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2,661,009

STRIP PICKLING APPARATUS AND SATURABLE REACTOR CONTROL THEREFOR

Filed Oct. 24, 1949

2 Sheets-Sheet 1

Fig. 1.

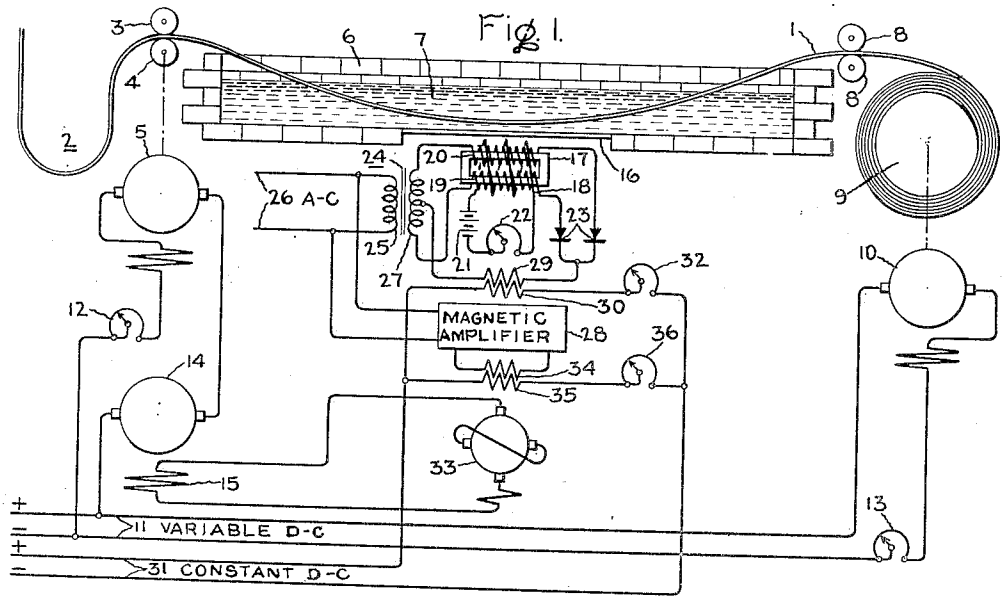


Fig. 2.

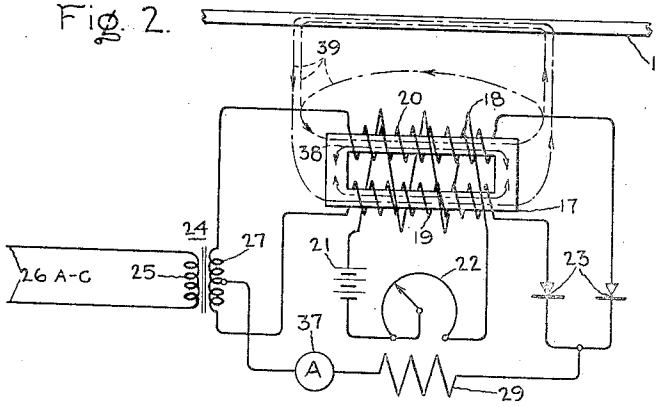
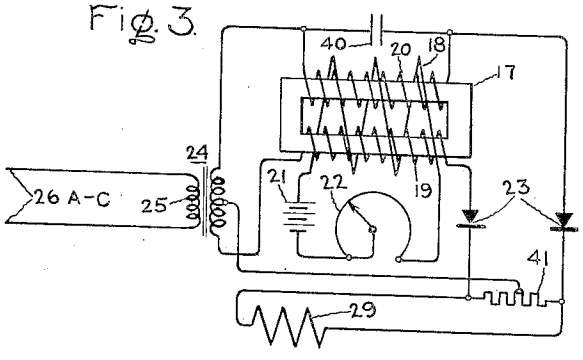


Fig. 3.



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2 Sheets-Sheet 2

Fig. 5.

