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Johnson

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[54] **ARCHIMEDES SPIRAL WOBBLE CONTROL**

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[73] Assignee: **General Electric Company,** Salem, Va.

[22] Filed: **June 30, 1972**

[21] Appl. No.: **268,086**

[52] **U.S. Cl.** **242/83**
[51] **Int. Cl.** **B21c 47/28,** B65h 75/02
[58] **Field of Search** 242/83, 82; 28/21; 19/159; 140/92.2

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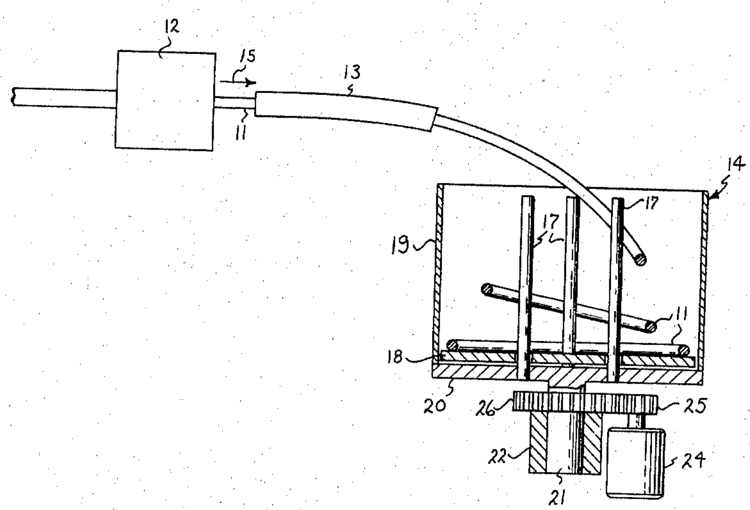
Primary Examiner—John W. Huckert
Assistant Examiner—John M. Jillions
Attorney, Agent, or Firm—Arnold E. Renner; Harold H. Green, Jr.

[57] **ABSTRACT**

A control system for a pouring reel to allow a product to be deposited in the reel in continuous layers, each layer forming an Archimedes spiral. The control system produces a reel speed reference signal by dividing a signal proportional to the linear speed of the product by a signal proportional to the desired coil convolute radius of the product in the reel to obtain the desired result.

