United States Patent [19]

Cook

[11] **3,852,983**

[45] **Dec. 10, 1974**

[54] **WORK STRIP GAUGE CHANGE DURING ROLLING IN A TANDEM ROLLING MILL**

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[73] Assignee: **Westinghouse Electric Corporation,** Pittsburgh, Pa.

[22] Filed: **Apr. 25, 1973**

[21] Appl. No.: **354,288**

[52] **U.S. Cl.** **72/12,** 72/240

[51] **Int. Cl.** **B21b 37/00,** B21b 37/14

[58] **Field of Search** 72/6–12, 16, 72/17

[56] **References Cited**

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Attorney, Agent, or Firm—R. G. Brodahl

[57] **ABSTRACT**

A control method and apparatus are disclosed for controlling the gauge of strip material being rolled by a tandem rolling mill while the strip is in motion and moving through the mill. A gauge change in the work strip is accomplished by changing, in proper timed sequence, the stand speed and roll gap openings starting from the first to the last stand. In order to change gauge or thickness of the work strip material during rolling, as the gauge change point engers the first stand the roll gap opening of the first stand is initially changed. As the gauge change point enters each succeeding stand, the speeds of all the previous stands are adjusted for the changed schedule and the tension controlling roll gap system senses the change in tension at the entry side of the gauge change stand and adjusts the gauge change stand roll gap to maintain the desired tension and consequently the desired change in delivery gauge leaving that roll stand.

13 Claims, 5 Drawing Figures

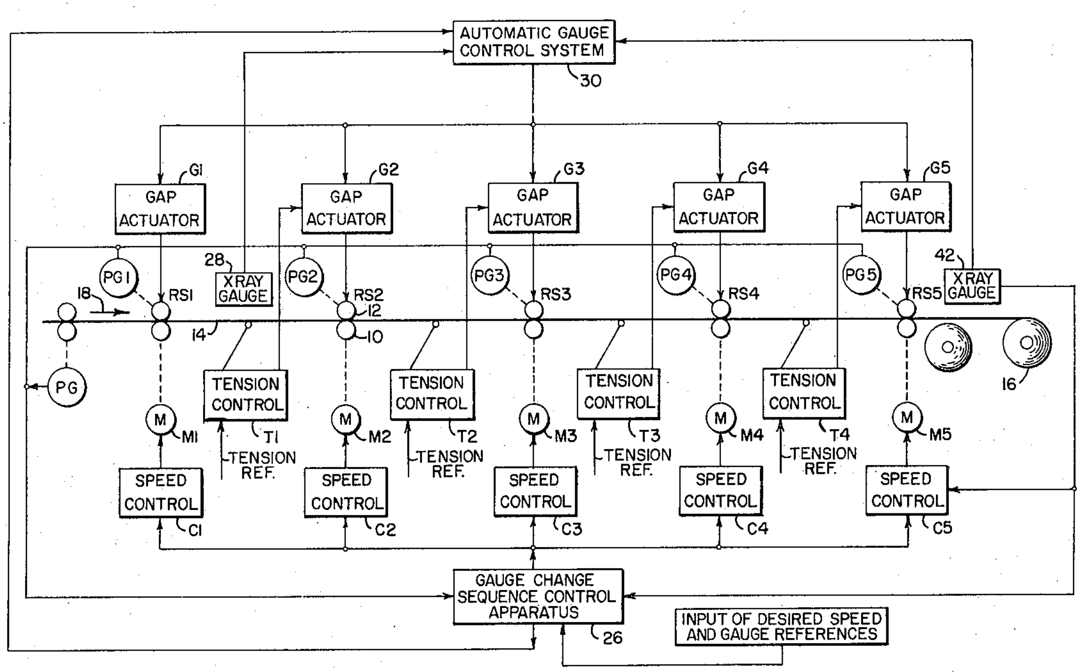


FIG.1

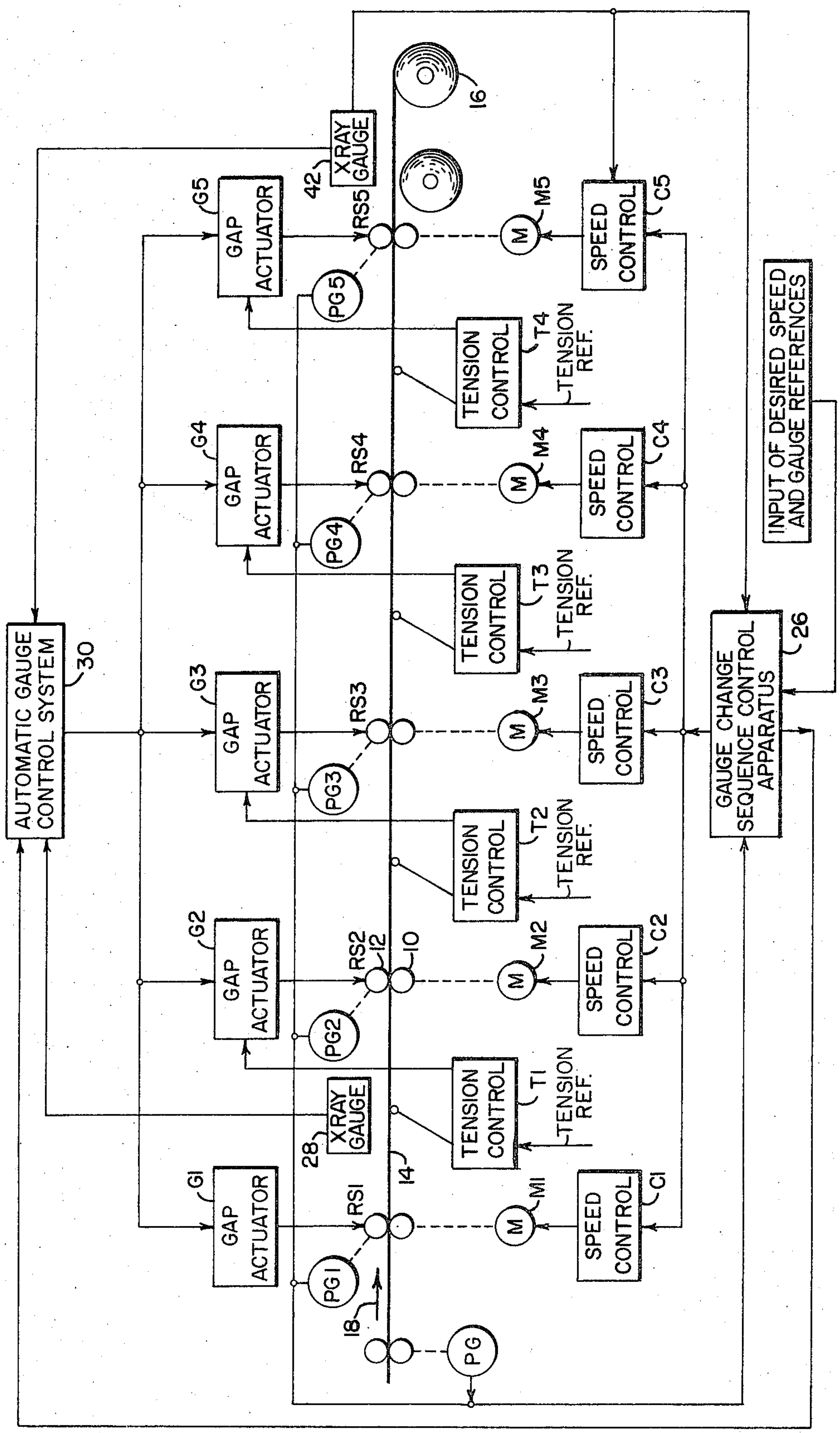
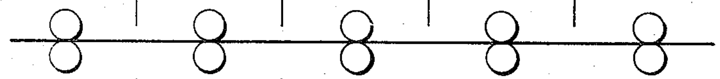

