, the force-temperature relationship is expressed as a function of the slab temperature and a force ratio established by dividing the initially established or predicted force $F_f$ into the apparent or measured force $F_a$. If a slab is at a planned temperature, the measured force equals the predicted force, yielding a force ratio value of 1.0. If the measured forces are greater than the predicted forces (the force ratio is greater than 1.0) the slab temperature is apparently lower than the planned temperature. Similarly, where the measured forces are less than the predicted forces (the ratio is less than 1.0) the slab temperature is apparently greater than the planned temperature. The approximately linear relationship between the force ratio and the slab temperature in the roughing temperature range is illustrated in FIG. 3. This relationship makes it possible to use a circuit such as that illustrated in FIG. 4 in determining the revised transfer temperature.

During each pass through the roughing mill stand, signals which may be either analog or digital in form are applied to a dividing circuit 44 which provides an output force ratio FR equal to $F_a/F_f$. Each force ratio is transmitted through a register selector 46 which routes it to a different register in a register bank 48. The number of registers in the register bank 48 depends on the number of force ratios which are to be stored during any one rolling schedule through a roughing mill stand. When the passes in the roughing mill stand schedule have been carried out and force ratios have been computed and stored for each pass, the stored ratios are applied to an averaging circuit 50 which determines the average force ratio (FR ave.) over the entire roughing schedule. If the average force has been 20 percent greater than the average initially predicted force over all the passes through the roughing mill stand, this average force ratio would have a value such as 1.2.

A linear approximation 60 of the 2,000° F. region of the curve 62 illustrated in FIG. 3 would take the form $X=MY+B$ where $X$ is the slab temperature in Fahrenheit degrees, $M$ is the slope of the curve in Fahrenheit degrees per unit force, $Y$ is the average force ratio, and $B$ is the X-intercept of the linear curve. Observations have shown that a 100° F. deviation in slab temperature will cause a 20 to 25 percent deviation in the measured force relative to the predicted force. Therefore, the slope of the linear curve is on the order of −400° F./ΔF to −500° F./ΔF where ΔF represents a percentage deviation of measured forces relative to predicted forces. For purposes of this illustration, it may be assumed that the slope of the line is −500° F./ΔF. Knowing this slope, a deviation from expected roll force can be converted into a corresponding deviation from expected temperature through the relationship $T=-500\Delta F$. Thus, for example, a force ratio of 1.2, signifying a 20 percent deviation from predicted force, would indicate a −500×0.20 or −100° F. deviation from expected temperature. A function generator 52 converts the average force ratio to an average force deviation and multiplies this by a signal representing slope to obtain a signal representing an average temperature deviation. Multiplication by a stabilizing gain factor yields a temperature correction that may be used in deriving an improved estimate of transfer temperature to be used in later calculations.

Each of the elements described in block diagram form in connection with FIG. 4 may be analog, digital or hybrid in form. Since circuits which can perform the particular functions illustrated are themselves conventional, they are not described in detail.

While the invention has been described with reference to a rolling mill having separate roughing and finishing stands, it should further be recognized that the technique may similarly be applied to a single mill stand by dividing the rolling schedule into two arbitrary phases. The purpose of the roughing phase is to reduce and thereby elongate the slab to a desired length. When the desired length is obtained, the slab is turned 90° making the slab length the width of the finished plate. The turning marks the end of the roughing phase and the beginning of the finishing phase to be carried out in the same stand.

Where this type of mill and rolling schedule are used, a revised temperature $T_r$ might first be obtained during the last pass prior to turning the slab or by use of the described force ratio averaging or temperature difference averaging techniques applied to several of the passes during the roughing phase.

We claim:

1. For use in operating a rolling mill having means for measuring extant roll forces during sequential rolling operations in roughing and finishing mills where roll forces are known as functions of workpiece temperatures for diverse rolling conditions, a method of revising an initially established workpiece temperature comprising the steps of:

a. selecting at least one roll force-workpiece temperature function corresponding to the dimensions, composition and planned drafts of the workpiece for a plurality of rolling operations in the roughing mill,

b. establishing initial temperatures of said workpiece at which rolling is anticipated to occur during said plurality of rolling operations in said roughing mill,

c. theoretically predicting from said selected roll force-workpiece temperature functions the roll forces which should occur during each of said plurality of roughing mill rolling operations for the initially established temperatures of the workpiece,

d. measuring the roll forces which actually do occur during the plurality of roughing mill rolling operations,

e. entering each of the selected functions with the appropriate measured roll forces to obtain the temperature values associated with the measured roll forces for each of said plurality of roughing mill rolling operations,

f. establishing the differences between the initially established temperatures and the temperature values associated with the measured roll forces for each of the plurality of roughing mill rolling operations,

g. averaging the temperature differences obtained during each of the plurality of rolling operations of the roughing mill, and

h. revising the initially established temperature of the workpiece as a function of the average temperature difference only upon entry of the workpiece into the finishing mill to obtain a revised temperature to be used in calculating force and draft in the finishing mill.

2. For use in setting up a rolling mill for executing finishing phase rolling operations when the mill includes means for measuring extant roll forces during at least one roughing phase rolling operation and roll forces are known as functions of workpiece temperature for different dimensions, compositions and planned drafts of the workpiece, the method of revising an initially established value of workpiece transfer temperature at the beginning of the finishing phase comprising the steps of:

a. selecting a roll force-workpiece temperature function in accordance with the dimension, composition and planned draft of the workpiece for at least one roughing mill rolling operation,

b. establishing the initial temperature of said workpiece at which rolling is anticipated to occur during said roughing mill rolling operation,

c. predicting from said roll force-workpiece temperature function the roll forces which should occur during said roughing mill rolling operation for the initially established temperature of the workpiece,

d. measuring the roll forces which actually do occur during the roughing phase operation,

e. obtaining the quotient of the theoretically predicted roll force and the actually measured roll force utilizing electronic dividing means to obtain a force ratio,

f. determining the temperature difference corresponding to said force ratio by accessing selected functions defining force ratio as a function of workpiece temperature, and

g. modifying the initially established value of workpiece transfer temperature at the initiation of the finishing phase by an amount proportional to the temperature difference determined from the force ratio.

3. A method of revising an initially established value of workpiece transfer temperature according to claim 2 further including averaging the force ratio over a plurality of roughing phase rolling operations to obtain an average force ratio, determining the temperature difference corresponding to said average force ratio and modifying the workpiece transfer temperature by the temperature difference corresponding to the average force ratio.

4. An apparatus for use in a rolling mill having means for measuring roll forces during at least one rolling operation where the ratio of measured to predicted roll forces are expressed as inverse approximately linear functions of workpiece temperatures for different rolling conditions, said apparatus including:

a. dividing means having one input corresponding to the roll force required at a rolling stand to produce an anticipated draft in a workpiece of known composition and dimension at an initially established temperature and a second input corresponding to the roll force actually measured at the rolling stand, said dividing means establishing a ratio of measured to predicted roll force for at least one rolling operation,

b. storage means connected to said dividing means for receiving and storing each of said force ratios,

c. averaging means connected to said storage means for calculating an average force ratio,

d. function-generating means having inputs representing the average force ratio and the slope of the approximately linear function defining workpiece temperature as a function of force ratio, said function-generating means producing an output signal corresponding to the workpiece temperature deviation between the calculated average force ratio and a force ratio of 1.0, and

e. means for varying the initially established workpiece temperature by an amount proportional to the output signal from said function generator means.

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