7 Claims, 9 Drawing Figures



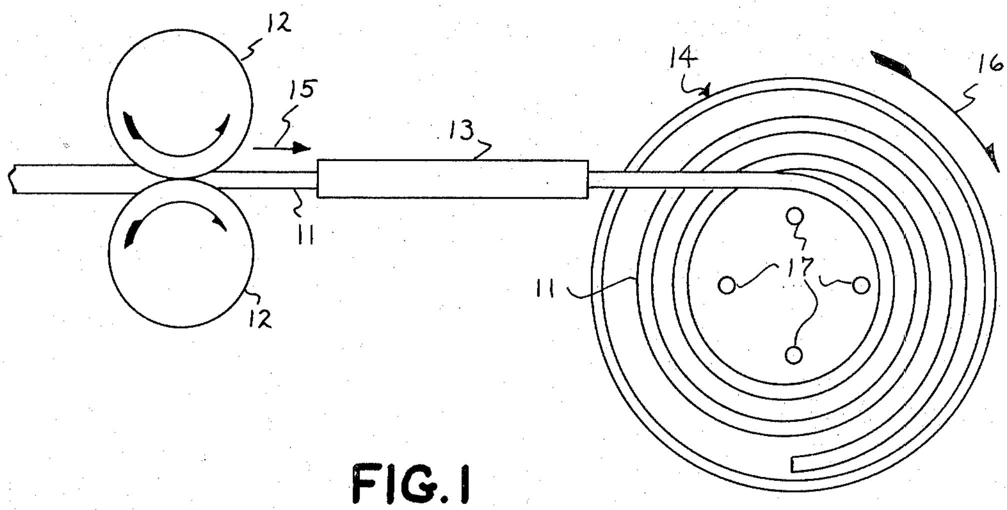

12
15
13
14
16
11
17
11
12

FIG. 1

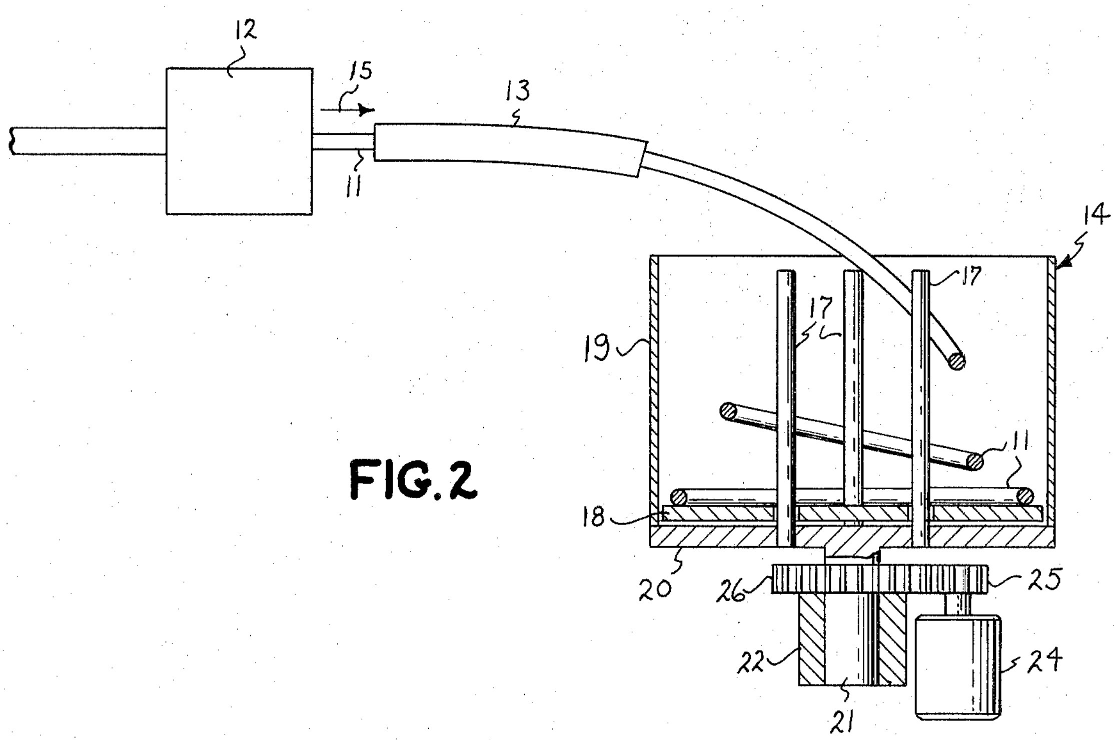

12
15
13
11
14
17
17
19
11
18
20
26
25
22
24
21

FIG. 2

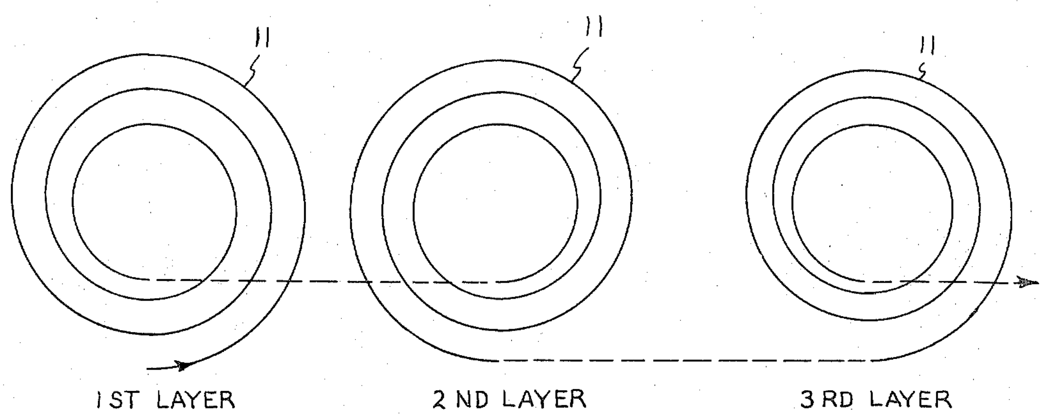

11
11
11
1 ST LAYER
2 ND LAYER
3 RD LAYER

FIG. 3

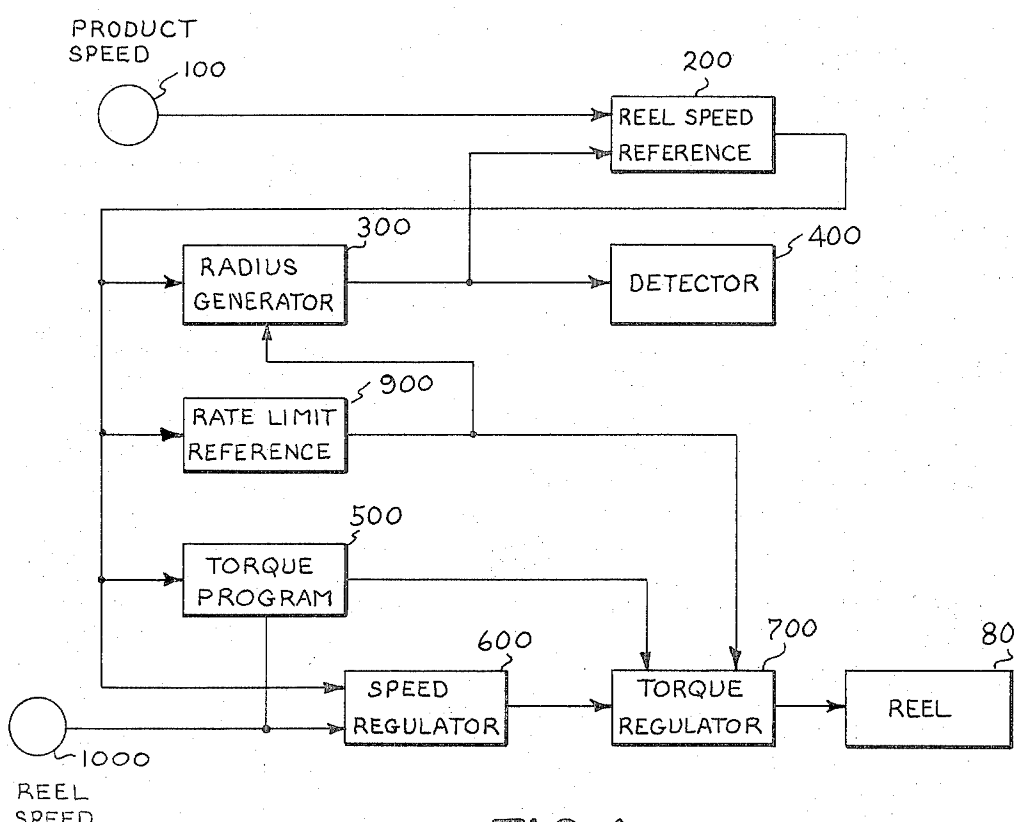

PRODUCT SPEED
100
200
REEL SPEED REFERENCE
300
RADIUS GENERATOR
DETECTOR
400
900
RATE LIMIT REFERENCE
500
TORQUE PROGRAM
600
SPEED REGULATOR
700
TORQUE REGULATOR
800
REEL
1000
REEL SPEED