AUTOMATIC GAUGE CONTROL SYSTEM
30
GAP ACTUATOR
G1
G2
G3
G4
G5
RS1
RS2
RS3
RS4
RS5
12
10
14
16
18
PG
PG1
PG2
PG3
PG4
PG5
X RAY GAUGE
28
X RAY GAUGE
42
TENSION CONTROL
T1
T2
T3
T4
TENSION REF.
M
M1
M2
M3
M4
M5
SPEED CONTROL
C1
C2
C3
C4
C5
GAUGE CHANGE SEQUENCE CONTROL APPARATUS
26
INPUT OF DESIRED SPEED AND GAUGE REFERENCES

FIG.2



	STAND NO. 1	STAND NO. 2	STAND NO. 3	STAND NO. 4	STAND NO. 5
SCHED #1	S_{11}=446 H_{11}=.085	S_{21}=583 H_{21}=.065	S_{31}=758 H_{31}=.050	S_{41}=903 H_{41}=.042	S_{51}=1000 H_{51}=.038
TRANS AT STD #1	S_{11}=446 H_{12}=.070	S_{21}=583 H_{21}=.065	S_{31}=758 H_{31}=.050	S_{41}=903 H_{41}=.042	S_{51}=1000 H_{51}=.038
TRANS AT STD #2	S_{122}=416 H_{12}=.070	S_{21}=583 H_{22}=.050	S_{31}=758 H_{31}=.050	S_{41}=903 H_{41}=.042	S_{51}=1000 H_{51}=.038
TRANS AT STD #3	S_{123}=390 H_{12}=.070	S_{223}=546 H_{22}=.050	S_{31}=758 H_{32}=.036	S_{41}=903 H_{41}=.042	S_{51}=1000 H_{51}=038
TRANS AT STD #4	S_{124}=310 H_{12}=.070	S_{224}=433 H_{22}=.050	S_{324}=602 H_{32}=.036	S_{41}=903 H_{42}=.024	S_{51}=1000 H_{51}=.038
TRANS AT STD #5	S_{125}=286 H_{12}=.070	S_{225}=400 H_{22}=.050	S_{325}=555 H_{32}=.036	S_{425}=833 H_{42}=.024	S_{52}=1000 H_{52}=.020

		STAND ONE		STAND TWO		STAND THREE		STAND FOUR		STAND FIVE	
	INPUT GAUGE H_0	DELIVERY GAUGE H_1	SPEED S_1	DELIVERY GAUGE H_2	SPEED S_2	DELIVERY GAUGE H_3	SPEED S_3	DELIVERY GAUGE H_4	SPEED S_4	DELIVERY GAUGE H_5	SPEED S_5
GAUGE SCHEDULE 1	.110	.085	446	.065	583	.050	758	.042	903	.038	1000
GAUGE CHANGE TRANSITION AT STAND ONE	.100	.070	446	.065	583	.050	758	.042	903	.038	1000
PER UNIT MULTIPLIER		$\frac{(S_{21})(H_{22})}{(S_{11})(H_{12})} = .933$									
GAUGE CHANGE TRANSITION AT STAND TWO	.100	.070	416	.050	583	.050	758	.042	903	.038	1000
PER UNIT MULTIPLIER		$\frac{(S_{31})(H_{32})}{(S_{21})(H_{22})} = .937$			.937						
GAUGE CHANGE TRANSITION AT STAND THREE	.100	.070	390	.050	546	.036	758	.042	903	.038	1000
PER UNIT MULTIPLIER		$\frac{(S_{41})(H_{42})}{(S_{31})(H_{32})} = .794$			.794		.794				
GAUGE CHANGE TRANSITION AT STAND FOUR	.100	.070	310	.050	433	.036	602	.024	903	.038	1000
PER UNIT MULTIPLIER		$\frac{(S_{51})(H_{52})}{(S_{41})(H_{42})} = .921$			.921		.921		.921		
GAUGE CHANGE TRANSITION AT STAND FIVE	.100	.070	286	.050	400	.036	555	.024	833	.020	1000
GAUGE SCHEDULE 2	.100	.070	286	.050	400	.036	555	.024	833	020	1000

