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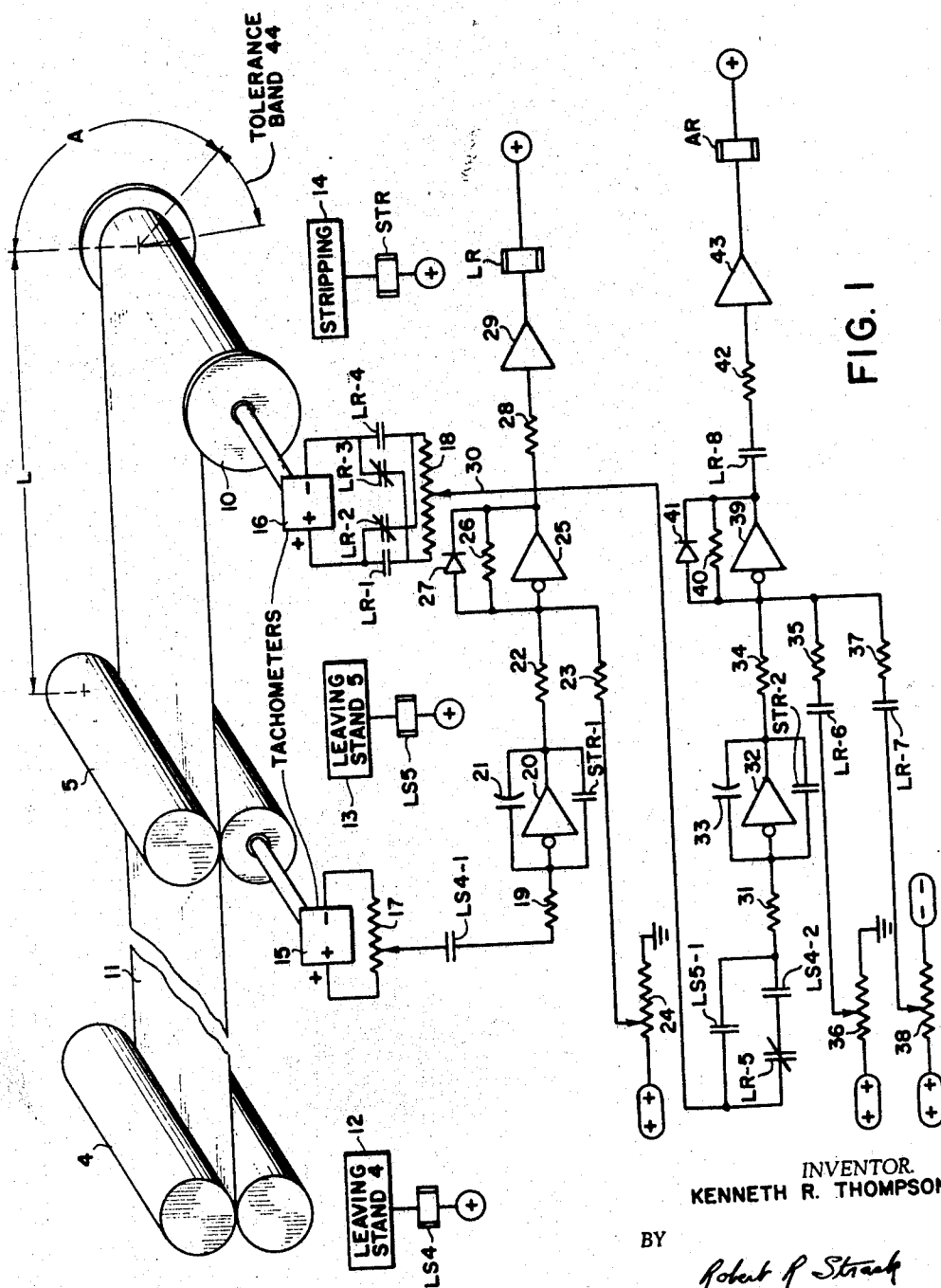
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AUTOMATIC CONTROL SYSTEMS FOR ROLLING MILLS