FIG. 4

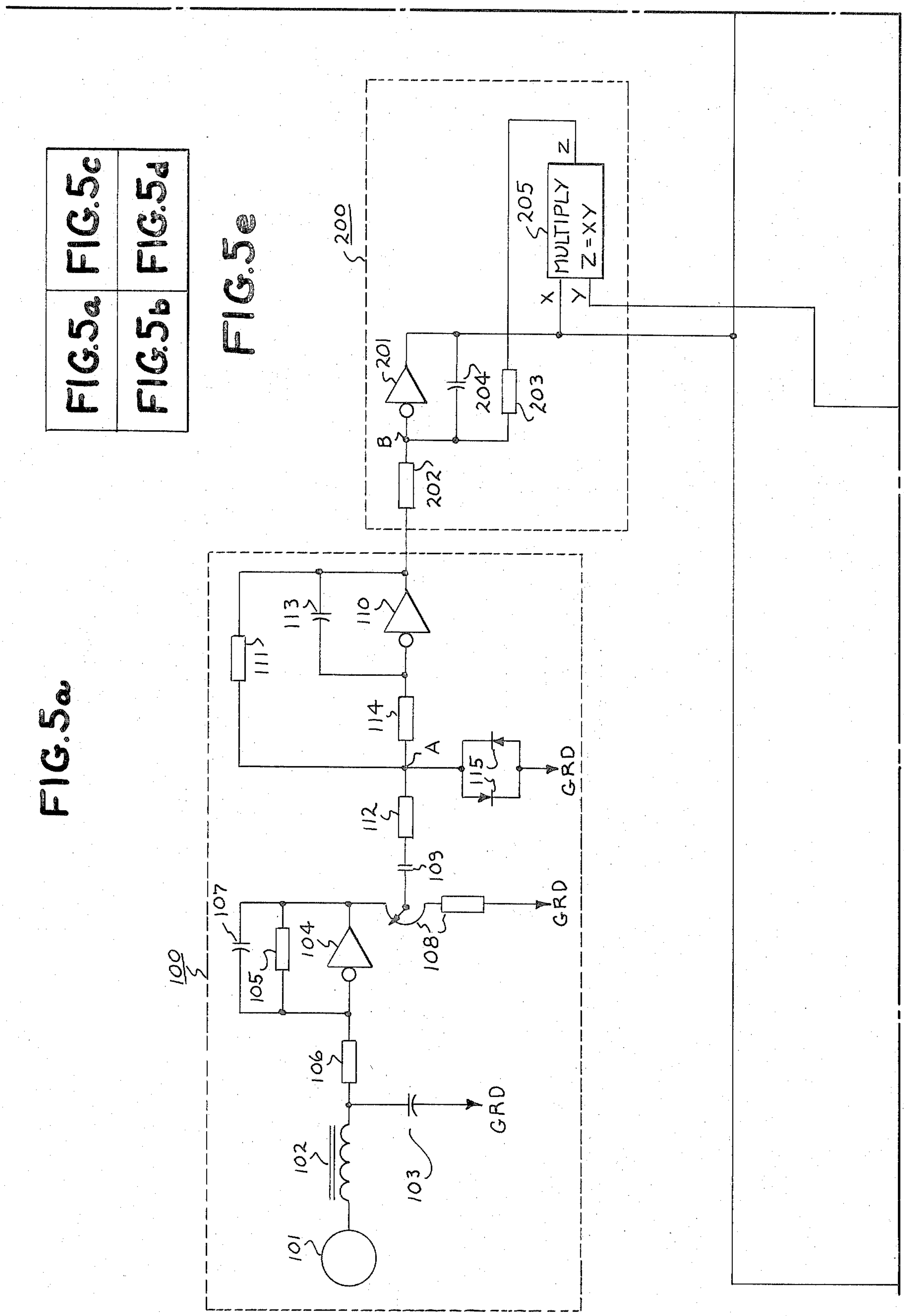


FIG.5a FIG.5c
FIG.5b FIG.5d
FIG.5e
200
205
MULTIPLY
Z=XY
X
Y
Z
201
204
203
B
202
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
A
GRD
GRD
GRD
GRD

FIG.5a

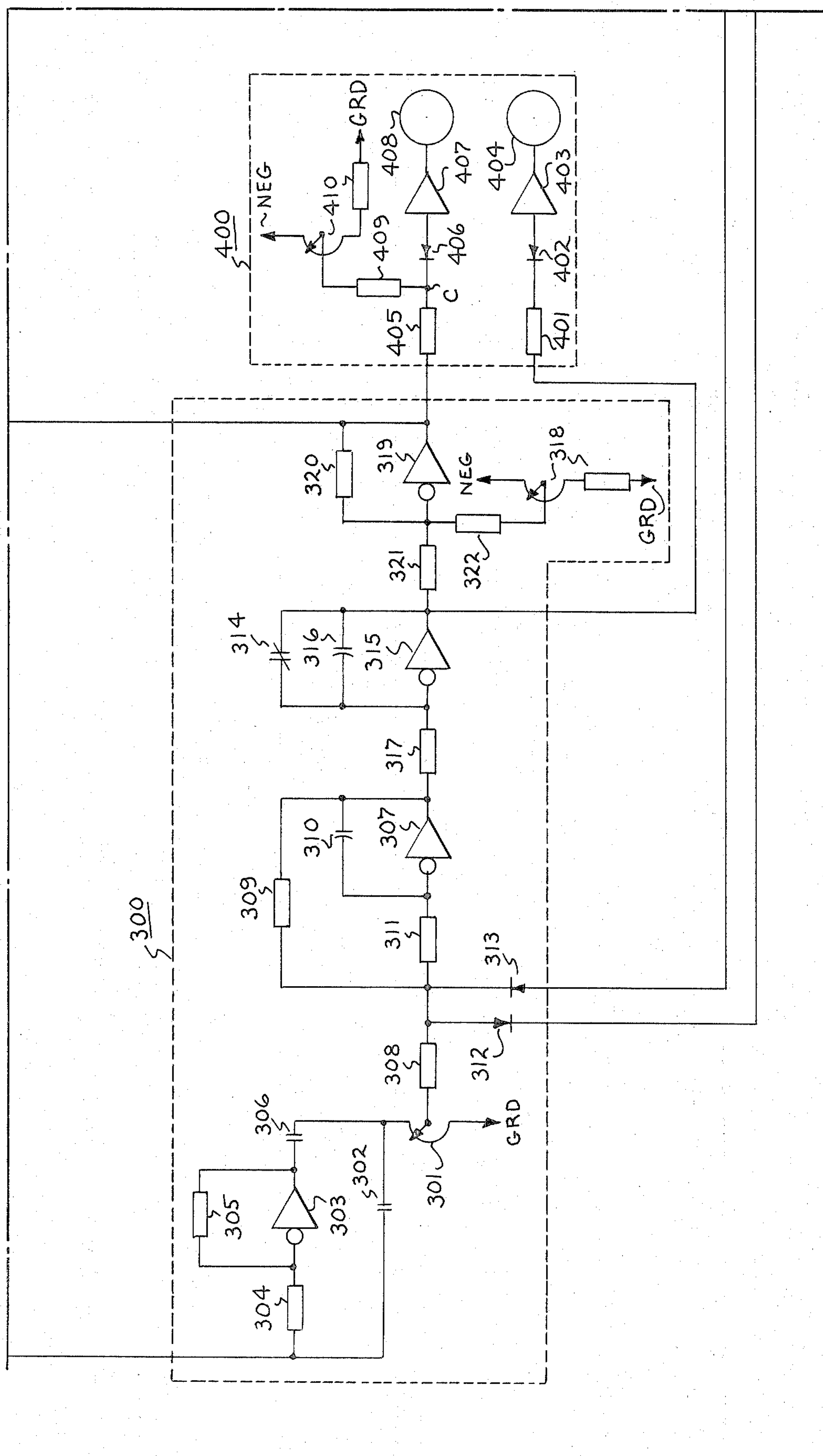
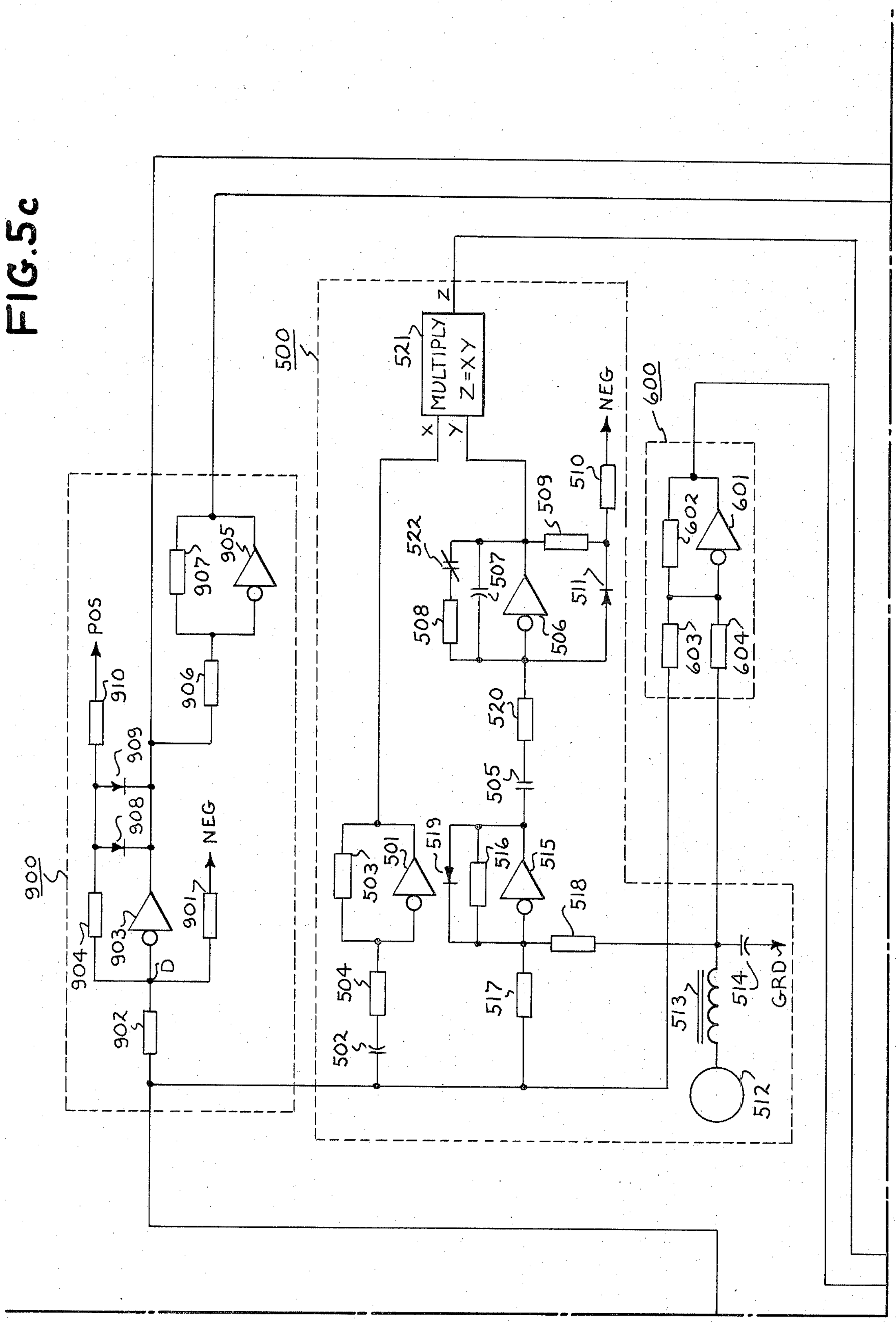