FIG. 3

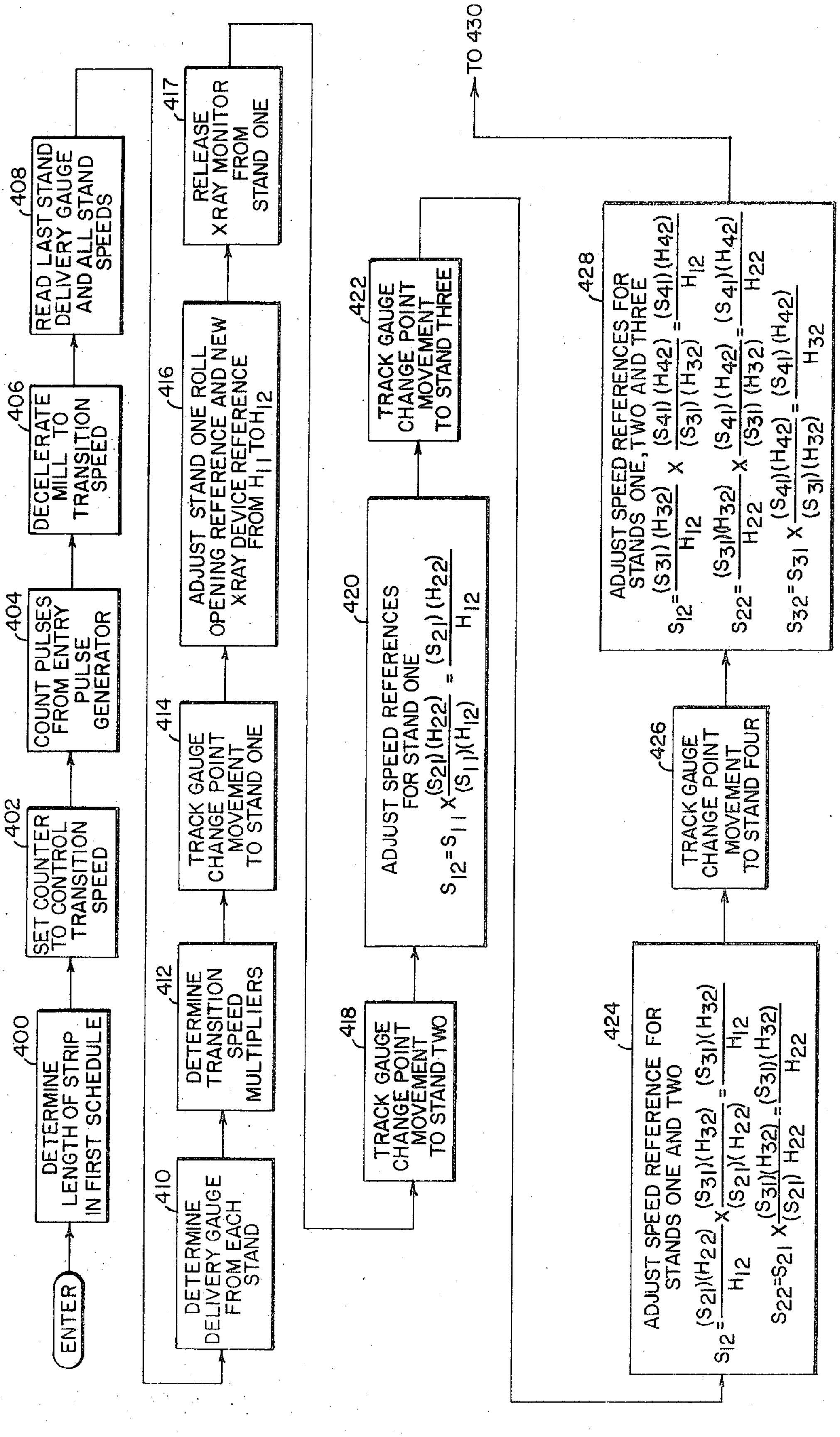

ENTER
400 DETERMINE LENGTH OF STRIP IN FIRST SCHEDULE
402 SET COUNTER TO CONTROL TRANSITION SPEED
404 COUNT PULSES FROM ENTRY PULSE GENERATOR
406 DECELERATE MILL TO TRANSITION SPEED
408 READ LAST STAND DELIVERY GAUGE AND ALL STAND SPEEDS
410 DETERMINE DELIVERY GAUGE FROM EACH STAND
412 DETERMINE TRANSITION SPEED MULTIPLIERS
414 TRACK GAUGE CHANGE POINT MOVEMENT TO STAND ONE
416 ADJUST STAND ONE ROLL OPENING REFERENCE AND NEW XRAY DEVICE REFERENCE FROM H11 TO H12
417 RELEASE XRAY MONITOR FROM STAND ONE
418 TRACK GAUGE CHANGE POINT MOVEMENT TO STAND TWO
420 ADJUST SPEED REFERENCES FOR STAND ONE
S12=S11 X (S21)(H22)/(S11)(H12) = (S21)(H22)/H12
422 TRACK GAUGE CHANGE POINT MOVEMENT TO STAND THREE
424 ADJUST SPEED REFERENCE FOR STANDS ONE AND TWO
S12=(S21)(H22)/H12 X (S31)(H32)/(S21)(H22) = (S31)(H32)/H12
S22=S21 X (S31)(H32)/(S21) H22 = (S31)(H32)/H22
426 TRACK GAUGE CHANGE POINT MOVEMENT TO STAND FOUR
428 ADJUST SPEED REFERENCES FOR STANDS ONE, TWO AND THREE
S12=(S31)(H32)/H12 X (S41)(H42)/(S31)(H32) = (S41)(H42)/H12
S22=(S31)(H32)/H22 X (S41)(H42)/(S31)(H32) = (S41)(H42)/H22
S32=S31 X (S41)(H42)/(S31)(H32) = (S41)(H42)/H32
TO 430

FIG. 4A

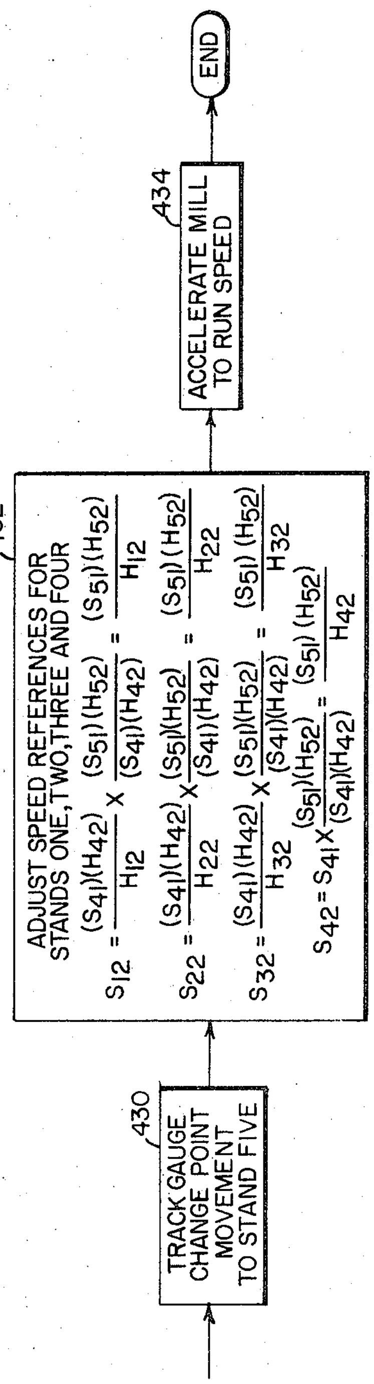

TRACK GAUGE CHANGE POINT MOVEMENT TO STAND FIVE
430
ADJUST SPEED REFERENCES FOR STANDS ONE, TWO, THREE AND FOUR
$S_{12} = \frac{(S_{41})(H_{42})}{H_{12}} \times \frac{(S_{51})(H_{52})}{(S_{41})(H_{42})} = \frac{(S_{51})(H_{52})}{H_{12}}$
$S_{22} = \frac{(S_{41})(H_{42})}{H_{22}} \times \frac{(S_{51})(H_{52})}{(S_{41})(H_{42})} = \frac{(S_{51})(H_{52})}{H_{22}}$
$S_{32} = \frac{(S_{41})(H_{42})}{H_{32}} \times \frac{(S_{51})(H_{52})}{(S_{41})(H_{42})} = \frac{(S_{51})(H_{52})}{H_{32}}$
$S_{42} = S_{41} \times \frac{(S_{51})(H_{52})}{(S_{41})(H_{42})} = \frac{(S_{51})(H_{52})}{H_{42}}$
432
ACCELERATE MILL TO RUN SPEED
434
END

FIG. 4B

WORK STRIP GAUGE CHANGE DURING ROLLING IN A TANDEM ROLLING MILL

CROSS REFERENCE TO RELATED APPLICATIONS

Reference is made to the following related patent applications which are assigned to the present assignee:

Ser. No. 293,618, filed Sept. 29, 1972, by J.J. Connors, now issued as U.S. Pat. No. 3,807,206 and entitled "Strip Gauge Change During Rolling In A Tandem Rolling Mill."