3 Sheets-Sheet 1

Filed Dec. 3, 1962



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3 Sheets-Sheet 2

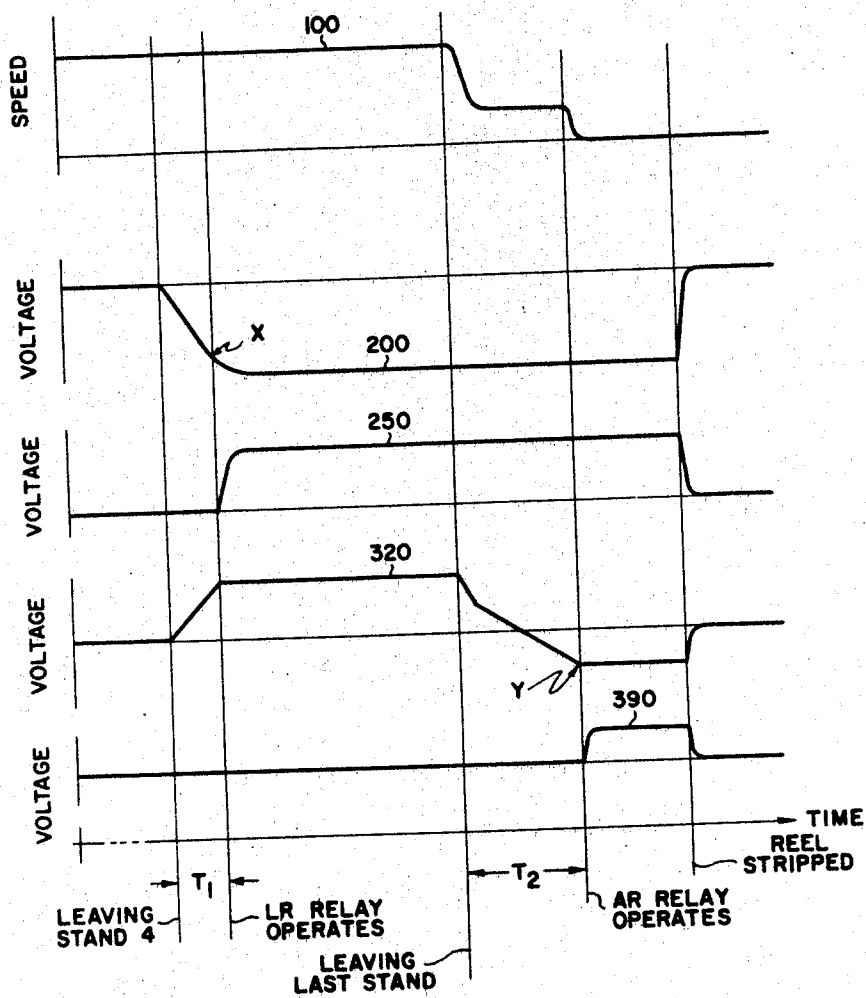


FIG. 2

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3 Sheets-Sheet 3

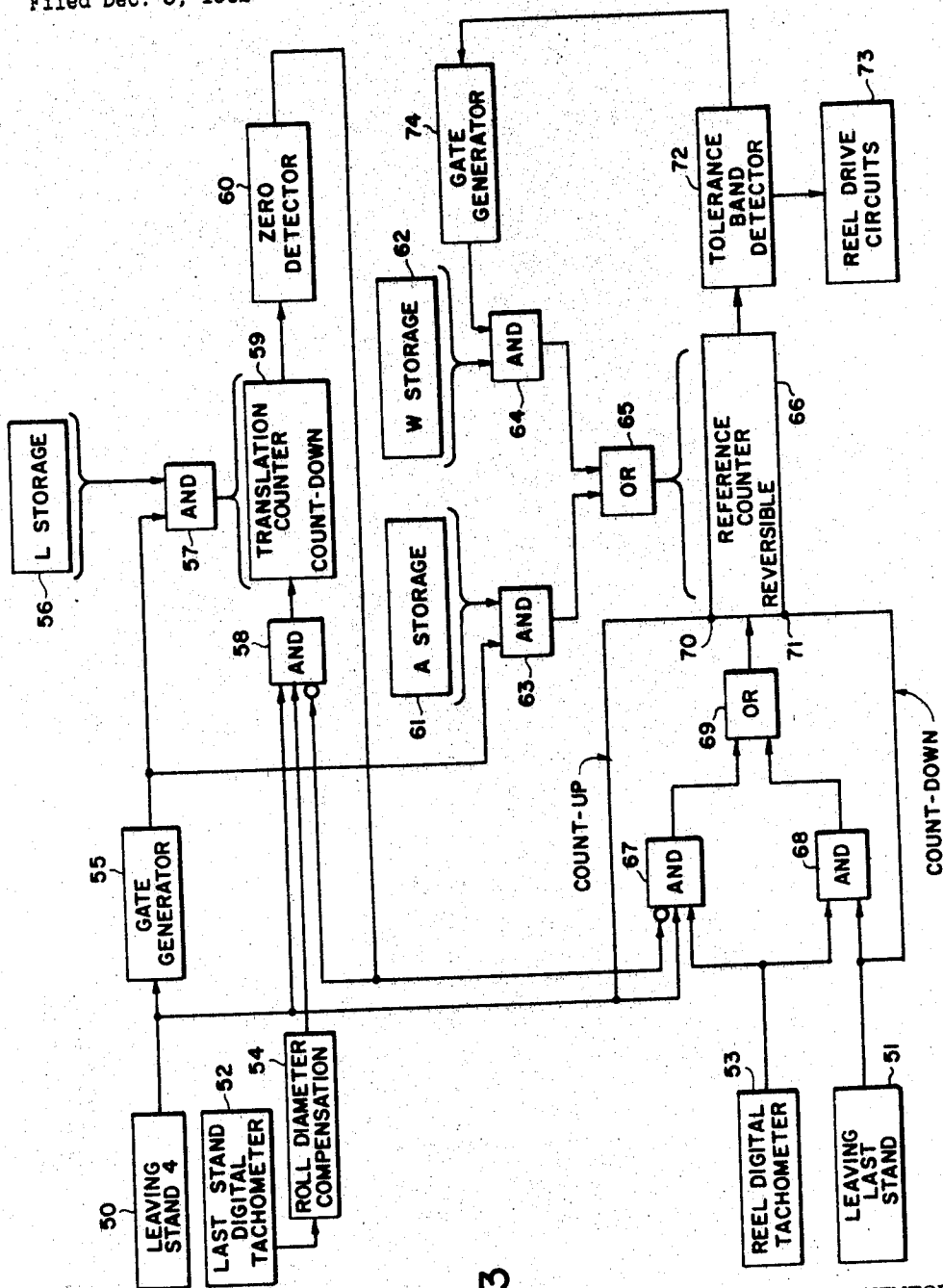


FIG. 3

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AUTOMATIC CONTROL SYSTEMS FOR ROLLING MILLS

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This invention relates to the production of material by rolling or drawing through multi-stand tandem mills. More particularly, the invention relates to automatic means for controlling the winding reel at the end of such a mill.

In the handling of strip material, the speed of operation greatly affects the operating efficiency of a system. Every time it is necessary to slow down the system to insert or extract strip material, valuable time is lost. When a strip of material nears the end of processing and the tail end approaches a winding reel, it has been the practice in the past to reduce the mill speed and "jog" the drive mechanism while visually observing the strip in order to position the tail end of the strip as desired. The winding reel is stopped so that the tail end of a strip of material is located at a particular position on the reel. This facilitates subsequent handling after the reel is stripped.

An object of the present invention is to increase the operating speed and efficiency of rolling mills.

Another object of the present invention is to improve the automation of strip rolling mills by eliminating manual operation under visual observation.

Still another object of the present invention is to provide automatic means for stopping a winding reel within a preselected tolerance band in order to position the tail end of strip material as desired.

In providing automatic means for stopping a winding reel, it is necessary to consider the fact that the accumulating coil has a diameter which increases in accordance with the amount of material stored therein. Furthermore, it is often the case that the mill rolls prior to the winding reel may be of variable diameter.

In accordance with the invention, a control system is provided for calculating the number of revolutions the winding reel must make in order to bring the tail end of a strip of material from the bite of the last mill to a preselected point on the circumference of the reel. The calculations include variables introduced by various diameter mill rolls, and the ever-changing diameter of the winding reel. This system is rendered operative a minimum amount of time before actual stopping is to occur and permits maximum handling speed and efficiency.