300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
GRD
NEG
400
401
402
403
404
405
406
407
408
409
410
C

FIG. 5b

FIG.5c


900
901
902
903
904
905
906
907
908
909
910
POS
NEG
D
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
MULTIPLY
Z=XY
X
Y
Z
NEG
GRD
600
601
602
603
604

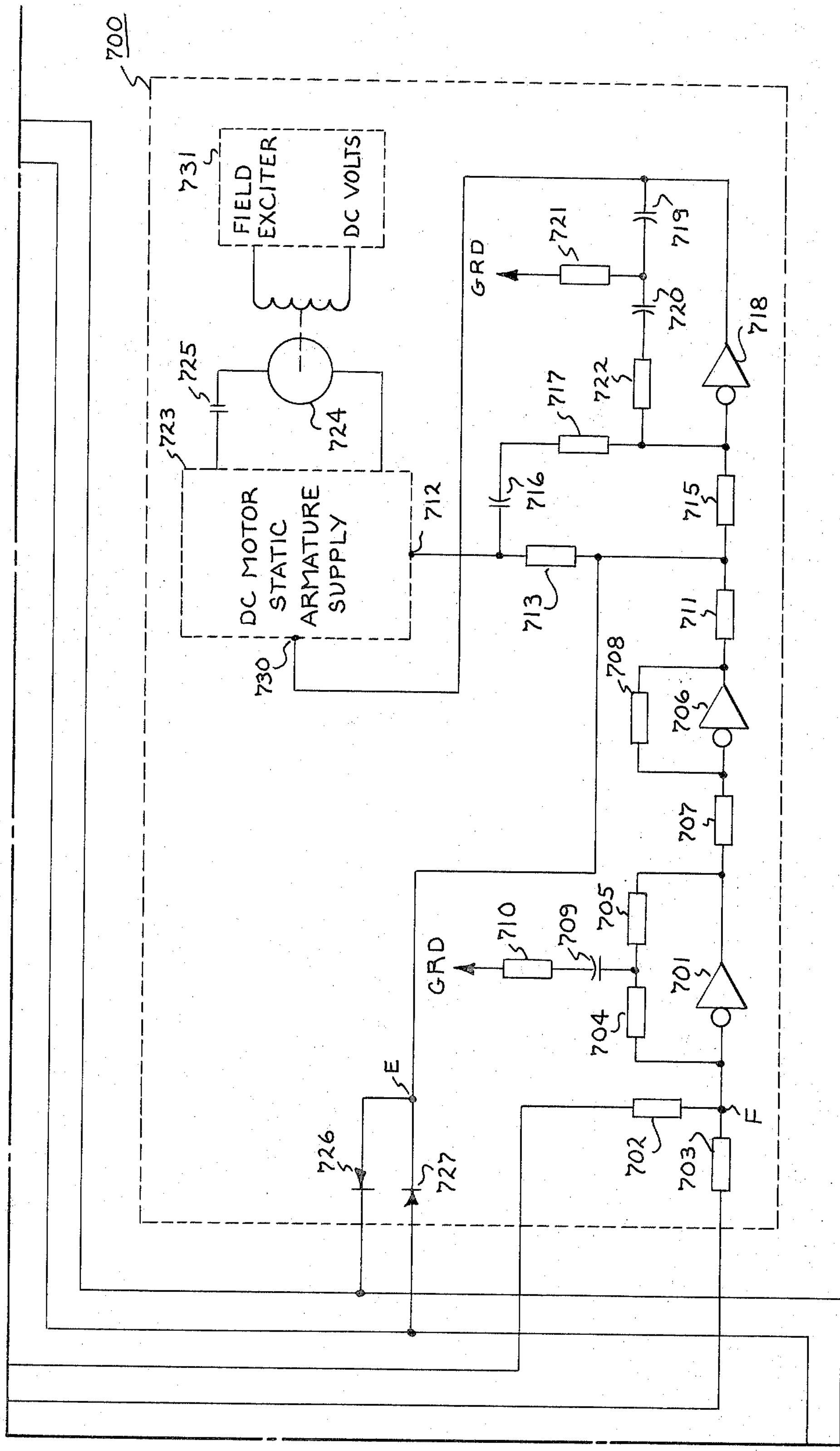

700
731
FIELD EXCITER
DC VOLTS
GRD
721
719
720
718
725
723
724
717
722
716
712
715
DC MOTOR STATIC ARMATURE SUPPLY
713
711
730
708
706
707
705
710
709
GRD
701
704
E
F
726
727
702
703

