April 21, 1970 A. V. SILVA 3,507,134

INTERSTAND TENSION CONTROL FOR TANDEM COLD ROLLING MILLS

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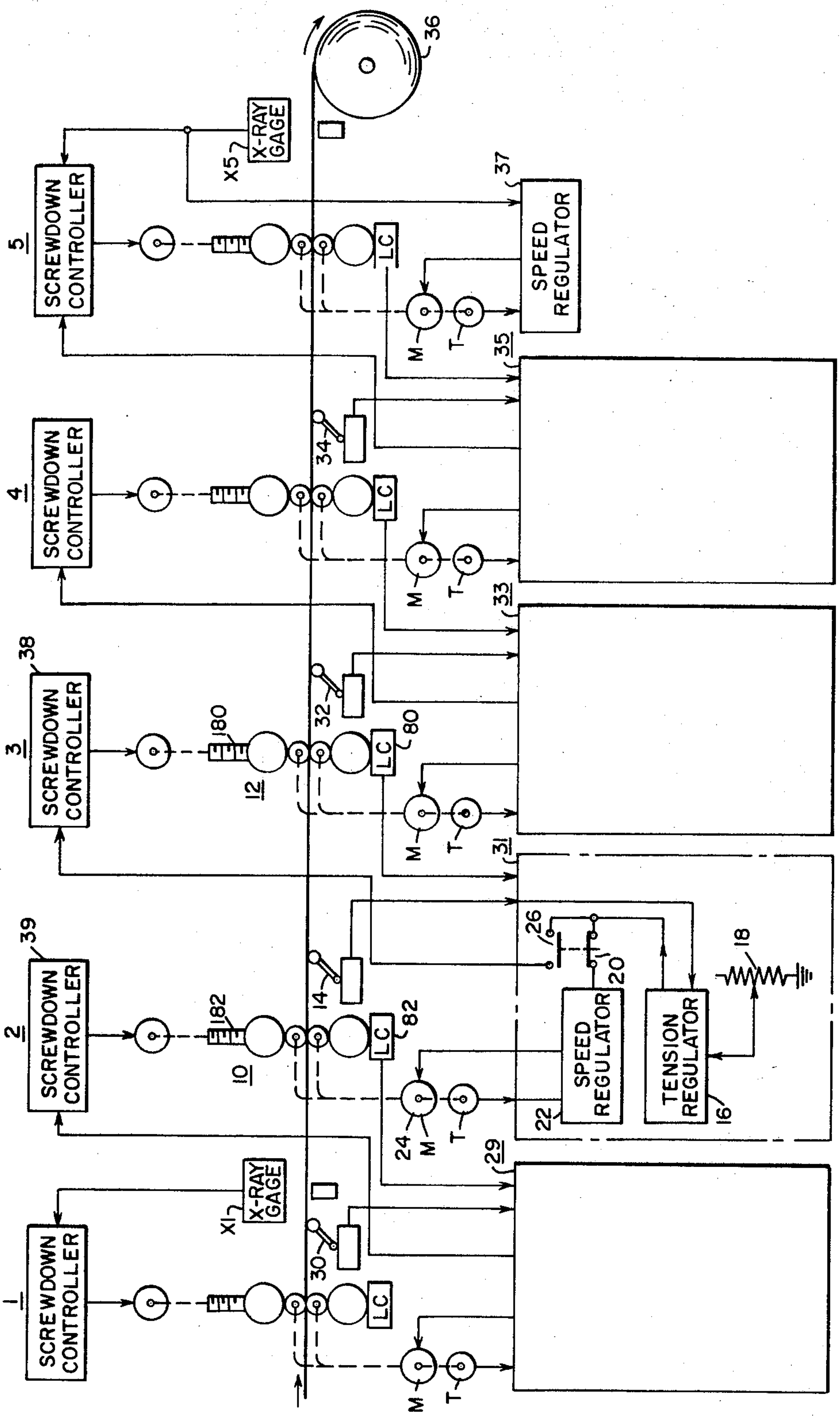

FIG. 1.