The illustrative embodiments disclosed hereinafter comprise means for accomplishing the described control operations by both analog and digital techniques. The novel features of the invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, together with further objects and features thereof, may best be understood by reference to the following description taken in conjunction with the drawings wherein:

FIGURE 1 comprises an illustrative circuit schematic of an analog control system in accordance with the invention;

FIGURE 2 comprises a plurality of typical waveforms appearing at selected points in the circuit schematic of FIGURE 1; and

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FIGURE 3 comprises an illustrative logic block schematic of a digital control system in accordance with the invention.

The sketch appearing across the top of FIGURE 1 illustrates the pertinent components of a multiple stand mill of the nature contemplated by the present invention. As shown therein, a strip of material 11 is handled by a plurality of mill stands represented by mill rolls 4 and 5, and after leaving the last stand 5, the strip is coiled upon a reel 10.

It is desired to stop the reel when the tail end of the strip is within the tolerance band 44, illustrated in the figure. Last stand 5 is considered to be separated from the reel 10 by a distance "L" and the tolerance band commences at an arc distance "A" from the point of strip contact with reel 10. Thus, the tolerance band may be defined as extending for a preselected angle from a point L+A removed from last stand 5.

Using the defined distances, a knowledge of the diameter of mill rolls 5, and the measurable rotational velocities of rolls 5 and reel 10, the instant of time at which the reel should be stopped can be calculated.

The relationship between the time "T₁" required to transport a length "L" of strip and the rotational velocity "ω₅" of the last stand is:

$$L = \frac{\pi d_5}{60} \int_0^{T_1} \omega_5 dt \quad (1)$$

where d₅ is the stand roll diameter.

The relationship between time T₁ and the rotational velocity "ω_c" of the reel is:

$$L = \frac{\pi d_c}{60} \int_0^{T_1} \omega_c dt \quad (2)$$

where d_c is the variable coil diameter.

Time T₁ may be calculated from Equation 1 and used in Equation 2 to determine the diameter d_c.

The distance between the last stand and the stopping point is:

$$L + A = \frac{\pi d_c}{60} \int_0^{T_1} \omega_c dt + \frac{\pi d_c}{K} \quad (3)$$

where A is represented by a friction, 1/K, of the coil circumference.

In terms of the complete time "T₂" required from the time the tail end of the strip leaves stand 5 until stopping, the relationship with the rotational velocity of the reel is:

$$L + A = \frac{\pi d_c}{60} \int_0^{T_2} \omega_c dt \quad (4)$$

Combining Equations 3 and 4 and simplifying yields:

$$\frac{1}{60} \int_0^{T_1} \omega_c dt + \frac{1}{K} = \frac{1}{60} \int_0^{T_2} \omega_c dt \quad (5)$$

Since T₂ is the only unknown quantity, it can be determined by integrating the rotational velocity of the reel until it equals the value appearing on the left of Equation 5. In essence, the circuits shown hereinafter perform the required calculations.

In order to more succinctly set forth the circuit schematics, conventional symbols have been used to represent various logic and circuit functions. Any number of specific circuit configurations may be developed by those skilled in the art to perform the functions designated by the various symbols. The voltages supplied to operate the

circuits are, of course, dependent upon the specific components employed; consequently, only the polarity of the voltage source is shown in the circuit schematic. In situations where it is desired to express a difference in magnitude between a first and second voltage of the same polarity, a different number of polarity symbols are used. For example, (+) is less than (++) . These symbols do not convey the degree of the difference in magnitude, only the sense of the difference.

In connection with the control relays, shown in FIGURE 1, it will be seen that the detached contact form of notation has been used. This type of illustration lends itself to increased clarity of circuit description and a more complete understanding of circuit operation by locating the contacts of a relay in the portion of a circuit drawing where their activation performs an operative function. The designation for each pair of contacts consists of an alphabetic prefix identical to the designation of its associated relay coil and a numerical suffix individual thereto. In the symbols used, short parallel lines orthogonal to the circuit conductors represent normally open contacts. When these parallel lines are intersected by a slanting line, they represent normally closed contacts.

The circuitry in FIGURE 1 is designed to perform the required control calculations and furnish control signals in response to voltage conditions wherein the voltage magnitude is commensurate with strip length. In other words, the circuit of FIGURE 1 performs the control operation on an analog basis.