FIG. 5d

ARCHIMEDES SPIRAL WOBBLE CONTROL

BACKGROUND OF THE INVENTION

This invention relates to a control system for a pouring reel which accepts a moving product such as that utilized in rod, bar and merchant mills and the invention is also applicable to laying heads or laying cones for wire and rod mills.

In the manufacturing of rods, bars and the like for the purpose of storage and shipment, individual billets are rolled into one continuous strand which is accumulated as a coil or coils in a tub or reel.

It is well known in the art that denser depositing or pouring of the product in the tub or reel can be accomplished by having the product deposited in the reel in a continuous Archimedes spiral with the spiral direction reversed on alternate layers.

The mechanical forces causing the product to bend in the reel to an optimum radius at any instant are relatively small; therefore, relatively small disturbing forces will cause undesirable radii to be formed.

Prior art attempts to achieve the formation of a coil approximating an Archimedes spiral with the spiral direction reversed on alternate layers usually utilized a control system which caused the reel to wobble or vary in a manner to effect a desired pouring pattern. However, the reel was caused to wobble as a function of the reel speed. New disturbances were introduced into the control system through the use of reel gears and tachometer eccentricities.

A further problem involved in the prior art generally caused by the torque rate capacity of a driving motor being finite was realized when each layer forming the coil in the reel required a sprial direction reversal.

The foregoing problems have been substantially eliminated by providing in a preferred embodiment of my invention a control system which produces a reel speed reference signal to control the angular motion of the reel. The reel speed reference signal, in accordance with this invention, is produced by dividing a signal proportional to the linear speed of the moving product by a signal proportional to the desired instantaneous coil convolute radius of the product in the reel. The above problems have further been minimized by incorporating in my preferred embodiment subsystems for continuously calculating the desired coil convolute radius of the product and for continuously calculating the desired reel torque by taking into consideration the changing inertia of the reel as the size of the coil in the reel increases.

SUMMARY OF THE INVENTION

It is an object of this invention to provide a new and improved control system which will result in the denser pouring of a product into a reel.

It is another object of this invention to provide a new and improved control system for a pouring reel which will provide a fast transient response by programming the desired reel torque into the control system.

It is another object of this invention to provide a new and improved control system which will provide a smoother and more accurate Archimedes spiral pattern of a product to be deposited in a reel and to minimize disturbances and produce more evenly spaced convolutes of such spiral.

It is a still further object to provide a new and improved control system which will reduce the time required for effectively reversing the spiral direction by more fully utilizing the machine capacity.

Briefly stated, and according to one aspect of my invention, the foregoing objects are achieved by producing a new and improved control system for a pouring reel in which a reel speed reference signal controls the reel angular motion. The reel speed reference signal is derived from the division of a signal proportional to the linear speed of the product by a signal proportional to the desired coil convolute radius of the product being deposited in the reel.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention, both as to its organization and principle of operation together with further objects and advantages thereof may better be understood by reference to the following detailed description of an embodiment of the invention when taken in conjunction with the accompanying drawings in which:

FIG. 1 is a top view of a product being poured into a reel to form an Archimedes spiral in accordance with this invention.

FIG. 2 is a side view of a product being poured into a reel with a cross section of the reel and associated driving mechanisms in accordance with this invention.

FIG. 3 is a graphical representation of the product deposited in a reel to form a continuous coil in three distinct layers, each layer approximating an Archimedes spiral with the spiral direction reversed in accordance with this invention.

FIG. 4 is a simplified block diagram of a control system for a reel in accordance with this invention.

FIGS. 5*a* through 5*d* taken together as shown in FIG. 5*e* constitute a simplified diagram of a control system of FIG. 4 but in greater detail in accordance with this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

For simplification, the preferred embodiment of my invention will be in the environment of a pouring reel receiving a moving product, such as a bar, in a continuous multi-layer Archimedes sprial.

Referring to FIG. **1**, a bar or product **11** is delivered from a finishing stand **12** through a guide **13** into tub or reel **14** in the direction indicated by arrow **15** and rotates with the reel **14** in a direction, as indicated by arrow **16.** As is well known in the art, pins **17** are affixed inside reel **14** to provide an inner or minimum radius for the formation of an Archimedes spiral in reel **14.**

In FIG. **2,** product **11** is shown traveling in the direction of arrow **15** from finishing stand **12** through guide **13** into reel **14** to form the Archimedes spiral. The reel **14** comprises a coil plate **18,** side wall **19** defining a maximum or outer radius, base plate **20,** and pins **17** mounted on a vertical shaft **21** which rides in a fixed bearing **22.** The reel **14** is driven in the direction indicated by arrows **16** in FIG. **1** about a vertical axis by driving means shown as DC motor **24,** through pinion **25** and gear **26.**

FIG. **3** illustrates the product **11** in the denser coil pattern, that is, the deposition of the product in the reel in layers forming Archimedes sprials, with the spiral direction of alternate layers reversed. The pattern in FIG. 3 has three layers formed from a continuous product 11, and each layer is shown to be serially connected for clarity of illustration. The Archimedes spiral pattern is mathematically expressed as follows:

First layer,	$r = r_o - a\,\theta$	From r_o to r_i.
Second layer,	$r = r_i + a\,\theta$	From r_i to r_o.
Third Layer,	$r = r_o - a\,\theta$	From r_o to r_i.

where:

r = radius of product convolute, in feet.

a = Archimedes spiral constant, in feet per radian.

θ = angular displacement since initiation of the layer, in radians.

r_i= inner or minimum radius, in feet.

r_o= outer or maximum radius, in feet.

FIG. 4 in block diagram illustrates a transducer **100**, which is positioned proximate to the finishing stand **12** (shown in FIG. 1), which produces a first signal or voltage, proportional to the linear speed represented as ds/dt of a product leaving the finishing stand.