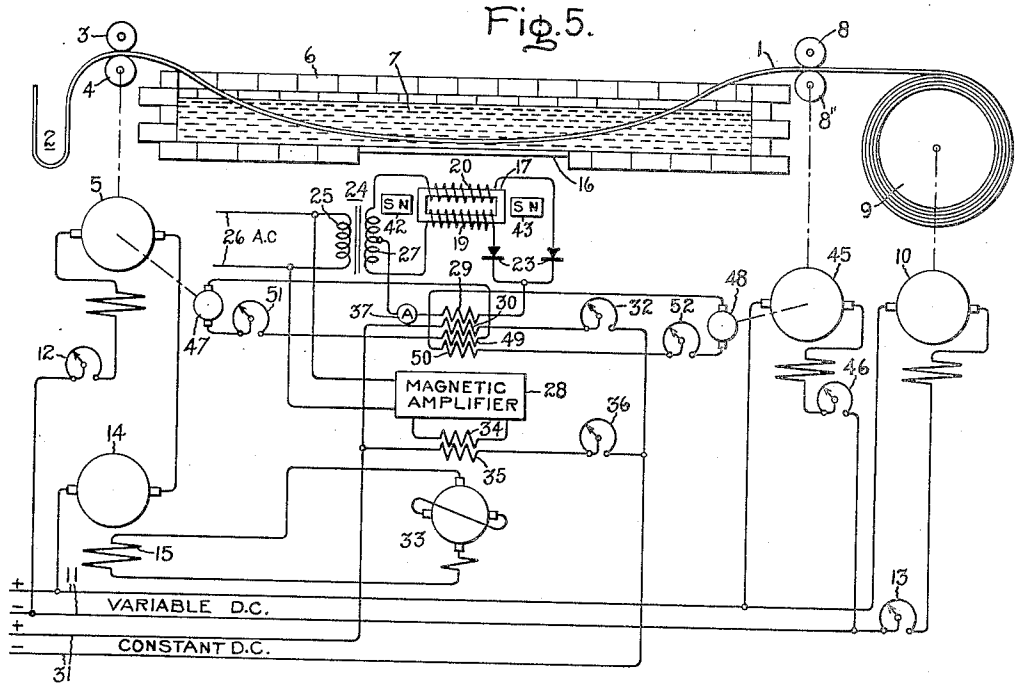
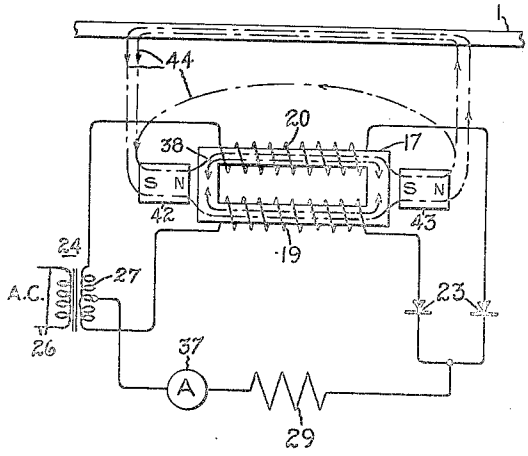


Fig. 4.



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STRIP PICKLING APPARATUS AND SATURABLE REACTOR CONTROL THEREFOR

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Application October 24, 1949, Serial No. 123,296

7 Claims. (Cl. 134—57)

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This invention relates to a saturable reactor type proximity gauge and control system for regulating the positioning of ferromagnetic material.

This application is a continuation-in-part of our application Serial Number 48,893, filed September 11, 1948 (now abandoned), and assigned to the same assignee as the present application.

A particular object of the invention is to provide an improved control system to regulate the immersion of continuously moving steel strip in a pickling bath. Although described in terms of this particular use, it will be appreciated that the system, in whole or in part, can be used in other similar applications.