The analog circuit is activated in response to a signal generated when the tail end of a strip leaves a preselected point. In the illustration, a generator 12 provides this signal when the strip leaves stand 4 and a relay LS4 is energized in response thereto. The particular means used for detecting this condition and operating relay LS4 is not germane to the invention. Upon closure of contacts LS4-1 and LS4-2 in response to energization of the relay, the circuit sequentially proceeds to make the calculations required to determine at what instant the reel must be stopped.

First, the time required for the strip to travel a distance L is determined by integrating the rotational velocity of mill roll 5. A tachometer 15, mechanically driven by the mill roll, generates a voltage proportional to the speed of the strip, having the polarity shown. This voltage is integrated by an integrating amplifier circuit comprising inverting amplifier 20 and capacitor 21. The limits for this integration are imposed by comparing the integrator output with a voltage magnitude commensurate to the length L. A potentiometer 24 interconnected between a positive source and ground provides means for establishing this voltage under a broad range of conditions.

The output of the inverting integrator and the preset voltage representing distance L are supplied via resistors 22 and 23, respectively, to the input of an adder comprising inverting amplifier 25, resistor 26, and rectifier 27. When the magnitude of the integrator output is equal to that of the preset voltage, the adder provides an output which is operative via a resistor 28 and amplifier 29 to energize relay LR. Thus, relay LR is operated after a time, as measured from the initial operation of relay LS4, equal to the time required for the strip material to be transported a distance L.

During the period between operation of relays LS4 and LR, the rotational velocity of the reel 10 is integrated to develop a voltage magnitude commensurate with length L. This electrical integration corresponds to Equation 2 above, and is implemented by connecting the output of a reel tachometer 16 via normally-closed contacts LR-3, potentiometer 18, conductor 30, normally-closed contacts LR-5, operated contacts LS4-2, and resistor 31 to an integrator comprising inverting amplifier 32 and capacitor 33. Due to the inclusion of the normally-closed contacts LR-5, the integrating process takes place until relay LR

operates upon elapse of the period of time required to transport a length of strip L.

Thus, when relay LR operates, a voltage is present at the output of integrating amplifier 32 that has a magnitude commensurate with the length L. In FIGURE 2, the output of integrating amplifier 20 is shown by waveform 200 and the output of integrating amplifier 32 is shown by waveform 320. From the foregoing discussion, it will be apparent that the voltage magnitude "X" on waveform 200, at which the LR relay operates, is determined by potentiometer 24. The circuit remains in the present condition until a signal is generated upon detection of the tail end of the strip leaving the last stand. This causes generator 13 to energize relay LS5 and initiate a timing cycle that ends in stopping the reel in the desired position.

The voltage at the output of integrator 32 is commensurate with length L; by adding a value commensurate with the angle A, and comparing the sum with the integrated rotational velocity of the reel, Equation 5 may be solved electrically to yield the instant of time at which stopping should be initiated.

The value A is established by means of a potentiometer 36 connected between a positive voltage source and ground. The voltage from the slider of this potentiometer is connected via normally-open contacts LR6 and resistor 35 to the input of an adder comprising inverting amplifier 39, resistor 40, and rectifier 41. Other inputs to this adder include the output of integrating amplifier 32 and a variable voltage from a potentiometer 38 used to make small adjustments in the stopping position. In effect, potentiometer 38 serves as a vernier adjustment.

When the tail end of the strip leaves the last mill stand, operation of relay LS5 causes contacts LS5-1 to provide a path from reel tachometer 16 to the input of integrating amplifier 32. Because relay LR is energized at this time, the input signal is of positive polarity and the output of inverting integrator 32 is, therefore, of negative slope. Advantageously, the mill is initially slowed upon operation of relay LS5 preparatory to stopping. This slowing is illustrated in the reel velocity waveform 100 in FIGURE 2, and explains the changing slope from the output of amplifier 32 in waveform 320.

At time Y, the integrated output from the reel tachometer is commensurate with a distance $L+A$ and relay AR is operated by the output of adding amplifier 39 via contacts LR-6, resistor 42, and amplifier 43. Obviously, energization of relay AR indicates that the tail end of the strip is at the commencement of the tolerance band 44. The reel is, therefore, stopped by any desired means.