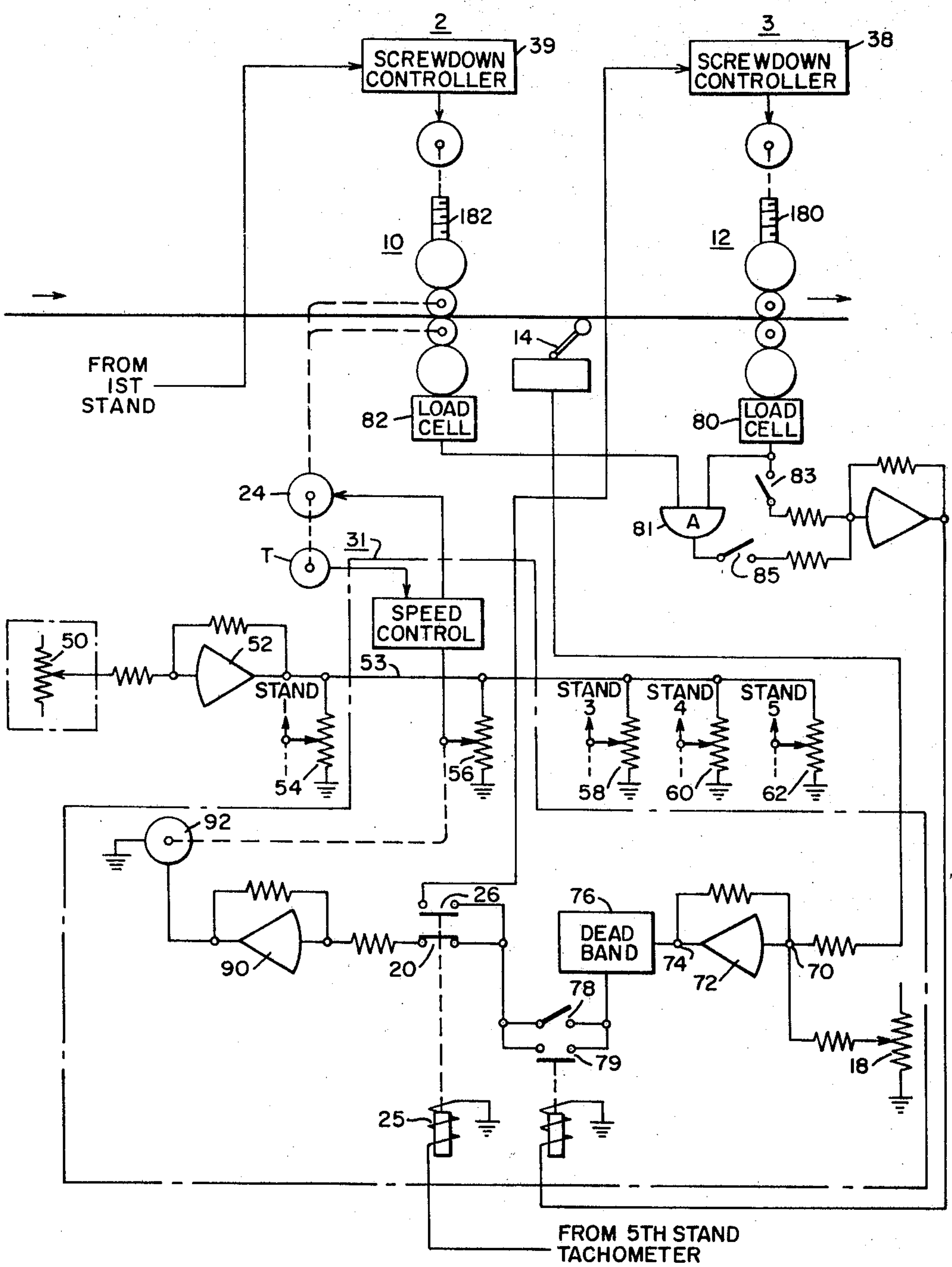

FIG. 2.

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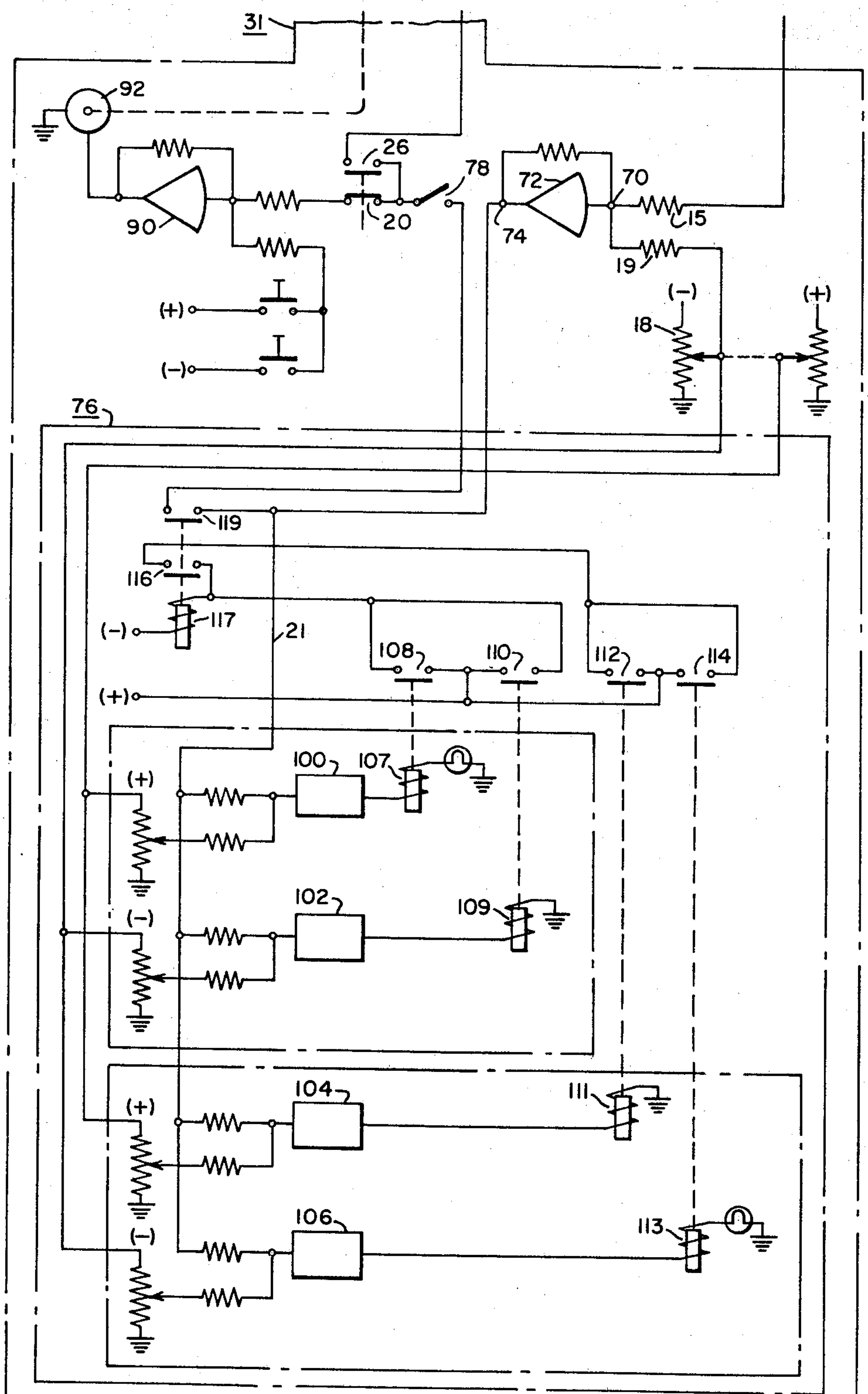
31
92
26
78
72
70
90
20
74
15
19
(−)
(+)
18
(+)
(−)
76
119
116
117
(−)
21
108
110
112
114
(+)
(+)
100
107
(−)
102
109
(+)
104
111
(−)
106
113