Ser. No. 354,286 filed Apr. 25, 1973 filed concurrently herewith by A.W. Smith, Jr. and entitled "Work Strip Gauge Change During Rolling In A Tandem Rolling Mill BACKGROUND OF THE INVENTION

In the operation of prior art tendem rolling mills, it has been the common practice to roll the entire length of metal strip material in one coil to a single desired and specified gauge (sometimes spelled gage) or thickness. That is, there was no satisfactory way of changing gauge while the strip material was in motion and passing through the rolling mill. One complete coil had to be rolled to a specified thickness; and the roll gap and speed settings in relation to a succeeding and different gauge coil then changed for the respective stands while the mill was not in use and before the succeeding coil was rolled to a different delivery gauge. As a result, small single coil orders of different delivery gauges meant small and separate coils and a resultant reduced production efficiency. Furthermore, it has not been too successful with prior art systems to weld together several lengths of strip material of varying thicknesses and roll them to a constant, final delivery gauge.

In an article published in the 1966 Iron and Steel Engineer Year Book, at pages 659 to 667, there is a disclosure of a tandem rolling mill operation including respective X-ray gauge sensing devices operative for thickness control purposes after each of the first and last roll stands, with interstand control apparatus operative ahead of and providing roll opening control for each of the roll stands other than the first roll stand. In addition, continuous rolling operation of a tandem mill is broadly discussed.

In U.S. Pat. No. 3,170,344 there is disclosed a tandem mill operation including X-ray gauge sensing devices operative after each of the first and last roll stands, with interstand tension control apparatus operative ahead of and providing roll opening control for each of the roll stands of the mill other than the first roll stand and the last roll stand.

In an article published in the 1966 Iron and Steel Engineer Year Book, at pages 328 to 334, there is a disclosure of digital computer program organization for the control of a rolling mill, including the sequencing of desired operations.

In an article published in the January, 1969 Westinghouse Engineer, at pages 2 to 8, there is a disclosure of integrated process control for more efficient and more effective control of modern rolling mills, by use of a stored program digital control computer.

SUMMARY OF THE INVENTION

When it is desired for a given work strip to pass through the successive roll stands of a particular rolling mill, for example a five stand tandem rolling mill, initially at a first schedule of operation whereby a first delivery gauge leaves the last stand of the rolling mill and then subsequently at a second and different schedule of operation whereby a second delivery gauge leaves the last stand of the rolling mill, a controlled sequence of successive predetermined operations for the respective roll stands is here provided for this purpose.

The rolling mill is operated, when the work strip is passing through the successive roll stands of the rolling mill, such that a first X-ray gauge sensing device positioned after the first roll stand controls the roll opening of that first roll stand to effect a coarse gauge control of the work strip leaving that first roll stand, and a second X-ray gauge sensing device positioned after the last roll stand controls the speed of that last stand to effect a vernier gauge control of the work strip leaving that last roll stand. A tension regulating device is positioned to sense the work strip interstand tension after each of the first, second, third and fourth roll stands and is operative respectively to control the roll opening of the following roll stand for maintaining the rolling mill operation in accordance with the well-known mass flow relationship:

$$(H_1)(S_1)=(H_2)(S_2)=(H_3)(S_3)=(H_4)(S_4)=(H_5)\ (S_5) \qquad (1)$$

where H_1 is the work strip delivery gauge leaving the first roll stand at speed S_1, where H_2 is the work strip delivery gauge leaving the second roll stand at speed S_2 and so forth.

When it is desired to change the operation of the rolling mill from the initial first gauge schedule of operation to the second gauge schedule of operation as a predetermined gauge change point of the work strip passes through the successive roll stands, this gauge change point movement can be established and followed in several ways, for example a weld detector can sense physically the gauge change point in the form of a welded joint in the work strip or a provided pulse generator and associated bridle roll arrangement can be operative with a pulse counter to sense the movement of the work strip and after a predetermined number of feet of incoming work strip have passed through the first roll stand in accordance with the first schedule it may be desired to effect a change to the second schedule operation when the predetermined gauge change point of the work strip arrives at and enters the first roll stand. A provided sequence control system prior to this event senses the work strip delivery gauge leaving the last roll stand and senses the operating speed of each roll stand, and then determines by mass flow considerations the work strip delivery gauges respectively leaving each of the first, second, third and fourth roll stands in accordance with the relationship of above equation (1).

When the gauge change point of the work strip arrives at the first roll stand the roll opening of that stand is changed by a predetermined amount by the sequence control system such that the delivery gauge of the work strip leaving the first roll stand is now in accordance with the desired second gauge schedule and since the work strip in accordance with the first schedule is still passing through the remaining subsequent roll stands the speeds of those remaining stands as well as the speed of the first stand are not changed. When the gauge change point of the work strip enters the second roll stand, the operating speed of the first roll stand is changed in accordance with the predetermined second schedule of operation, while the speed of the second rollstand is not changed since the work strip in accordance with the first schedule is still passing through the third, fourth and fifth roll stands, and the speeds of the third, fourth and fifth roll stands are not changed so as to continue the desired operation in accordance with the first gauge schedule. When the gauge change point of the work strip enters the third roll stand, the operating speeds of the previous first and second roll stands are changed in accordance with the second gauge schedule of operation, and the speeds of the third roll stand and the following roll stands are not changed since the work strip in accordance with the first gauge schedule is still operative with those roll stands. When the gauge change point of the work strip enters the fourth roll stand, the speeds of the previous first, second and third roll stands are changed in accordance with the second gauge schedule of operation, and the speeds of the fourth and fifth roll stands are not changed since the work strip in accordance with the first gauge change schedule is still operative with those roll stands. When the gauge change point of the work strip enters the fifth roll stand, the speeds of the previous first, second, third and fourth roll stands are changed in accordance with the second gauge schedule of operation, and the speed of the fifth roll stand is not changed. It is important to note here that the above described sequential operations, for a five stand tandem rolling mill, have resulted in four speed changes of the first roll stand, three speed changes of the second roll stand, two speed changes of the third roll stand and one speed change of the fourth roll stand. The rolling mill is now operative with the work strip in accordance with the second gauge schedule. If it should be desired to undertake a third gauge schedule of operation, the sequential control changes made to the respective roll stands would again be similarly provided in this manner.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other advantages and features of the present invention will become more apparent from the following detailed description taken in conjunction with the accompanying drawings which form a part of this specification, and in which:

FIG. 1 is a block schematic diagram of a tandem rolling mill and a gauge change sequence control system operative with that rolling mill in accordance with the present invention;

FIG. 2 is a chart illustrating typical speed and work strip gauge or delivery thickness conditions as a gauge change point of the work strip passes through the roll stands 1 to 5 of the rolling mill;

FIG. 3 is a chart illustrating the operation of the predetermined per unit multipliers to control the speeds of the roll stands in relation to the original gauge schedule and showing the progression of provided speed changes as the gauge change point of the work strip passes through the respective stands of the tandem rolling mill;
and

FIGS. 4A and 4B show a flow chart of a suitable instruction control program for a digital control computer included within the gauge change sequence control apparatus shown in FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

With reference particularly to FIG. 1 of the drawings, the control system shown includes a five-stand tandem rolling mill having stands RS1, RS2, RS3, RS4 and RS5. Each stand comprises a pair of work rolls 10 and 12, between which work strip material being rolled is passed. The associated backup rolls for each stand are not shown. The strip issuing from the last stand RS5 is wound on a coiler 16, with the direction of strip movement being from left to right as indicated by the arrow 18 in FIG. 1.

The rolls of each stand are driven by means of respective drive motors M1, M2, M3, M4, and M5 each controlled by a suitable speed control circuit C1, C2, C3, C4, and C5, respectively. In this respect, and since each of the stands in the mill is reducing the strip in thickness, the speed of the material issuing from any stand must be greater than that entering the stand in accordance with the well-known constant volume principle of material mass flow. Accordingly, the speed of stand RS2 must be greater than the speed of stand RS1; the speed of stand RS3 must be greater than the speed of stand RS2, and so forth as well known to persons skilled in this art, with the speed of the last stand RS5 being the greatest.

It should be noted that the gauge change sequence control 26 is connected to control each drive motor speed through operation of the respective speed controls. It will be understood that a reference speed signal is supplied to each of the respective speed controls C1 to C5 for this purpose.

In the embodiment of the invention shown herein, the roll gap opening of each roll stand is determined by respective gap actuators G1, G2, G3, G4 and G5 as shown, and preferably including hydraulic cylinders, such that for each roll stand a hydraulic cylinder provides the necessary roll force at the stand to reduce the strip 14 in delivery gauge or thickness; and it will be understood that only one cylinder may be provided for each stand or there may be hydraulic cylinders on opposite sides of each mill stand, loading the chocks at the opposite ends of the work rolls. A mechanical screwdown mechanism including an electrical screwdown motor can be used if desired to effect the required roll force at each stand, but the hydraulic cylinders may be preferred because of their more rapid speed of operation.

The delivery gauge of strip material passing through the first stand RS1 is measured by means of an X-ray gauge 28 or the like positioned at the delivery side of first stand RS1, which X-ray gauge 28 is operative in conjunction with the automatic gauge control system 30 to control the roll opening of roll stand RS1 to cause the gauge error leaving roll stand RS1 to be reduced to zero. The automatic gauge control system 30 is operative with a gauge reference in accordance with the desired exit gauge from stand RS1. If the actual gauge at the output of stand RS1 does not match the desired reference gauge, then automatic gauge control system 30 operates in conjunction with X-ray gauge 28 to either increase or decrease the roll opening of stand RS1 to increase or decrease the roll force of stand S1 and thereby vary the roll opening of stand RS1 and thereby vary the delivery gauge of the work strip material issuing from stand RS1 until the delivery gauge matches the desired reference gauge.

Between successive pairs of the roll stands are tension control device T1, T2, T3 and T4 which measures tension in the strip between each set of stands, such as the tension in the strip material **14** between stands RS1 and RS2, and produces an electrical signal proportional thereto. This tension signal in relation to tension control T1 is compared with a tension reference signal in accordance with desired tension, and which may be supplied by the sequence control apparatus **26**, and if the two are not the same, then the tension control device T1 will vary the pressure exerted by the gap actuator G2 for stand RS2, thereby varying the roll gap opening and/or the roll force of stand RS2. Similar tension control operations are provided for stands RS3 and RS5, respectively. Each tension control device measures a particular interstand tension and compares it with a desired reference tension, and if the two are not the same, then the roll gap opening for the succeeding stand is varied as required for work strip gauge correction.

For illustration, let us assume that the work strip tension increases between stand RS2 and stand RS3. Under these circumstances, comparison of the increased tension signal within the tension control device T2 with the desired reference tension act to decrease the roll gap and increase the roll force of the rolls on stand RS3 until the work strip tension between stands RS2 and RS3 is reduced to the desired value. Similarly, if the tension between stands RS2 and RS3 should fall, then this provided tension control operation will act to increase the roll gap and decrease the force until the tension rises to the desired value. All of this, of course, assumes that the relative speeds of the stands remain unchanged.

The final delivery output gauge of the strip material passing through the tandem rolling mill is measured by means of an X-ray gauge **42** or the like, which produces an electrical signal proportional to the actual and measured output work strip gauge error. If the actual output gauge does not match the desired reference gauge, then the gauge error signal is applied to the speed control circuit C5 to increase or decrease as required the speed of drive motor M5 of stand RS5, which in turn changes the tension between the last two stands to correct for the variation from the desired delivery gauge. If the correction is large enough to exceed the provided tension control dead band, the tension control device T4 will appropriately increase or decrease the roll gap of the last stand RS5 as required for correction of the interstand tension. In most cases, however, speed and tension control for varying final output gauge is desired on the last stand and the roll gap is changed only when the delivery gauge error is very large.

As was discussed above, rolling mills of this general arrangement have in the past been generally operative to roll a continuous length of strip on a coil to a single specified thickness of delivery gauge along the entire length of the strip.

However, situations arise where it is desired to change the gauge of the strip material on a single and perhaps larger coil while it is in motion through the rolling mill and being rolled. As was explained above, this may happen, for example, on small orders where, in the past, it has been necessary to roll a single coil of strip material of limited length, and this previously required stopping the mill between successive, small coils, and resetting the respective stand speed and gauge references after each such limited length coil was rolled. The requirement for making gauge schedule changes while rolling will also apply for the new continuous operating rolling mills which roll work strips made up of several individual coils attached together end to end to eliminate the previous need for threading the individual work strip coils through the roll stands of the rolling mill.