In order to develop a reel speed reference signal, which will be used as a first input to a radius generator **300**, rate limit reference **900**, torque program **500** and speed regulator **600**, reel speed reference means **200** is provided. Reel speed reference means **200** receives the first signal at a first input and a second signal proportional to the desired coil convolute radius r at its second input. The reel speed reference means **200** produces the reel speed reference signal at its output by dividing the first signal by the second signal thereby producing the reel speed reference signal represented as $d\theta/dt$ which is equal to $(1/r)(ds/dt)$. The above equation, equal to the reel speed reference signal, is derived by the differentiation of the basic Archimedes spiral equation, $r = a\,\theta$, taken for an arc segment in a manner well known in the art.

A radius generator **300** is provided in order to produce at its output the second signal proportional to the desired coil convolute radius which, as previously mentioned, is connected to the second input of the reel speed reference means **200**. The output of the radius generator is further connected to a detector **400** which detects the inner and outer radii limits and reverses the direction of radius change each time the inner and outer radii limits respectively are reached.

A torque program **500** is provided which produces a torque signal T to a first input of a torque regulator **700** which in turn regulates the torque on reel **800**. The signal T which is proportional to the reel torque required to overcome inertia, is produced by multiplying a signal J, proportional to the inertia of the reel by the derivative of the reel speed reference signal, or $T = J\,(d^2\theta/dt^2)$. The torque program **500** is connected at a second input from a sensing device **1000**, which provides a reel speed signal proportional to the actual reel speed.

In order to provide an error signal to the second input of the torque regulator **700**, which will modify the torque as required to maintain accurate speed, a speed regulator **600** is provided. The speed regulator **600** determines the error signal by comparing the reel speed reference signal at its first input with the reel speed signal from sensing device **1000** at its second input.

The rate limit reference **900** which limits the second derivative of the desired coil convolute radius with respect to time to produce smooth and optimum response for reversal of the spiral constant is connected as a second input to radius generator **300** and is further connected as a third input to torque regulator **700** to limit the torque rate.

Therefore, torque regulator **700** regulates the torque on reel **800** in accordance with torque program **500**, speed regulator **600** and rate limit reference **900**.

Refer now to FIGS. 5*a* through 5*d*, in which, for convenience, the blocks of FIG. 4 are understood to be represented by dashed blocks. In FIG. 5*a* transducer **100** includes a tachometer **101** which is utilized to produce the first signal representative of the linear speed of the product. The output of tachometer **101** is serially connected to an input of amplifier **104** through inductor **102** and resistor **106**. At a point between inductor **102** and resistor **106**, a bypass capacitor **103** is connected to ground. Amplifier **104** has a parallel combination of resistor **105** and capacitor **107** connected between the input and output thereof. The output of amplifier **104** is connected to ground through a combination series rheostat resistor **108**, the tap of the rheostat resistor **108** is serially connected to a point A through a normally open contact **109** and resistor **112**. Point A is also connected to ground through the parallel combination of reverse diodes **115**, and to an output of amplifier **110** through resistor **111**. Point A is further connected to an input of amplifier **110** through a resistor **114**. A capacitor **113** is connected between the input and output of amplifier **110**. At the output of amplifier **110** is the first signal proportional to the linear speed of the product.

The output of amplifier **110** is connected as the first input to the reel speed reference means **200**. The output of amplifier **110** is connected to a point B at the input of amplifier **201** with filter capacitor **204** connected between the input and output thereof, through input resistor **202**. Point B is further connected as an input to amplifier **201** from an analog multiplier **205** through feedback resistor **203** to provide the second signal proportional to the desired coil convolute radius. The output of amplifier **201** is connected to a first input of analog multiplier **205**, a first end of resistor **304** normally open contact **302**, (FIG. 5*b*), resistor **902**, capacitor **502**, resistor **517**, and resistor **603** (FIG. 5*c*). A second input of analog multiplier **205** is connected to the output of amplifier **319**. Amplifier **201** and multiplier **205** divide the first signal by the second signal and result in the reel speed reference signal.

In radius generator **300** (FIG. 5b) which receives the reel speed reference signal at the first end of resistor **304**, a second end of resistor **304** is connected to an input of amplifier **303**. A resistor **305** is connected between the input and output thereof. The output of amplifier **303** is connected through a normally open contact **306** to a grounded rheostat **301**. This output is also connected to a second end of normally open contact **302**. Rheostat **301** sets the Archimedes spiral constant on the desired coil convolute spacing to be utilized in determining the desired coil convolute radius rate. Rheostat **301** is further connected to resistor **308** which in turn is connected through resistor **311** to the input of amplifier **307**. Amplifier **307** has a capacitor **310** connected thereacross. Resistor **308** is further connected to the anode of diode **312** and the cathode of diode **313** and through resistor **309** to the output of amplifier **307**.

The output of amplifier **307** is serially connected to the input of amplifier **315** through resistor **317** with the parallel combination of normally closed contact **314** and capacitor **316** between the input and output thereof. The output of amplifier **315** is serially connected to relay **404** through resistor **401**, diode **402**, and amplifier **403**, the latter four elements forming a part of the detector **400**. The output of amplifier **315** is further connected through resistor **321** to the input of amplifier **319** with resistor **320** connected between the input and output thereof. The top of combination rheostat resistor **318** is connected to the input of amplifier **319** through resistor **322**. The rheostat section of rheostat resistor **318** is connected to a negative DC voltage, and the resistor section is connected to ground. Rheostat resistor **318** is utilized to set the initial or maximum radius, and amplifier **319** sums this initial radius with the radius change signal from amplifier **315** to provide the second signal "r" for amplifier **201**.

The output of amplifier **319** is further connected to a point C through resistor **405** of the detector **400**.

Point C is serially connected to a series combination rheostat resistor **410** in detector **400** (which monitors the radius signal) through a bias resistor **409** and to relay **408** through diode **406** and amplifier **407**. The rheostat section of rheostat resistor **410** is connected to a negative DC voltage while the resistor section is connected to ground.

The rate limit reference **900** (FIG. 5c) which limits the rate of change of the radius rate receives the reel speed reference signal at a first end of resistor **902** and has the second end of resistor **902** connected at point D to a negative DC voltage through resistor **901** and to a positive DC voltage through the series connection of resistor **904** and resistor **910**. Point D is further connected to the input of amplifier **903**; the output of amplifier **903** is connected to a point between resistor **904** and **910** through diodes **908** and **909**. The output of amplifier **903** is further connected to the cathode of diode **312** (FIG. 5*b*) and then connected to point E through diode **726** (FIG. 5d) and is still further connected through resistor **906** to the input of amplifier **905** having a resistor **907** connected between the input and output thereof, and then serially connected to the anode of diode **313** and through diode **727** to point E.