FIG. 3.

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INTERSTAND TENSION CONTROL FOR TANDEM COLD ROLLING MILLS

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Int. Cl. B21b *37/00*
U.S. Cl. 72—8 7 Claims

ABSTRACT OF THE DISCLOSURE

The method and apparatus for the control regulation of the respective interstand tensions and thereby the rolled strip thickness in a tandem rolling mill by a predetermined combination of stand screwdown adjustment and stand speed control. In the operation of a tendem rolling mill, adjacent stands are coupled by the strip tension; and during the desired operation of the rolling mill, whereby the final thickness of the strip delivered from the mill is held substantially constant, the respective interstand tensions should be controlled to be substantially constant such that the same volume of material should pass through each stand per given unit of time. When there is obtained this continuity condition on the volumetric flow of material through the rolling mill, with the interstand tensions held substantially constant, the following relationship exists between the thickness h of strip delivered from each stand and the speed v of the strip leaving each stand,

$$h1v1=h2v2=h3v3=h4v4=h5v5$$

BACKGROUND OF THE INVENTION

For the steady-state operation of a tandem mill, the volume of metal passing through each stand in a given time should be the same. This has already been described in U.S. Patent 3,334,502, of Heindel et al. which issued Aug. 8, 1967. If the screw setting of the rolls of any one stand or the speed of the motor on that one stand is altered so as to alter the mass flow rate through that stand, then it is desired that the other stands should be capable of adjusting to this disturbance in reference to the screwdown setting and/or the speed setting of those other stands. In wide strip rolling, such as here contemplated, the volume of the metal is practically unaffected by the amount of work it receives and the lateral spread of the strip is so small that its width may be taken as substantially constant. It has been known in the prior art to establish a desired speed cone relationship of the various stands of a tandem mill such that a desired operating speed relationship is established between each stand and the other stands of the mill to determine a desired distribution of the total reduction load of the respective stand motors for the desired thickness reduction by each stand to be achieved by passing the strip through the tandem mill. It has been the practice for mill operators to establish a desired speed of operation for each stand at a thread speed operation of the mill, and this same generally desired speed relationship of the respective stands is held for acceleration up to a run speed of operation of the tandem mill. Further it has been the practice in the past to provide an interstand tension sensing device or looper which is operative throughout the entire speed range to adjust one of the respective succeeding stand speed regulator or preceding stand speed regulator for the purpose of maintaining a substantially constant interstand tension between each of the respective pairs of stands. Further, it has been known in the prior art, as shown by U.S. Patent 1,145,880 of Clark, to sense the tension between a given pair of stands and to adjust the screwdown setting of either the preceding stand or the succeeding stand relative to the sensed interstand tension throughout the entire mill speed range for the purpose of maintaining a substantially constant tension between that pair of stands.

In the prior art control of a tandem rolling mill the above two approaches have been generally used for the control of interstand tension for the purpose of regulating the interstand tension to remain substantially constant. The second approach of tension regulation, feeding the sensed tension error signal to the screwdown speed regulator of one of the adjacent stands, can have the advantage of in some instances being faster, it can be made more stable and the variations in the delivery gauge of the final product can be reduced due to the inherent control of mass flow provided by the screwdown adjustment approach.

However, a difficulty can arise when the interstand tension is regulated to remain substantially constant by adjustment of the screwdowns when the rolling mill is running at low speeds such as thread speed or below. If the run speed of a rolling mill is in the order of 5000 feet per minute, the typical thread speed may be in the order of 10% of run speed or about 500 feet per minute. At low mill speeds, such as thread speed or below, the required screwdown adjustment may involve an appreciable movement by the screws in order to have any control effect over the interstand tension. At the extreme situation where the mill is actually stopped, the screws can run any distance and no change in interstand tension will occur.

If, when the operator is threading a mill, he has not properly set the mill speed cone, or the speed relationship between the respective stands, as necessary for stable operation of the mill, and the various screw positions are not at the required relationships with each other, the resulting interstand tensions will not be as desired and will not remain substantially constant. When the tension regulators operative with the screwdowns are then activated, these will cause the respective stand screws to run up or down as needed in an effort to reduce the sensed tension errors to zero. However, since the mill is now operating at low speed, it can be necessary for the screws to run a large distance before the tension error between a given pair of stands is reduced to zero. This can cause a severe disturbance to the mill set up, and if the initial tension error is large enough, the screws can either lose contact with the strip by opening too much or run-down to the extent that the strip is broken. The latter fact imposes a serious limitation on the tension control by the screws and the control arrangement may have to be automaticaly turned off when the mill is operated below a certain minimum speed such as thread speed. However, it is desired, and an object of the present invention, to control the interstand tensions as soon as the strip is entered into the respective stands of the mill from zero speed of operation to top mill speed.