Other objects and advantages of the invention will become apparent as the description proceeds

The features of the invention which are believed to be novel and patentable are pointed out in the claims which form a part of this specification. For a better understanding of the invention, reference is made in the following description to the accompanying drawing, in which Fig. 1 is a schematic diagram of a complete control system associated with a pickling bath; Fig. 2 is a schematic diagram of the preferred proximity gauge used in the system shown in Fig. 1; Fig. 3 is a schematic diagram of a modified form of the proximity gauge; Fig. 4 is a schematic diagram of another modified form of the proximity gauge; and Fig. 5 is a schematic diagram showing modifications of the complete control system. Where the same or an identical part appears in more than one figure of the drawing, it is always represented by the same reference number.

Referring now to Fig. 1, in a steel strip processing operation, steel strip 1 is drawn from take-up loop 2 through rollers 3 and 4. Roller 4 is driven by a variable-speed D.-C. motor 5. From rollers 3 and 4 the strip is fed into pickling tank 6 which contains a pickling solution 7. Tank 6 may be made of bricks, as illustrated, or other suitable material to withstand the corrosive action of the pickling solution.

Strip 1 is drawn from the pickling tank, through rollers 8, and wound upon reel 9 by variable-speed D.-C. motor 10. Motors 5 and 10 are supplied with variable direct current through connections 11, which may, for example, be connected to a Ward-Leonard system which controls the speed at which the steel strip is processed. Rheostats 12 and 13 are provided so that motors 5 and 10 may be adjusted to run at approximately the desired speeds.

It is desirable that strip 1 be immersed as far as possible in the pickling solution without dragging the bottom of the tank 6. Usually an average clearance of about six inches between the strip and the bottom of the tank is considered desirable. It is evident that if the strip drops too close to the bottom of the tank, it can be restored to the correct position by slightly decreasing the speed of motor 5; and that if strip 1 is pulled up too far above the bottom of the tank, it can be restored to its correct position by slightly increasing the speed of motor 5. These variations in the speed of motor 5 can be effected by having a booster generator 14 electrically connected in series with motor 5, as shown, to raise or lower the net voltage applied to the motor, as required. Generator 14 has a field winding 15 adapted to be externally excited. Any suitable means, for example an electric motor, not shown, may be employed to drive the rotor of generator 14.

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In control systems previously used, the depth of immersion of strip 1 in the pickling solution has been gauged by a mechanical dancer arm riding upon the strip. Because of the highly corrosive nature of the pickling solution, the life of mechanical parts in contact with the solution is short, and resulting mechanical failures have been numerous and troublesome. By providing a saturable reactor type proximity gauge as hereinafter described, contact of gauge parts with the corrosive pickling solution is eliminated.

Preferably the proximity gauge is embedded in the floor of the pickling tank, as shown in Fig. 1. A plate 16 of lead, or other non-magnetic, corrosion-resistant material, is used to protect the gauge from the corrosive solution. Since, as hereinafter explained, only direct magnetic flux passes through the lead plate, there are no losses due to induced eddy currents as would be the case if alternating flux passed through the plate.

The proximity gauge includes a two-legged saturable magnetic element 17. Preferably element 17 is about twice as long as the distance from the gauge to strip 1. Thus, if element 17 is embedded three inches below the floor of tank 6 and strip 1 is to clear the floor by six inches, element 17 may be about eighteen inches long. A first winding 18 is provided about both legs of element 17, and second and third windings 19 and 20 are provided about respective ones of the two legs. A battery 21 and a rheostat 22 are connected to energize winding 18 with an adjustable value of direct current.

Rectifiers 23 are respectively connected in series with windings 19 and 20. A transformer 24, having a primary 25 adapted to be energized with alternating current through connections 26, has

a center-tapped secondary 27. The two halves of secondary 27 are respectively connected across the two sets of series-connected rectifiers and windings. Thus, two alternating voltages in phase opposition are provided across winding 19 and its associated rectifier and across winding 20 and its rectifier, respectively.