In accordance with the present invention, one or more delivery gauge changes can be effected during rolling of a single work strip, by initially changing the roll gap setting of the first stand RS1 to change the delivery gauge of the strip material issuing from the first stand. Thereafter and in timed sequence, the respective control speed references of succeeding stands are changed until all roll gap settings and speeds of the stands in the mill have been set to accommodate the desired new delivery gauge. In this respect, it is necessary only to change the gauge references to the first stand RS1 and the X-ray gauge positioned after the first stand. For all other stands, it is necessary only to change the speed reference provided for the stand. The roll gap opening of each stand following the first stand is controlled and varied as required by means of the tension control devices T1 to T4.

In accordance with the present invention, the change from one delivery gauge to another is done in a way to preserve the required constant mass flow of work strip through the stands of the rolling mill for both the first delivery gauge schedule and the second delivery gauge schedule. Since the mill has no facility to store work strip material between stands, the original mill setup was required to satisfy the mass flow relationship of above equation (1), where the product of the speed S times the strip delivery gauge or height H for each of the stands is equal to this same product for the other stands. The thickness is decreased as it passes through each stand, so the speed increases to provide the well-known constant volume flow operation. When the gauge change transition point passes midway between stands **2** and **3**, for example, there are two heights between stands **2** and **3**, the original work strip height H_{21} and the new work strip height H_{22}, where H_2 is the delivery gauge leaving stand RS2, H_{21} is for the first schedule and H_{22} is for the second schedule. The first value of the above set of equations no longer applies since the initial value H_{11} of the delivery gauge from stand **1** no longer exists but the remainder of the equation will still apply because the portion of the strip entering stand **3** is still the original height H_{21}. This means that speeds S_2, S_3, S_4 and S_5 are still maintained at the original values to satisfy the requirements of that portion of the initial schedule that is still in that portion of the mill.

The constant mass flow relationship, for the second schedule of work strip heights H_{12} and H_{22} being rolled in the stands **1** and **2** is:

$$(S_{122})(H_{12})=(S_{21})(H_{22}) \quad (2)$$

The speed S_{21} of stand RS2 is shown to be the initial schedule value to satisfy the speed requirements of the first gauge or height schedule. The new speed S_{122} for stand RS1 is chosen to satisfy the constant mass flow requirements of the second gauge or height schedule, after the first sequential speed change for the first roll stand RS1.

Similarly, when the gauge change point is between stands RS3 and RS4, the speed of stand RS3 must be maintained until all of the original gauge schedule passes to stand RS4, and the speeds of stands RS1 and RS2 must satisfy the constant mass flow relationships for the new height schedule so that:

$$(S_{123})(H_{12})=(S_{223})(H_{22})=(S_{32})(H_{32}) \quad (3)$$

and so forth.

In the actual operation of such a mill, the reference stand speeds, roll openings, and interstand tensions are preset and adjusted to the desired work and deliver the required gauge out of the first stand and the last stand, and the gauge being delivered from each of the other stands is determined by the relationship between the stand speeds. The speed pattern is directly related to the respective delivery gauges being produced, so the rolling schedule for each work strip is primarily established by the desired speed relationship pattern and the roll gaps and tensions are preset and adjusted to suit that desired speed relationship.

The initial speed pattern in relation to the first gauge schedule product before the desired gauge change has to be determined and also the second gauge schedule pattern of speeds that is required after all of the stands are filled with the second gauge product after the desired gauge change. This might be done by the operator using his experience and judgement, by a wired basic sequence controller, or by a predetermined and stored control program operative with an on line digital computer. In accordance with the teachings of the present invention, there is provided the desired sequential control of the rolling mill operation during the transition period as the gauge change enters each roll stand of the mill and passes successively from stand to stand.

In FIG. 2 there is provided a chart to illustrate typical sequential changes in the rolling mill operating conditions as a work strip gauge change point moves through the roll stands of that rolling mill. At the top of the chart there is shown the first gauge schedule operation, with the first stand speed S_{11} (stand one and first schedule) equal to **446** and delivery gauge H_{11} equal to **0.085** being indicated, as well as the second stand speed S_{21} (stand two and first schedule) equal to **583** and delivery gauge H_{21} equal to **0.065**, the third stand speed S_{31} equal to **758** and delivery gauge H_{31} equal to **0.050** and so forth.

When the gauge change point or transition of the work strip arrives at the first roll stand, the gauge change sequence control apparatus **26** as shown in FIG. **1** provides a different delivery gauge reference H_{12} (stand one and second schedule) to the automatic gauge control system **30** and the associated gap actuator G1 of the first stand RS1, such that the delivery gauge H_{12} now equals **0.070.** The first stand speed S_{11} is still equal to **446** and the operational conditions for the remaining stands two through five stay the same.

When the gauge change point or transition arrives at the second roll stand, the gauge change sequence control apparatus provides a different speed reference to the speed control C1 operative with the first stand RS1, such that the speed reference now becomes S_{122} equal to **416.** The delivery gauge for the second schedule from the first stand remains at H_{12} equal to **0.070,** but due to the operation of the tension regulating device **T1,** the delivery gauge from the second stand now becomes H_{22} equal to **0.050.** The second stand speed remains the same, with S_{21} equal to **583,** and the operating conditions for the subsequent third, fourth and fifth stands remain the same.

When the gauge change point or transition of the work strip arrives at the third roll stand RS3, the gauge change sequence control apparatus provides a different speed reference to each of the first and second roll stands, such that the first stand speed S_{123} is equal to **390** and the second stand speed S_{223} is equal to **546.** The delivery gauge for the second schedule from each of the first and second roll stands remains unchanged such that the first stand gauge H_{12} is equal to **0.070** and the second stand gauge H_{22} is equal to **0.050.** However, through operation of the tension control device **T2** the delivery gauge from the third roll stand RS3 changes such that this gauge H_{32} is equal to **0.036.** The third stand speed S_{31} remains the same at **758,** and the operating conditions for the fourth and fifth stands do not change.

When the gauge change point of the work strip arrives at the fourth roll stand **RS4,** the gauge change sequence control apparatus provides a different speed reference to each of the first, second and third stands, such that the first stand speed S_{124} is equal to **310,** the second stand speed S_{224} is equal to **433** and the third stand speed S_{324} is equal to **602.** The delivery gauge from each of the first, second and third roll stands remains unchanged, such that the first stand gauge H_{12} is equal to **0.070,** the second stand gauge H_{22} is equal to **0.050** and the third stand gauge H_{32} is equal to **0.036.** However, through operation of the tension control device **T3** the delivery gauge from the fourth roll stand S4 changes such that this gauge H_{42} is equal to **0.024.** The fourth stand speed remains the same at **903** and the operations of the fifth stand do not change.