SUMMARY OF THE PRESENT INVENTION

The interstand tension control here disclosed employs a combination of screwdown and stand speed changes to obtain the desired substantially constant interstand tension regulation throughout the entire mill speed range. This is accomplished by providing an interstand tension sensing device, such as a tensiometer, between each pair of adjacent stands of the rolling mill and providing an actual interstand tension signal which is compared with a desired or reference interstand tension signal to generate an interstand tension error signal for each pair of stands. For low speed operation of the mill, this tension error signal relative to each pair of stands is supplied to the coarse speed regulator of one of that pair of adjacent stands, such as the preceding stand, to provide in plied to the coarse speed regulator of one of that pair of adjacent stands, such as the preceding stand, to provide in this manner a proper speed cone speed setting for that stand to reduce any interstand tension error and to maintain a substantially constant and desired interstand tension relationship between that pair of stands, regardless of the actual low operating speed of the mill at this time. When the operating speed of the mill is increased above this predetermined low speed operation, which in fact may be the thread speed operation of the mill or in the order of 10% of the established run speed of the mill, this interstand tension error signal is removed from the coarse speed stand regulator and is applied to this screwdown speed regulator or controller for the succeeding stand of the particular pair of stands being regulated to reduce the interstand tension error. After the strip has passed through all of the stands of the rolling mill, with each stand or pair of stands being controlled to be operative as previously described, and the strip has taken a sufficient number of wraps around the windup reel, the operator can now change the operating speed of the rolling mill to be increased to run speed. The speed cone of the rolling mill will at this time be established such that the operating speed of the rolling mill can increase to run speed without being subject to the undesired adjustment of the respective screws as previously described, and the mill should be subject to no objectionable disturbance in the now provided mill speed setup relationships, and the interstand tensions can now be maintained substantially constant as desired.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a general illustration of the interstand tension control in accordance with the present invention applied, in the detailed example, to regulate the interstand tension between the second and third stands of a tandem rolling mill;

FIG. 2 illustrates in greater detail one suitable circuit arrangement provided for adjusting the interstand tension of the strip between the second and third stands of a tandem rolling mill;

FIG. 3 illustrates in greater detail the operation of the deadband gate shown in FIG. 2.

In the normal operation of a tandem rolling mill, a thread speed bus can be energized to regulate the operating speeds of the individual stand drive motors in accordance with individually set reference speeds to provide a desired thread speed cone relationship, and this is done prior to the steel strip entering the first stand. With the entire rolling mill operating at thread speed, the steel strip now enters the first stand and passes through the succeeding stands until it is wrapped onto the tension reel. The thread speed is generally in the order of 10% of run speed, or for a mill having a run speed of 5000 feet per minute in relation to the delivery speed of the strip from the last stand and entering the windup reel; the thread speed at this point would be in the order of 500 feet per minute. The low mill speed of operation here considered is up to thread speed, and can be anywhere from zero speed to about 10% of the mill run speed, and it generally applies to the initial portion of the total length of the strip that passes through the mill. It is desired in this regard to increase the total on gauge strip delivered from the mill even during this initial low speed of operation when the mill is being threaded and before the mill is energized by the master run bus to increase its operating speed up to the desired run speed of operation.

Tension control between stands by operation of the adjacent screwdown controllers has several advantages. However, if the operator has not established a good speed cone relationship for the operation of the respective stands of the mill, and has an incorrect setup in this regard, the prior art automatic tension adjustment control by operation of the screwdowns would require an undesired amount of screwdown adjustment and for this reason it is here desired that the tension control by screwdown adjustment be deenergized until the operator has raised the operating speed of the mill up to at least thread speed of operation. The teachings of the present invention enable the establishment of a good speed cone setup during the low speed and threading operation of the mill, such that when it is desired to increase the operating speed of the mill up to run speed this can be done without requiring substantial change in the speed cone setup. It should be understood that it is sometimes desirable to thread the mill at a speed below 10% of run speed for various reasons; and the 10% of run speed should be understood to be a maximum thread speed, and many times depending upon the characteristics of the strip supplied to the mill a lower threading speed may be desired. It should be further understood that the mill setup for a given strip usually is changed for succeeding strips, if the succeeding strips do not have the same thickness and material characteristics as the previously run strip which passes through the mill. In accordance with the present invention, the tension error signal is utilized below maximum thread speed for adjustment of the stand speed reference to initially establish the speed cone relationship as the strip passes through the succeeding pairs of stands of the rolling mill; and after this desired speed cone relationship is established and the strip has taken a few wraps on the windup reel and the mill is increased in speed above the maximum thread speed of operation, the stand speed regulators are no longer adjusted by the interstand tension error signal and only the screwdown controller is adjusted by this signal. At this point of operation, the control of the present invention has established the right speed cone relationship for the respective stands of the mill and the acceleration of the mill up to run speed provides no problems in terms of excessive screwdown adjustment, and the position of the screwdowns at this point is proper as well as the speed regulation of the individual stand speed regulators. It should be understood that a proper speed cone relationship at 100 or 200 feet per minute is substantially the same as the speed cone relationship for the run speed of 5000 feet per minute. In particularly cold mill operation, succeeding strips change substantially from earlier run strips in terms of desired gauge and with of strip and material characteristics and the like, and for this reason the speed cone relationship for a particular strip is usually not the same as the desired speed cone relationship for succeeding strips. Therefore the speed cone relationship for a tandem cold mill requires continual adjustment for the various strips which pass through the mill.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIGURE 1 there is shown a five stand tandem cold mill including a second stand **10** and a third stand **12**. Interstand tension sensing device **14**, such as a looper roll, provides an actual tension signal to a tension regulator **16**. A desired or reference interstand tension signal is supplied from a potentiometer **18** to a second input of the tension regulator **16**. The latter tension regulator **16** is operative to provide a tension error signal by a difference comparison of the actual interstand tension signal received from the device **14** and the desired interstand tension signal received from the potentiometer **18**, which error signal it applies through an initially closed contactor **20** to the stand speed regulator **22** provided for the coarse speed regulation of the drive motor **24** for the previous stand **10**. The contact **20** is closed below maximum thread speed, which is in the order of 10% of the run speed of about 5000 feet per minute for the rolling mill shown in FIG. 1. A second contact **26** is normally open below the maximum thread speed.