Digital control system

The circuit embodiment just described illustrates an arrangement for reel positioning wherein analog components and techniques are employed to establish a voltage level equivalent to a desired number of revolutions. It is also within the teaching and contemplation of this invention to control a reel by means of a digital technique. In such a digital circuit, conventional bistable counting devices are employed in conjunction with logic components to develop a discrete number representative of the number of revolutions the reel must make after the tail end is detected leaving the last mill stand 5. A reference counter is preset with a value that is equivalent to the sum of $L+A$. Thereafter, when the tail end of the strip leaves the last stand, the output of a digital tachometer associated with the reel is used to decrease the number registered in this reference counter until a zero is detected. At that time, stopping is initiated. Means for implementing this digital technique are illustrated in the logic circuit schematic in FIGURE 3.

In the circuit representation of FIGURE 3, standard components have been illustrated by appropriately labeled blocks. Thus, a translation counter 59 and a reference counter 66 comprising respectively a count-down device and reversible counting device, are shown. It is

well known in the art to fabricate such devices in binary form wherein the number registered may be increased or decreased by successively applied trigger pulses to an input terminal. These devices may be preset to initially register any number within the capacity of the counter in several ways. One of these ways includes individually setting each stage and another involves selectively introducing counting pulses until the desired number is registered. Either technique would be acceptable for pre-setting the counters in the application considered herein.

It is also well known in digital art, to represent certain operations as being either "AND" or "OR" functions. Both of these functions are employed in the embodiment of FIGURE 3. In an AND operation, if all of the inputs are of a particular nature, there is a discrete output. In an OR operation, if any of the inputs are of a particular nature, there is a discrete output. The means for implementing these operations are well known.

The digital circuit shown in FIGURE 3 operates in response to four signals. These signals correspond to those employed in conjunction with the analog circuit in FIGURE 1. Specifically, a signal is generated when the tail end of the strip leaves stand 4 and another is generated when it leaves the last stand 5. Signal generating means 50 and 51 are employed to provide these signals. Furthermore, digital tachometers 52 and 53 are connected to the last stand 5 and the reel 10, respectively, and provide pulses at a repetition rate proportional to the rotational velocities of the associated equipment.

The initiation signal produced by generator 50 when the tail end of the strip leaves stand 4, is used to preset translation counter 59 with a number representing the length L. Simultaneously, reference counter 66 is preset with a number representing the angle A. This is implemented by means of a gate generator 55 and AND gates 57 and 63. Upon leaving stand 4, generator 50 produces a signal pulse. This pulse is applied to gate generator 50, the output of which is a pulse of fixed duration. The number representing L is stored in a storage means 56 which may, for example, be in the form of a plurality of binary stages. When the output of gate generator 55 is produced, this output in conjunction with the number stored in means 56, is operative via AND gate 57 to preset the translation counter 59 with that number.

Those familiar with the art will realize that the AND function represented by gate 57 may in fact be performed by a plurality of coincidence gates which are enabled by the output from gate generator 55 to transfer the information from storage means 56 into the appropriate stages of the translation counter. However, the AND gate 57 may also be of simpler variety wherein a single input from the gate generator 55 in coincidence with successively appearing pulses from the storage means 56 will be operative to increase the count of the translation counter 59 until a number is registered therein which is representative of length L. Either type of AND function circuit is acceptable in the present embodiment. The important result is the presetting of the translation counter 59.

A number representing angle A is similarly preset into the reference counter 66 by means of an AND gate 63 and an OR gate 65. The output from gate generator 55 in combination with the number in storage means 61 provides a discrete output from AND 63 and this in turn generates an output from OR gate 65 that is applied to preset the reference counter 66.