The second end of capacitor **502** in torque program **500** is connected to a first input of analog multiplier **521** through the series circuit of resistor **504** connected to the input of amplifier **501**, amplifier **501** having resistor **503** connected between its input and output. The output of analog multiplier **521** is applied at point F through resistor **702**.

The second end of resistor **517** is connected to the input of amplifier **515** with the parallel combination of resistor **516** and diode **519** connected between the output and input thereof. The output of amplifier **515** is serially connected through normally open contact **505** and resistor **520** to the input of amplifier **506**. Amplifier **506** has the parallel combination of a capacitor **507** and a normally closed switch **522** with a series connected resistor **508** connected between the input and output thereof. Diode **511** is connected to the input of amplifier **506** and is also connected to a negative DC voltage through resistor **510** and to the output of amplifier **506** through resistor **509**. The output of amplifier **506** is applied as a second input to analog multiplier **521**.

A reel tachometer **512**, which produces a reel speed signal, has its output serially connected through inductor **513** and resistor **604** of speed regulator **600** to an input of amplifier **601** with resistor **602** connected between the input and output thereof. Capacitor **514** is connected to ground at a point between inductor **513** and resistor **604**. Also a point between inductor **513** and resistor **604** is connected to the input of amplifier **515** through resistor **518**. The input of amplifier **601** is also connected to the second end of resistor **603**. The output of amplifier **601** is connected through series resistor **703** to point F.

Point F in torque regulation **700** (FIG. 5d) is further connected to the input of amplifier **701**. It is also connected to ground through resistor **704**, capacitor **709**, and resistor **710**. The output of amplifier **701** is connected through resistor **705** to the connection between resistor **704** and capacitor **709**. The output of amplifier **701** is also connected through resistor **707** to the input of amplifier **706** with resistor **708** connected between the output and input thereof. The output of amplifier **706** is connected through resistor **711** to point E.

Point E is connected through resistor **713** to a current feedback signal terminal **712** to DC motor static armature supply **723** and is further serially connected to a firing angle reference signal terminal **730** of DC armature supply **723** through resistor **715** and amplifier **718**. The current feedback signal terminal **712** is further connected to the input of amplifier **718** through the serially connected capacitor **716** and resistor **717**. Connected between the input and output of amplifier **718** is the series circuit of resistor **722**, capaictor **720** and capacitor **719**. The point between capacitor **720** and capacitor **719** is connected to ground through a resistor **721**.

Reel motor **724** with its associated shunt field exciter **731** is connected across DC armature supply **723** with normally open contactor **725** connected in series at one end of reel motor **724**.

In operation, tachometer **101** is geared to a motor which drives the finishing stand to produce a signal which is filtered by inductor **102** and capaictor **103** and amplified by amplifier **104** with further filtering by capacitor **107**. The bridge **108** is adjusted in proportion to the roll diameter of the finishing stand to produce a signal proportional to the linear speed of the product **11**. When contact **109** is closed, the signal is amplified by amplifier **110** with the rate of change of amplifier **110** limited by capacitor **113**, resistor **114** and diodes **115**. The output of amplifier **110** is a first signal proportional to the linear speed of the product or ds/dt.

This first signal is amplified by amplifier **201** and filtered by capacitor **204**. A feedback voltage from amplifier **201** is multiplied in analog multiplier **205** by a second signal proportional to the desired coil convolute radius or "r", thereby making the gain of amplifier **201** inversely proportional to the desired coil convolute radius. Thus, the output of amplifier **201** is its input or first signal ds/dt divided by the desired coil convolute radius or second signal, this equals the reel speed reference signal $d\theta/dt$. Mathematically, this is expressed as $d\theta/dt = (1/r)(ds/dt)$.

Differentiation of the basic Archimedes spiral equation, $r = a\ \theta$, produces the equation $dr/dt = a\ (d\theta/dt)$ which is the desired coil convolute radius rate. A radius rate signal dr/dt is obtained by multiplying the reel speed reference signal $d\theta/dt$ by the Archimedes spiral constant "a", or by the desired coil convolute spacing as set by the rheostat **301**.

For decreasing radius, the reel speed reference signal is applied to rheostat **301** through contact **302.** For increasing radius, the reference polarity is reversed by amplifier **303,** and the reel speed reference signal is applied to rheostat **301** through contact **306.** The radius signal rate dr/dt is amplified by amplifier **307** with its rate of change limited by capacitor **310,** resistor **311,** diodes **312** and **313** and a voltage from the rate limit reference **900.** This limits the rate of change of radius rate or the second derivative of radius d^2r/dt^2. The purpose of this limit, which is controlled by the reel speed reference signal, is to produce smooth reversal of the spiral constant at the maximum rate permitted by the machine torque rate capacity. In a practical arrangement, the machine torque rate capacity exceeds the torque rate required for generating a spiral layer, therefore, the limit on d^2r/dt^2 does not have an effect except during reversal of the spiral constant.

When the reel speed is being wobbled or varied, contact **314** is open. A radius change signal "dr" is produced by integrating the radius rate signal dr/dt with respect to time by amplifier **315.**

The initial radius is preset by rheostat resistor **318** and the total radius signal or second signal "r" proportional to the desired coil convolute radius is produced by summing in amplifier **319** the initial preset radius with the radius change signal. This second signal then is applied to the analog multiplier **205** to produce the reel speed reference signal as previously described.

In detector **400,** the radius change signal "dr" is monitored by resistor **401,** diode **402,** amplifier **403,** and relay **404** so that the outer radius r_o is sensed, and relay **404** is energized when the radius is equal to or greater than the initial radius or value set by rheostat resistor **318.** The second signal "r" is monitored by resistor **405,** diode **406,** amplifier **407,** and relay **408** with a bias for resistor **409** in rheostat resistor **410** so that the inner radius is sensed, and relay **408** is energized when the radius is equal to or less than the value set by rheostat resistor **410.**

Referring to torque program **500,** which basically produces a signal proportional to desired reel torque by multiplying a signal, either fixed or variable, proportional to the reel inertia by the second derivative of the desired angular displacement of the reel with respect to time. The derivative of the reel speed reference signal or $d^2\theta/dt^2$ is provided by differentiating the reel speed reference signal with respect to time by amplifier **501** with capacitor **502** and resistor **503** and **504.** When the product is not being delivered to the reel, contact **522** is closed, and contact **505** is opened; and amplifier **506** will produce a signal proportional to the empty reel inertia as determined by capacitor **507,** resistors **508, 509, 510** and diode **511.** When the product is sensed, contact **522** opens and the reel inertia signal is stored by capacitor **507.**

The reel speed signal from tachometer **512** is filtered by inductor **513** and capacitor **514** and summed with the reel speed reference signal by amplifier **515** with resistors **516, 517,** and **518** so that amplifier **515** produces a voltage proportional to the speed error except that the output will only be produced if the speed is lower than the reference because of diode **519.** When

varying the reel speed, contact **505** will close a time delay after each time contact **302** is closed, and it will remain closed until contact **302** is open.