As the strip initially moves from the first stand to the second stand **10** the tension sensing device **30** is operative with a generally similar interstand tension regulation control **29** to control the drive motor for the first stand for mill operation below maximum thread speed and operative with the screw-down controller **31** for the second stand above maximum thread speed. When the strip passes from the second stand **10** into the third stand **12**, the tension sensing device **14** becomes operative to sense the interstand tension between the second and third stands. As the strip moves from the third stand into the fourth stand, the tension sensing device **32** is operative with a similar tension regulation control **33** to control the interstand tension between the third and fourth stand. As the strip moves from the fourth stand into the fifth stand, a tension sensing device **34** is operative with a similar control to control the interstand tension between the fourth and fifth stands. As the strip moves from the fifth stand onto the windup reel **36**, and takes a few wraps around the windup reel as desired by the mill operator, the operator can now press a run speed button (not shown) which causes the drive motors of the respective stands to be energized in a well known manner by a run bus as compared to a thread bus, such that the operation of the mill accelerates from the thread speed to the run speed. The speed cone relationship established as above described during the threading operation is retained in general during the acceleration and while the mill is operating at run speed.

When the operator pushes the run button to cause the rolling mill to accelerate from thread speed up to run speed, the contact **20** shown in FIGURE 1 opens and the contact **26** is closed such that any interstand tension error signal supplied by the tension regulator **16** will now be no longer supplied to the stand speed regulator **22** and instead will be applied to the screwdown controller **38** for the third stand **12** such that screw adjustments are made as required to maintain a substantially constant tension between the second and third stands of the rolling mill. In regard to the output signal from the tension regulator **16** it is the speed regulation of stand **2** relative to stand **1** and stand **3** which is unchanged by the tension regulator **16** above the maximum thread speed of the mill. This means that the ratio of $v1$ to $v2$ and the ratio of $v2$ to $v3$ is not changed by the tension regulator **16** above the maximum thread speed operation of the rolling mill. A similar tension regulator control is provided in accordance with the teachings of the present invention between stand **1** and **2** and between stand **3** and **4** and between stand **4** and **5**, as is illustrated in FIG. 1. Each of these tension regulator controls operates in succession as the strip passes between the respective stands to provide the desired speed cone relationship for the entire mill prior to the operator pressing the run button and accelerating the mill from maximum thread speed or below up to desired run speed.

In FIG. 2 there is shown in greater detail the interstand tension control arrangement of the present invention including a master speed reference potentiometer **50** operative through an operational amplifier **52** for energizing a bus **53** to control the pattern operating speed of all stands of the rolling mill. A potentiometer **54** is operative with the first stand for providing a coarse speed adjustment function, a potentiometer **56** is operative with the second stand for providing a coarse speed adjustment of the operating speed of the second stand, a potentiometer **58** is operative to provide a coarse speed regulation of the third stand, a potentiometer **60** is operative to provide a coarse speed regulation of the fourth stand, and a potentiometer **62** is operative to provide a coarse speed regulation of the fifth stand. It should be understood that the potentiometers **54, 56, 58, 60** and **62** are the coarse speed motor operated rheostats for the respective stands of the mill. The signal from the actual tension sensing device **14** and the signal from the desired tension reference potentiometer **18** are summed together at a summing junction **70** operative with an operational amplifier **72** for providing an amplified tension error signal at output junction **74** which passes through a dead-band gate device **76**, which will be described in greater detail in relation to FIG. 3. A contact **78** is provided for manual operation of the rolling mill in that for the tension regulation control shown in FIGURE 2 to be properly operative the operator should observe that strip should be present between the second and third stands of the mill; otherwise the tension sensing device **14** will provide an erroneous signal.

When strip is present between the second and third stands, as for example can be sensed by a roll force sensing load cell device **80** as shown in FIGURE 1 operative with the third stand of the rolling mill, the contact **79** can be closed through switch **83** when the roll force load cell device **80** indicates that strip is present in the third stand of the rolling mill. If it is desired to make certain that the tail end of a given strip has not left the second stand and is present in the third stand, the output signal from a roll force load cell device **82** operative with the second stand can be used in combination with the output signal from the roll force load cell device **80** of the third stand, for example in a well known AND gate **81**, to provide an output signal through switch **85** only when strip is present between the stands two and three for the purpose of closing the contact **78** when this condition occurs.