Immediately after being preset, translation counter 59 has count-down pulses applied to the input thereof at a repetition rate determined by the speed of the last stand 5. These count-down pulses are generated by the last stand digital tachometer 52 and are applied via a roll diameter compensation circuit 54 and an AND gate 58.

is merely to provide means for taking into account any possible variation in the roll diameter of the last stand. If a fixed diameter roll is used, this means may be eliminated. AND gate 58 is of a conventional nature and connects the output of last stand digital tachometer 52 to count-down translation counter 59 upon receipt of the signal from generator 50 when the translation counter is not at zero. The latter condition is imposed by means of a zero detector 60 which applies an inhibiting signal to the input of AND 58 when the number registered in translation counter 59 equals zero. It will thus be appreciated that translation counter 59 continuously decreases the number registered therein at a rate determined by the speed of the last stand roll until zero is attained.

During the time that translation counter 59 is being counted down, reference counter 66 is counted up by pulses occurring at a repetition rate equivalent to the speed of the reel 10. This is accomplished via an AND gate 67 and OR gate 69. The input to AND gate 67 comprises a pulse train from reel digital tachometer 53; the signal from generator 50 that the tail end has left stand 4; and a signal from zero detector 60 indicating that the translation counter does not register zero. These connections are effective during the period of time that the translation counter is being counted down, to provide output pulses from AND gate 67 that are applied via OR gate 69 to the count input of reference counter 66. The reference counter increases the number registered therein in response to each pulse because the signal from generator 50 is also used to enable count-up input 70.

Since A was initially preset into reference counter 66, the pulses applied during this period are added thereto and the final number registered will equal the number of pulses produced by the reel tachometer 53 while a length of strip $L+A$ is being transported past a fixed point. The control system resides in this state until the tail end is detected leaving the last stand.

When the tail end of the strip leaves stand 5, a signal is generated by generator 51 which is applied to the count-down input 71 of reference counter 66. Simultaneously, the output from reel digital tachometer 53 is applied to the count input via AND gate 68 and OR gate 69. In response to these counting pulses, the reference counter decreases the number registered therein and when a zero is detected by the tolerance band detector 72, a signal is applied to the reel drive circuits 73 to stop the equipment. Obviously, for this phase of the operation, the tolerance band detector may take the form of a simple zero detector operative when the reference counter registers a zero.

If the reel drive circuits 73 are unable to stop the reel within a preselected tolerance band, means are provided to permit the reel to make another revolution and stop within the band on the second attempt. These means include a storage means 62 and an upper limit on tolerance band detector 72. In accordance with this feature, the reference counter is permitted to continue counting down to a number equivalent to the number of pulses generated by the reel tachometer 51 while the reel traverses the tolerance band. When this number is detected, a gate generator 74 is energized to produce an output which operates in conjunction with storage means 62 to preset the reference counter to a number equal to the number of pulses that would be generated by the reel tachometer during rotation from the end of the tolerance band to the commencement of the band. In other words, a number is preset into the reference counter which equals the difference between the tolerance band and a complete revolution. This number is a fixed value and has been designated W. The means for presetting it into the reference counter include AND gate 64 and OR gate 65. Once preset, the reference counter again controls the reel drive circuits 73 via tolerance band detector 72 and due to the now decreased speed of the reel, insures stopping within the band 44.

The above described circuits constitute particular embodiments of the invention. It will, of course, be understood that it is not wished to be limited thereto since modifications can be made both in the circuit arrangements and in the instrumentalities employed. It is contemplated in the appended claims to cover any such modifications as fall within the true spirit and scope of the invention.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A system for coiling strip material on a reel including means for stopping said reel to selectively position the end of said strip material in a predetermined spatial location, comprising a source of a signal, first means operative in response to said signal to produce a first control signal when a preselected length of material passes a point, control means operative during the interval between said signal and said first control signal to discretely identify the number of revolutions made by said reel, second means operative to produce a second control signal when the end of said material passes a point that is said preselected length distant from said reel, and means controlled by said control means and operative in response to said second control signal to stop said reel after said identified number of revolutions plus a preselected fraction of a revolution.

2. A system for coiling strip material on a reel including means for stopping said reel to selectively position the end of said strip material in a predetermined spatial location, comprising rotating means located a known distance from said reel and coupled to said material to rotate at a velocity proportional to the velocity thereof, a source of a signal, means operative in response to said signal and controlled in accordance with the velocity of said rotating means to produce a first control signal when a length of material equal to said known distance passes a point, control means operative during the interval between said signal and said first control signal to discretely identify the number of revolutions made by said reel, means operative to produce a second control signal when the end of said material leaves said rotating means, and means controlled by said control means and operative in response to said second control signal to stop said reel after said identified number of revolutions plus a preselected fraction of a revolution.