As coil size increases, the reel inertia increases, thus tending to cause the reel speed signal to be lower than the reel speed reference signal while the reel is accelerating until the inertia signal "J" is increased in proportion to the increase in inertia. This occurs when contact **505** is closed, and amplifier **515** transmits a current to amplifier **506** through resistor **520** thus causing inertia signal "J" to increase. Analog multiplier **521** multiplies the derivative of the reel speed reference signal or $d^2\theta/dt^2$ by inertia signal "J" to produce the torque program $T = J\,(d^2\theta/dt^2)$.

The filtered output of the reel tachometer **512** is summed with the reel speed reference signal by amplifier **601** to produce a speed error signal. This speed error signal modifies the torque program to reduce low frequency and steady state errors resulting from friction and changes in circuit parameters. This results in the necessary speed accuracy with a slow enough response to produce the necessary insensitivity to undesirable disturbances from the tachometer and to permit proper operation of the inertia compensation amplifier **506** as previously described.

The torque program signal is summed with the speed error signal by amplifier **701** and is further amplified by amplifier **706.** Capacitor **709** provides a faster response, and resistor **710** provides reduced sensitivity to noise at high frequencies.

Since the reel is driven by a DC motor with a fixed shunt field and in such a machine the torque is proportional to the armature current, then the output of amplifier **706** constitutes a motor current reference signal. The motor current reference signal is applied through resistor **711** and is summed with a current feedback signal from terminal **712** through resistor **713** to produce a current rate reference signal at point E. The current rate reference signal applied through resistor **715** is summed with the current rate feedback signal at the input to amplifier **718.** Amplifier **718** provides a firing angle reference signal at terminal **730** for the static armature supply **723** which in turn provides the armature voltage for reel motor **724** when contactor **725** is closed. The current rate for reel motor **724** is limited by limiting the current rate reference signal with diodes **726** and **727** and by limiting the voltage from the rate limit reference **900.** As a result, the current rate and current are regulated in response to the motor current reference signal in a manner well established in the art.

Since a DC motor is capable of commutating higher current rate when running at lower speeds, the voltage produced by the rate limit reference **900** is reduced at higher speeds in a manner well known in the art. A fixed bias to resistor **901** is summed with the reel speed reference signal by amplifier **903.** Amplifier **903** provides rate limit reference voltage for one polarity through diodes **312** and **726**; and a rate limit reference voltage of opposite polarity is provided through diodes **313** and **727** by amplifier **905** to invert the polarity of amplifier **903.**

In practice, while a coil is being removed from a reel, the reel is stopped and contacts **109, 302, 306, 505** and **725** are open and contacts **314 522** are closed. When the coil removal is completed, contacts **109** and **725** close thus causing the reel to accelerate at a rate determined by amplifier **110** to a speed synchronized with the product at a radius determined by rheostat resistor **318.** A sensor (not shown) senses when the product arrives at the reel. When the product is sensed, contacts **314** and **522** open, and after a predetermined time delay contact **302** closes. This time delay is to permit enough product to accumulate in the reel before wobbling starts so there will not be slippage between the coil and the reel. When contact **302** closes, the radius decreases, as previously described, and the reel accelerates.

Contact **505** closes a time delay after contact **302** closes to permit coil inertia compensation. When relay **408** detects the inner radius, as determined by rheostat resistor **410,** contacts **302** and **505** open and contact **306** closes causing the spiral constant to reverse at a rate determined by amplifier **307.** The radius increases as previously described, and the reel decelerates. When relay **404** detects the outer radius, contact **306** opens and contact **302** closes again. This cycle repeats continuously until the coil is completed. When the product sensor senses completion of the coil, the wobbling is interrupted, contacts **109** **302,** and **505** open, and contact **306** closes, the reel decelerates at a rate determined by amplifier **110** and the radius increases. When relay **404** senses that the second "r" signal has returned to the preset value, contact **306** opens, and the second "r" signal is held at its preset value and the reel continues to decelerate until it stops. A voltage relay (not shown) senses when the reel is stopped and causes contactor **725** to open and contacts **314** and **522** to close. Thus, the reel is returned to the original condition to permit coil removal, and the entire process repeats.

It has been shown that by providing a reel speed reference signal to control a pouring reel, that a denser pouring will result.

While an embodiment and application of this invention has been shown and described, it will be apparent to those skilled in the art that many more modifications are possible without departing from the invention concept herein described. The invention, therefore, is not to be restricted except as is necessary by the prior art and by the spirit of the appended claims.

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

1. In apparatus for pouring a moving product into a reel, a control system for controlling the reel angular motion to allow the deposition of the product in the reel in continuous layers, each layer forming a coil approximating an Archimedes spiral, with the spiral direction reversed on alternate layers, the control system comprising:

a. means for continuously producing a first signal proportional to the linear speed of the product;

b. means, including means for establishing a spiral constant, for continuously producing a second signal proportional to the desired coil convolute radius as a function of a reel speed reference signal and said spiral constant;

c. reel speed reference means for dividing said first signal by said second signal thereby producing said reel speed reference signal at the output of said reel speed reference means; and,

d. means controlling the reel angular motion in response to said reel speed reference signal.

2. A control system as in claim **1** wherein said means for producing a second signal includes means for continuously calculating the desired coil convolute radius of the product.

3. A control system as in claim **2** further including limiting means for limiting the second derivative with respect to time of said second signal.

4. A control system as in claim **3** further including means for determining maximum and minimum allowable values for the second derivative of said second signal as a function of said reel speed reference signal.

5. A control system as in claim **1** wherein the means for controlling the reel angular motion includes means for continuously calculating the desired reel torque, comprising;

a. means for producing an inertia signal proportional to the inertia of the reel;

b. means responsive to said inertia signal and said reel speed reference signal for producing a third signal proportional to the desired reel torque; and,

c. means for continuously regulating the reel torque in response to said third signal.

6. A control system as in claim **5** wherein said means for continuously calculating the desired reel torque includes means for differentiating said reel speed reference signal thereby producing a fourth signal, and means for multiplying said fourth signal by said inertia signal thereby producing said third signal proportional to the desired reel torque.

7. A control system as in claim **6** including means for increasing said inertia signal in proportion to the inertia increase of the reel as the size of the coil in the reel increases.

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