When the gauge change point of the work strip arrives at the fifth roll stand **RS5,** the gauge change sequence control apparatus provides a different speed reference to each of the first, second, third and fourth roll stands, such that the first stand speed S_{125} is equal to **286,** the second stand speed S_{225} is equal to **400,** the third stand speed S_{235} is equal to **555** and the fourth stand speed S_{425} is equal to **833.** The delivery gauges from respectively the first, second, third and fourth roll stands remain unchanged, however through operation of the tensioon control device **T4** the delivery gauge from the fifth roll stand **RS5** changes such that this gauge H_{52} is equal to **0.20.** The fifth stand speed S_{51} remains the same at **1000.**

In FIG. **3** there is provided a chart to illustrate the predetermined ratio multipliers that are utilized to establish the adjustments made in the previous stand speeds when the gauge change point of the work strip arrives at a particular roll stand. More specifically, when the gauge change point arrives at the second roll stand RS2, the speed of the first roll stand RS1 is adjusted by the multiplier $(S_{21})(H_{22})/(S_{11})(H_{12})$. When the gauge change point arrives at the third roll stand RS3, the respective speeds of the first and second roll stands RS1 and RS2 are adjusted by the multiplier $(S_{31})(H_{32})/(S_{21})(H_{22})$. When the gauge change point arrives at the fourth roll stand **RS4,** the respective speeds of the first, second and third roll stands **RS1, RS2** and **RS3** are adjusted by the multiplier

$(S_{41})(H_{42})/(S_{21})(H_{22})$. When the gauge change point arrives at the fifth roll and RS5, the respective speeds of the first, second, third and fourth stands RS1, RS2, RS3 and RS4 are adjusted by the ratio multiplier $(S_{51})(H_{52})/(S_{41})(H_{42})$. This completes the desired transition from rolling the work strip at the first gauge schedule and rolling the work strip at the second gauge schedule.

The initial first schedule is rolled on a five stand mill going from an input gauge of 0.110 inch to a finished gauge of 0.038 inch, with the drafting pattern in the respective roll stands as shown. When a desired gauge change is to be made, and when the selected gauge change point along the length of the work strip is passing through the roll stands, the second gauge schedule of operation will roll the work strip from an input gauge of 0.100 inch to a delivery gauge of 0.020 inch leaving the mill. The delivery speed from the fifth and last roll stand RS5 is held constant at 1,000 feet per minute during the schedule change. The first schedule parameters shown in FIG. 3 can be determined by the sequence control apparatus reading the speed of each stand as provided by the respective stand pilot generator signals prior to the schedule change, and then using the volumetric flow relationship of above equation (1) the work strip thickness leaving each of the first, second, third and fourth roll stands can be established. The second schedule parameters can be provided by the operator or determined by the control computer within the sequence control apparatus prior to the selected time for a gauge schedule change, and these parameter values will be stored in the computer memory or suitable storage locations until needed. The various per unit speed multipliers as illustrated in FIG. 3 can then be determined before the gauge schedule change is started. Thusly, when the gauge change point arrives at the first roll stand, the second schedule delivery gauge from the first roll stand has previously been determined to be 0.070 inch and a suitable roll gap opening reference is applied to control the first stand. When the gauge change point arrives at the second roll stand RS2, the speed of the first roll stand RS1 will be changed by the multiplier

$$(S_{21})(H_{22})/(S_{11})(H_{12}) = (583)(0.050)/(446)(0.070) = 0.933, \quad (4)$$

such that the speed of the first roll stand will be changed to (0.933) 446 = 416 FPM. When the gauge change point arrives at the third roll stand RS3, the speed of the first roll stand RS1 and the speed of the second roll stand RS2 will be changed by the multiplier

$$(S_{31})(H_{32})/(S_{21})(H_{22}) = (758)(0.036/583)(0.050) = 0.937, \quad (5)$$

such that the speed of the first roll stand will be changed to (0.937) 416 = 390 FPM and the speed of the second roll stand will be changed to (0.937) 583 = 546 FPM. The speed changes that occur when the gauge change point arrives at the fourth roll stand RS4 and then arrives at the fifth roll stand RS5 are similarly established and illustrated in the chart of FIG. 3. It should be noted that all roll stands ahead of the gauge change transition point are maintaining a correct speed relationship for the first gauge schedule and all roll stands behind the gauge change transition point are maintaining a correct speed relationship for the second gauge schedule.

The control operation logic flow chart shown in FIG. 4 is illustrative of one suitable embodiment of the present invention is provided by operation of the sequence control apparatus. A stored program digital computer could be utilized for this purpose if desired or a hardwired controlled apparatus could be provided if desired. When it is desired to enter the control program illustrated by this flow chart, at step 400 a determination is made from provided input information of the desired length of work strip in the first gauge schedule. At step 402 a counter is set with a predetermined count level to effect a desired slow down of the rolling mill operation to a selected transition speed just prior to the gauge change point of the work strip arriving at the first roll stand RS1. At step 404 the pulses from a pulse generator operative with the entry bridle or the delivery bridle positioned ahead of the first roll stand RS1, are counted to track the gauge change point movement, and when a predetermined slowdown initiate count is reached in the counter the rolling mill is decelerated to a selected transition speed at step 406. At step 408 a reading is made of the delivery gauge leaving the last roll stand RS5 through operation of the X-ray gauge device and the respective speeds of all the roll stands through operation of the pilot generator operative with each roll stand. At step 410 a determination is made of the delivery gauge from each of the first, second, third and fourth roll stands by operation of the mass flow relationship of above equation (1). At step 412 a determination is made by the sequence control apparatus of the required transition speed per unit multipliers, as shown in FIG. 3. At step 414 the gauge change point movement is tracked to arrive at the first roll stand RS1 through operation of perhaps a weld detector positioned a known distance ahead of the first roll stand to initiate counting of output pulses from the bridle roll pulse generator. When the gauge change point arrives at the first roll stand RS1, at step 416 the first roll stand roll opening is adjusted from the first schedule delivery gauge H_{11} setting to the second schedule delivery gauge H_{12} setting. At this time, allowing for necessary transport time delay, the gauge reference for the X-ray gauge device 28 is changed to the second schedule gauge H_{12}. At step 417 and X-ray monitor operation, provided by operation of the X-ray gauge device 42, is released from the first roll stand RS1, since the X-ray gauge device 42 is still operating with the first gauge schedule and the first roll stand is now operative with the second gauge schedule. At step 418 the gauge change point movement is tracked until arrival at the second roll stand RS2, through counting of output pulses from the pulse generator coupled with the first roll stand RS1. At step 420 the speed reference for the speed control C1 operative with the first roll stand RS1 is adjusted by the per unit multiplier shown in FIG. 3 such that the first roll stand is now operative at the desired speed relationship in accordance with the seocnd gauge schedule. At step 422 the gauge change point movement is tracked to arrive at the third roll stand RS3, through counting of output pulses from the pilot generator coupled to the second roll stand RS2. At step 424 and when the gauge change point arrives at the third roll stand RS3, the speed references for the respective speed controls C1 and C2 are adjusted by the per unit multiplier shown in FIG. **3** such that the first and second roll stands are now operative at the desired speed relationship in accordance with the second gauge schedule. At step **426** the gauge change point movement is tracked to arrive at the fourth roll stand RS4, through counting of output pulses from the pilot generator coupled to the third roll stand RS3. At step **428** and when the gauge change point arrives at the fourth roll stand, the speed references for the respective speed controls C1, C2 and C3 are adjusted by the per unit multiplier shown in FIG. **3** such that the first, second and third roll stands are now operative at the desired speed relationship in accordance with the second gauge schedule. At step **430** the gauge change point movement is tracked to arrive at the fifth roll stand RS5, through counting of output pulses from the pilot generator coupled to the fourth roll stand RS4. At step **432** and when the gauge change point arrives at the fifth roll stand, the speed references for the respective speed controls C1, C2, C3 and C4 are adjusted by the per unit multiplier shown in FIG. **3** such that the first, second, third and fourth roll stands, as well as the fifth roll stand, are now operative at the desired speed relationship in accordance with the second gauge schedule. At step **434** the rolling mill is accelerated to a predetermined run speed of operation, and the control program then ends.