3. A system for coiling strip material on a reel including means for stopping said reel to selectively position the end of said strip material in a predetermined spatial location, comprising rotating means located a known distance from said reel and coupled to said material to rotate at a velocity proportional to the velocity thereof, a source of a signal, first means operative in response to said signal and controlled in accordance with the velocity of said rotating means to generate an output discretely representative of the length of material passing a preselected point, second means for generating an output having a characteristic discretely representative of said distance, third means controlled by said first and second means to produce a first control signal when a length of material equal to said distance passes said point, control means operative during the interval between said signal and said first control signal to discretely identify the number of revolutions made by said reel, means operative to produce a second control signal when the end of said material leaves said rotating means, and means controlled by said control means and operative in response to said second control signal to stop said reel after said identified number of revolutions plus a preselected fraction of a revolution.

4. A system for coiling strip material on a reel including means for stopping said reel to selectively position the end of said strip material in a predetermined spatial location, comprising rotating means located a known distance from said reel and coupled to said material to rotate at a velocity proportional to the velocity thereof,

a source of a signal, first means operative in response to said signal and controlled in accordance with the velocity of said rotating means to generate an output discretely representative of the length of material passing a preselected point, second means for generating an output having a characteristic discretely representative of said distance, third means controlled by said first and second means to produce a first control signal when a length of material equal to said distance passes said point, control means operative during the interval between said signal and said first control signal and controlled in accordance with the velocity of said reel to generate an output having a characteristic discretely identifying the number of revolutions made by said reel, fourth means for generating an output having a characteristic discretely representative of a preselected amount of rotation of said reel, means operative to produce a second control signal when the end of said material leaves said rotating means, and means controlled by said control means and said fourth means and operative in response to said second control signal to stop said reel after said identified number of revolutions plus said preselected amount of rotation.

5. A system for coiling strip material on a reel including means for stopping said reel to selectively position the end of said strip material in a predetermined spatial location, comprising rotating means located a known distance from said reel and coupled to said material to rotate at a velocity proportional to the velocity thereof, a source of a signal, first means coupled to said rotating means and operative in response to said signal for generating a voltage having a magnitude proportional to the number of rotations thereof, second means for generating an output having a voltage magnitude proportional to the number of rotations of said rotating means during passage of material having a length equal to said distance, third means controlled by said first and second means to produce a first control signal when a length of material equal to said distance passes a point, fourth means coupled to said reel for generating a voltage having a magnitude proportional to the number of rotations thereof, control means responsive to the output of said fourth means and operative during the interval between said signal and said first control signal to generate an output having a voltage magnitude discretely identifying the number of rotations of said reel, means operative to produce a second control signal when the end of said material leaves said rotating means, and means controlled by said control means and operative in response to said second control signal to stop said reel after said identified number of revolutions plus a preselected fraction of a revolution.

6. A system for coiling strip material on a reel including means for stopping said reel to selectively position the end of strip material in a predetermined spatial location, comprising rotating means located a known distance from said reel and coupled to said material to rotate at a velocity proportional to the velocity thereof, a source of a signal, first means coupled to said rotating means and operative in response to said signal to generate a number of pulses proportional to the number of rotations thereof, second means for storing a first number equal to the number of pulses produced by said first means during passage of material having a length equal to said distance, a first counting means preset with said first number in response to said signal and operative to modify said first number in response to each pulse generated by said first means until a preselected number is registered therein, third means coupled to said reel and operative to generate a number of pulses proportional to the number of rotations thereof, a second counting means, means coupling said third means to said second counting means during the interval between said signal and registration of said preselected number in said first counting means to register a number therein proportional to

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the number of rotations of said reel during passage of material having a length equal to said distance, means operative to produce a second control signal when the end of said material leaves said rotating means, means operative in response to said second control signal to apply pulses from said third means to said second counting means to decrease the number registered therein until a second preselected number is registered, and means operative in response to said second preselected number to stop said reel.

7. A system as defined in claim 6 in combination with additional means for initially presetting said second count-

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ting means with a number equal to a preselected fraction of a rotation of said reel.

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