The contact **20** is normally closed, for low speed operation of the rolling mill, to apply any tension error signal passing through the deadband gate **76** to an operational amplifier **90** to energize the motor **92** for adjusting the position of the rheostat **56** which in turn is operative with the second stand speed controller for the purpose of adjusting the operating speed of the second stand in a direction to remove any tension error signal supplied at the output terminal **74** of the operational amplifier **72**.

The function of the deadband gate **76** is to prevent tension control in this manner by a small error signal less than about 2 or 3% of the tension reference value established by the potentiometer **18**. An error signal above 10% of the desired interstand tension value will pass through the deadband gate and be operative with the motor **92** to adjust the operating speed of the stand two. As long as the error is greater than 2 or 3%, the error signal is applied to the motor **92** to bring the tension error down to zero, and the error signal is continuously applied until the tension error drops to about 2 or 3% before the deadband gate will no longer pass the error signal to the amplifier **90**. The deadband gate **76** is operative in a similar manner relative to an opposite tension error signal.

It should be understood in general that each of the motor operator rheostats **54, 56, 58, 60** and **62**, operative with the respective stands of the rolling mill, are initially preset manually to provide a desired speed cone relationship. After this initial manual setting the tension regulating control of the present invention is operative to adjust these settings and change the operating speed of each particular stand drive motor in relation to the other stand motors, to thereby realign the speed relationship or speed cone settings of the respective motors as required to provide a substantially constant and desired interstand tension relationship between the respective adjacent stands of the rolling mill. Therefore, when the operator presses the run button to bring the operating speed of the rolling mill up to run speed, the bus **53** common to each of the stand speed rheostats has an increased voltage applied to it to thereby increase the operating speeds of the respective drive motors; however, the established relationship between those speeds is held constant as the voltage of the bus **53** increases to run speed value. The tension control arrangement shown in FIG. 2 is therefore seen to be operative to adjust the speed setting of the potentiometer **56** operative with the drive motor for the second stand in relation to the speed settings of the potentiometers for the other drive motors. Further, it should be understood that an interstand tension control arrangement similar to that shown in FIG. 2 is provided for each of the interstand tension sensing devices 30, 14, 32 and 34 as shown in FIGURE 1, and is operative with the respective stand potentiometers 54, 56, 58 and 60. After the strip enters the tension reel 36, and has taken a few wraps to the satisfaction of the operator, the operator presses the run button and opens the contact 20 and closes the contact 26 for each stand tension control such that any existing tension error signals relative to the strip present between the respective stands is now supplied to the screwdown speed regulator operative with the screwdown controller of the next adjacent stand. The contact 20 for each pair of stands is open such that the tension error signal supplied at the output of the tension error operational amplifier is no longer operative to adjust the speed setting of the drive motor of the associated stand. Thusly, since this same operation holds true for the interstand tension control arrangements for each of the pairs of stands, the now established speed cone relationship for the entire mill is no longer changed by tension changes occurring between the respective stands of the mill. Any adjustment of the respective interstand tensions after the operator has pressed the run button is provided by proper adjustment of the screwdown controllers of the succeeding stand relative to the particular interstand tension which needs correction.

The deadband gate 76 is operative such that small errors do not result in changes of the settings of the respective stand speed rheostats since noise and other objectionable signals otherwise would result in undesired changes in the speed cone relationship and unstable operating conditions might result for the interstand tension control arrangement. The deadband gate 76 is operative such that when the tension error signal is above the desired tension reference value by some predetermined amount, such as by an amount equivalent to about 10%, the full error signal is applied to the stand motor speed regulator. As the error signal is corrected and therefore decreases until it reaches a value in the order of 2%, the error signal is no longer applied to the speed regulator. Should the error then reverse itself, nothing happens until it reaches this predetermined amount, such as a value in the order of 10%, when it again passes through the deadband gate for its full value in the opposite direction until the tension error signal is corrected to a value where it is within 2% of the desired interstand tension at which time the tension error signal is again removed. This avoids unstable operation of the interstand tension regulation operation.

The contact 78 is used to manually load up the mill until some tension is present between the respective stands to be sensed by the tension sensing devices. Upon closing the contact 78 this causes the speed adjustment of the second stand motor to be such as to provide the desired interstand tension between the second and third stands. As the strip passes through the entire mill, similar controls successively operate for the respective interstand tensions between the first and second stand and then the second and third stand and then the third and the fourth stand and then the fourth and fifth stand such that, when the strip has entered the tension reel 36 and been wrapped around a couple times, the desired speed cone relationship is established for the mill. After this the respective screwdown speed regulators can be energized by any remaining tension error signals. If desired, the roll force signal from the second stand can determine the energization of the interstand tension control arrangement for the strip between the first and second stands, and the roll force signal from the third stand to indicate that the strip has entered the third stand can be operative to energize and make operative the interstand tension control arrangement for the strip between the second and third stands, and so forth, as the strip passes through the mill and enters the fourth stand and then the fifth stand in succession. As an alternate arrangement if desired a tachometer operative with the drive motor of the fifth stand can sense when the rolling mill is operative at maximum thread speed or above and can be operative to deenergize the interstand tension regulating apparatus operative with the speed regulators and instead send the respective interstand tension error signals to the successive stand screwdown controllers, by energizing a relay 25 for each of the interstand regulators, operative to open the contact 20 and close the contact 26 and corresponding contacts for the other interstand tension regulators. A well known bistable amplifier can be utilized for this purpose and which is not operative to switch its state of operation until a predetermined positive value input signal is applied to its input; it could be adjusted to indicate that the maximum thread speed of operation has been reached and the mill is operating at this level or above.