The following is an illustrative example of an instruction program listing that has been prepared of the respective roll stands in accordance with the functional logic flow chart shown in FIG. **4**.

I claim:

1. In a gauge control system for a tandem rolling mill having a plurality of roll stands operative to reduce the gauge of a work strip having a gauge change point and being passed through said rolling mill, the combination of means for controlling the operating speed of a first roll stand, and means responsive to the work strip movement for sensing the arrival of said gauge change point at a second roll stand for providing a predetermined change in the operating speed of said first roll stand while maintaining the present operating speed of the second roll stand, with said predetermined change being in accordance with a relationship including the present operating speed of the second roll stand and the new desired work strip delivery gauge from at least one of said first and second roll stands.

2. The gauge control system of claim **1**, including means for controlling the operating speed of said second roll stand, with said work strip movement responsive means sensing the arrival of said gauge change point at a third roll stand for providing desired changes respectively in the operating speed of said first roll stand and in the operating speed of said second roll stand while maintaining the present operating speed of the third roll stand, with said desired changes being in accordance with a second relationship including the present operating speed of the third roll stand and the new desired work strip delivery gauge from at least one of said second and third roll stands.

3. The gauge control system of claim **1**, with said predetermined change in the operating speed of said first roll stand being in accordance with the relationship

$$S_{12} = (S_{21})(H_{22})/H_{12}$$

where S_{12} is the new desired operating speed for said first roll stand, S_{21} is the present operating speed for the second roll stand, H_{22} is the new desired work strip delivery gauge from the second roll stand and H_{12} is the new desired work strip delivery gauge from the first roll stand.

4. The gauge control system of claim **1**, including means for determining the operating speed of each of said roll stands and the workstrip delivery gauge from each of said roll stands before said gauge change point arrives at said first roll stand.

5. The gauge control system of claim **1**, with said means responsive to the work strip movement being operative to provide said change in the operating speed of said first roll stand in accordance with the relationship

S_{N-1} = original speed (N-**1**)* (original speed N)(final gauge N)/(original speed N-**1**)(final gauge N-**1**)

where S_{N-1} is the speed reference for said first roll stand after said gauge point has arrived at said second roll stand, original speed N-**1** is the speed reference of said first roll stand before said gauge point arrives at said second roll stand, original speed N is the speed reference of said second roll stand before said gauge point arrives at said second roll stand, final gauge N is the work strip delivery gauge from said second roll stand after said gauge point arrives at said second roll stand and final gauge N-**1** is the work strip delivery gauge from said first roll stand after said gauge point arrives at said second roll stand.

6. In a gauge control system for a tandem rolling mill having a plurality of roll stands operative to reduce the gauge of a work strip having a gauge change point and being passed through said rolling mill, the combination of

means for controlling the operating speed of each of said roll stands,

means responsive to the movement of said work strip sensing the arrival of said gauge change point at roll stand N of said rolling mill for providing a change in the operating speed of previous roll stand X while maintaining the present operating speed of roll stand N, with said change being in accordance with the relationship

$$S_{X2} = (S_{N1})(H_{N2})/H_{X2}$$

where S_{X2} is the new speed reference for previous roll stand X, S_{N1} is the present speed reference for roll stand N, H_{N2} is the new delivery gauge desired from roll stand N and H_{X2} is the new delivery gauge desired from previous roll stand X.

7. The gauge control system of claim **6**, with said means responsive to the movement of said work strip being operative to provide a change in the operating speed of each roll stand previous to roll stand N in accordance with said relationship.

8. The gauge control system of claim **6**, including

means for controlling the roll opening of at least said roll stand N,

with said means responsive to the movement of said work strip providing a predetermined change in the roll opening of said roll stand N when said gauge change point arrives at said roll stand N.

9. A method for controlling the work strip gauge leaving a tandem rolling mill having a plurality of roll stands, with said work strip having a gauge change point passing through said roll stands, the steps of said method comprising determining the arrival of said gauge change point at a first roll stand,

providing a first predetermined change in the roll opening of said first roll stand when said gauge change point arrives at said first roll stand,

determining the arrival of said gauge change point at a second roll stand, and

providing a second predetermined change in the operating speed of said first roll stand when said gauge change point arrives at said second roll stand.

10. The method of claim **9**, including the steps of

determining the arrival of said gauge change point at a third roll stand, and

providing an additional change in the operating speed of said first roll stand when said gauge change point arrives at said third roll stand.

11. A method of controlling the work strip gauge leaving a tandem rolling mill having a plurality of roll stands, with said work strip having a gauge change point at which it is desired for the gauge of the work strip leaving the rolling mill to change from a first delivery gauge schedule to a second delivery gauge schedule, the steps of said method comprising

determining the arrival of said gauge change point at a selected roll stand of said rolling mill subsequent to at least the first roll stand of said rolling mill, and

controlling the operating speed of each roll stand of said rolling mill prior to said selected roll stand when said gauge change point arrives at said selected roll stand in accordance with a predetermined relationship including the operating speed of said selected roll stand for said first schedule and the new desired work strip delivery gauge for said second schedule from at least said selected roll stand.

12. The method of claim **11**, including the step of

controlling the roll opening of said first roll stand by measuring the actual workpiece delivery gauge for said second schedule leaving said first roll stand in comparison to a desired reference delivery gauge for the work strip leaving said first roll stand.

13. The method of claim **11**, including the step of sensing the work strip tension before each of predetermined roll stands of said rolling mill and controlling the roll opening of each of said predetermined roll stands for maintaining respective desired tension conditions in relation to said predetermined roll stands.

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