In FIG. 3 there is illustrated in greater detail the operation of the deadband gate 76. It should be understood that the embodiment illustrated in FIG. 3 is not intended to limit the scope of the present invention but rather to provide one suitable illustration of an operative form of deadband signal gate device. In general, a deadband gate per se is well known to persons skilled in this art and there are several suitable devices available on the open market at the present time which would be suitable for this purpose. In FIG. 3 the elements corresponding to those shown in FIGURE 1 and FIGURE 2 have been given like reference numerals. The stand speed rheostats 54, 56, 58 and 60 are adjusted by the interstand tension regulating arrangement of the present invention. In addition there are fine speed manually adjusted rheostats provided for the operator to preset the speed cone of the mill before metal is in the stands, with the usual practice that once the operator sets the fine speed rheostats he leaves them along and relies upon the operation of the tension control arrangement to adjust the speed rheostat as shown in the present invention.

In FIG. 3 there is shown the dead zone gate 76 to include four bistable amplifier circuits 100, 102, 104 and 106. These are respectively operative with the relay windings 107, 109, 111 and 113, for determining the operation of the associated contacts 108, 110, 112 and 114. It is assured that a negative tension error is initially present from the start, and is present until strip is entered into the mill. When the tensiometer device senses an interstand tension condition it applies an actual tension signal to input 15 of amplifier 72. The tension reference signal provided by the potentiometer 18 is applied to input 19. The error signal from the output of the amplifier 72 is applied to one input of each bistable amplifier through conductor 21. When this error is greater than about 2% in a positive direction it will cause the bistable amplifier 104 to energize the winding 111 to close contact 112. As the error signal becomes greater than about 10% in a positive direction, it will cause the bistable amplifier 100 to energize the winding 107 to close contact 108. The latter contact 108, when closed, energizes the relay winding 117 to close contacts 116 and 119. The contact 116 seals the winding 117 on itself through the already closed contact 112. Thus, contact 108 closes at an error of +10% and this applies the tension error signal from the amplifier 72 to the motor 92, until the tension error is reduced below +2%, when the contact 112 opens to remove the energization from winding 117 to open contact 119. It should be understood that the contact 108 opened prior to the tension error being reduced to +2%. For a negative tension error, the bistable amplifier 106 closes contact 114 at a tension error of about −2% and the bistable amplifier 102 closes contact 110 at a tension error of about −10%, such that the motor 92 is energized to increase the tension when the tension error becomes −10% and is no longer energized when the tension error reaches −2%. The bistable amplifiers including the associated relay per se are very well known devices and are available at the present time in the open market as Westinghouse Electric Corporation catalog item P–801.

In this manner the speed setting for each stand is adjusted by a motor corresponding to the motor **92** shown for stand two, such that the interstand tension condition fo reach pair of stands is in accordance with a desired tension value as the strip passes through the respective stands of the mill.

In the normal operation of the interstand tension control arrangement shown in FIGURES 1, 2 and 3 the interstand tension condition between the respective stands is succeedingly corrected as the strip passes through the mill from the first stand to the windup reel such that if an indicator light were operative with the output of the bistable amplifier of each tension control arrangement, such as the bistable amplifier **100**, this would indicate when the tension condition between the respective stands was such that it was less than positive 10% in error relative to the desired interstand tension condition; a similar light operative with the output of the bistable amplifier of each tension control arrangement, such as the bistable amplifier **102**, would indicate that the actual tension condition was no greater than 5% negative 10% away from the desired interstand tension reference condition. These lights could be located at an operator's console and indicate to the operator that the desired rough correction regulation had occurred between the respective stands, and that it was alright to press the run button to cause the mill to now increase its operating speed from maximum thread speed or below up to run speed. Since it is highly desirable to control the respective interstand tensions as soon as the strip is threaded regardless of the operating speed of the mill, from zero to top run speed, the control arrangement in accordance with the present invention uses a combination of screwdown adjustment and stands speed changes to obtain the desired tension regulation between the stands throughout the entire mill speed range. In the above description reference was made to the interstand tension control between the second and third stands of the five stand cold mill, but it should be understood that a similar interstand tension control arrangement can be applied to each of the other interstand tension conditions in a tandem mill with any number of stands. As soon as the head end of the strip reaches each succeeding stand and some tension is detected by the tension sensing device operative ahead of that stand the tension regulator control operative with that device is turned on. This can also be accomplished by a roll force sensing load cell device operative with each succeeding stand to indicate that strip has now entered a given stand and is therefore present up to that stand. With the mill operating at low speed, the tension between any pair of stands will be controlled by changing the speed of the preceding stand. In order to obtain a smooth operation when the speed of any stand is increased, above thread speed, the tension error is not fed directly to the speed regulator of that stand but is fed instead to the speed controlling motor operated rheostat of that stand. The tension error or difference between the desired tension and the actual interstand tension is sensed by the tension sensing device and is fed through a deadband gate to the motor operated rheostat for the number **2** stand. As illustrated the deadband has a hysteresis effect which means that the gate is closed to pass the error signal when the error is greater than a certain percentage of the desired tension condition and remains closed until the error is reduced to a predetermined lower value of the tension error condition. This gate can be made to operate in a percent basis by using the tension reference signal as a bias to the provided tension error detection bistable amplifiers.

While the mill is being threaded, the tension regulator controls will change the position of the motor operated rheostats controlling the speed of each stand to obtain the desired interstand tension relationships as called for

by the tension reference setting rheostats for the respective pairs of stands. When the head end of the strip reaches the tension or windup reel, all the stands speeds should be at the appropriate values for the desired interstand tensions for the now existing screw positions and the tension errors should be reduced between the stands to substantially zero. In other words, the speed cone of the mill will be correct for the existing screwdown settings. Since the speed correction for each stand has been made through the motor operated rheostat, when the mill is accelerated each stand will maintatin the correct relationship of speed to the other stands. This would not be true if the tension error were directly fed to the stand speed regulators. When the threading of this mill is completed, the tension error signal is removed from the motor operated rheostat drive motor and applied to the appropriate screwdown controller for the next succeeding stand through the stand deadband gate. The tension will now be controlled by operating on the screwdown mechanisms with all the advantages provided by the previous speed regulation. However, since the relative speeds of the stand are now correct, and the initial tension errors are substantially zero, no excessive running of the screwdown mechanisms will result.

It should be understood that it is within the scope of the present invention to control interstand tension for maintaining constant mass flow conditions between a given pair of stands by adjusting the speed and screwdown of either the previous or the succeeding stand. For example, if the interstand tension is too high, the product of thickness *hp* and strip velocity *vp* of the previious stand, should be made equal to the product of thickness *hs* and strip velocity *vs* of the succeeding stand; this can be done by raising the screwdown setting of the previous stand to increase *hp* or by increasing the previous stand speed *vp* to effectively reduce the tension between the stands; this can also be done by lowering the screwdown setting of the succeeding stand to reduce *hs* or by decreasing the succeeding stand speed *vs* to effectively reduce this same interstand tension. Further, it is within the scope of the present invention to provide an overlap in the operation of the described speed adjustment and the screwdown adjustment, for example, by controlling the opening of contact **20** for any given interstand tension controller to occur at a different and perhaps greater mill speed than does the closing of the contact **26** such that for a selected range of mill speed operation overlapping the thread speed, the speed adjustment and screwdown adjustment can be applied together. Also, it is within the scope of this invention to narrow the effective deadband provided by the deadband gate **76** as compared to the specific example set forth in this specification. As generally shown in FIGURE 1, the teachings of the present invention can be utilized in conjunction with the well known X-ray gage coarse thickness control system applied to stand one and the X-ray gage vernier thickness control system applied to stand five of the rolling mill.

While the present invention has been described with a certain degree of particularity it should be understood that various modifications and changes thereof can be made within the scope and spirit of the present invention.

I claim as my invention:

1. In control apparatus for a strip rolling mill having at least two successive stands of spaced roll members, the combination of

strip tension sensing means responsive to the actual tension of said strip relative to the passage of said strip between said two stands,

driving means for the roll members of at least one of said stands to provide a desired operating speed for the latter said roll members,

spacing control means operative with the roll members of at least one of said stands to provide a desired spacing between the latter said roll members, and thickness control means operative with said driving means and with said spacing control means for controlling the thickness of said strip in accordance with the difference between said actual tension and a desired strip tension between said stands, with said thickness control means being responsive to the speed of said strip passing between said stands to selectively operate in a predetermined manner with said driving means and with said spacing control means in accordance with said strip speed.

2. The control apparatus of claim 1, including

said thickness control means being responsive to the speed of said strip passing between said stands being one of below a predetermined strip speed or being above said predetermined strip speed and being operative with said driving means below said predetermined strip speed and being operative with said spacing control means above said predetermined strip speed.

3. The control apparatus of claim 1,

with said driving means being operative with the first of said two stands and with said spacing control means being operative with the second of said two stands,

said thickness control maens being operative with said first stand driving means below a predetermined strip speed to control the operating speed of the roll members of said first stand to reduce said tension difference.

and said thickness control means being operative with said spacing control means of the second stand above said predetermined strip speed to control the spacing between the roll members of the second stand to reduce said tension difference.

4. The method of controlling the delivery thickness of strip material passing through the plural stands of a tandem rolling mill, with each of said stands including spaced roll members, said method including

monitoring the actual tension of said strip material passing between a pair of said stands to determine the tension error in accordance with the difference between a desired tension condition and the actual tension condition of said strip material,

monitoring the speed of said strip material passing between said pair of stands,

controlling the operating speed of one of said pair of stands in accordance with said tension error when said strip speed is below a predetermined value for reducing said tension error and controlling the spacing between the roll members of one of said pair of

stands in accordance with said tension error when said strip speed is above said predetermined value for reducing said tension error.

5. The method of controlling the delivery thickness of strip material of claim 4, including,

controlling the operating speed of the first of said pair of stands when the strip speed is below the predetermined thread speed of said mill, and

controlling the spacing between the roll members of the second of said pair of stands when the strip speed is above said thread speed of said mill.

6. The method of claim 4, including

monitoring the actual tension of the strip material between each succeeding pair of said stands to determine the tension error between each succeeding pair of stands,

controlling the operating speed of the first stand of each said pair of stands in accordance with the tension error between that pair of stands to reduce the said tension error,

and controlling the spacing between the roll members of the second stand of each pair of stands in accordance with the tension error between that pair of stands to reduce said tension error.

7. The method of controlling the thickness of strip material passing through the plural stands of a tandem rolling mill, including

determining the actual tension of said strip material between a pair of said stands,

determining the speed of said strip material,

controlling the speed of at least one of said stands for a first range of said strip speed in accordance with said actual tension for controlling said actual tension,

controlling the screwdown setting of at least one of said stands for a second range of said strip speed in accordance with said actual tension for controlling said actual tension.

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