A magnetic amplifier 28 has a signal winding 29 connected in series with both sets of series-connected rectifiers and windings, as shown. A second signal winding 30, or bias winding, is energized from a constant D.-C. source through connections 31. The value of the bias current flowing through winding 30 can be adjusted by rheostat 32.

An amplidyne generator 33 has a field winding 34 connected to the output of magnetic amplifier 28. A second field winding 35 is energized by a bias current, the value of which may be adjusted by rheostat 36. The amplidyne generator rotor is driven by any suitable means, for example an electric motor, not shown. The output of amplidyne generator 33 is connected to energize field winding 15 of booster generator 14.

Refer now to Fig. 2, which shows the proximity gauge and its magnetic flux paths. Two alternating voltages in phase opposition are applied across winding 19 and its series-connected rectifier, and across winding 20 and its series-connected rectifier, respectively. Because of the rectifying action of rectifiers 23, pulsating direct current flows through windings 19 and 20. These pulsating currents have alternating components which produce alternating magnetic flux along the path indicated by broken line 38. This alternating flux is substantially confined within the saturable magnetic element, and thus follows what is herein referred to as a confined magnetic circuit.

Direct current through winding 18 and direct components of current through windings 19 and 20 produce direct magnetic flux which travels from left to right through element 17 and returns through the air or the pickling solution and through any magnetic material in proximity to element 17. Such flux paths are illustrated by broken lines 39. Since this flux is not confined to element 17, and since the paths which it follows vary depending upon the proximity of ferromagnetic materials, the direct flux follows what is herein referred to as an unconfined magnetic circuit.

The direct magnetic flux passing through element 17 partially staurates this element. When a ferromagnetic material, such as steel strip 1, is moved into proximity to the gauge, the reluctance of the unconfined magnetic circuit is reduced and hence the amount of direct flux through element 17 is increased. Since most of the reluctance of the circuit is in its non-magnetic portion, variations in thickness of strip 1 produce little effect, and proximity alone determines the reluctance. An increase in direct flux increases the saturation of element 17 and thereby reduces the reactance of windings 19 and 20. This permits more curernt to flow through these windings. The increased current has a larger direct component which still further increases the direct flux. Thus, the gauge has a regenerative action which provides very high sensitivity. If high sensitivity is not required, the rectifiers may be omitted.

It is, of course, not necessary that the entire element 17 be saturated by the direct flux. There may be, for example, saturable portions in each leg of element 17, and the remainder of the element may remain unsaturated.

Refer again to Fig. 1. Suppose strip 1 drops nearer the floor of tank 6; this increases the current through windings 19 and 20, and hence the current through signal winding 29 of the magnetic amplifier. This in turn increases the current through field winding 34 of the amplidyne generator, which then energizes field winding 15 of the booster generator with a polarity such that booster generator 14 generates a voltage opposing the voltage applied to motor 5. Thus, the net voltage applied to motor 5 is reduced, and that motor runs at a slower speed. This tends to restore strip 1 to its proper immersion depth. Conversely, if strip 1 is too far away from the bottom of tank 6, the current through winding 29 is reduced and motor 5 is caused to run at a higher speed until strip 1 is restored to its proper position.

Initial adjustments for the desired immersion depth of strip 1 are made by adjusting rheostats 22, 32, and 36. Rheostat 22 should be adjusted to give a degree of saturation of element 17 which will provide a relatively large change in inductance of windings 19 and 20 for small changes in reluctance of the unconfined magnetic circuit. Rheostat 32 may be adjusted to a good operating point for magnetic amplifier 28. Rheostat 36 is then adjusted to balance the system at the desired immersion depth.

If desired, an ammeter 37 can be connected in series with winding 29 and may be calibrated to indicate directly in appropriate units the immersion depth of strip 1.

Refer now to Fig. 3, which shows a modification of the proximity gauge. A capacitor 40 is connected in parallel with winding 20 as shown, and has a value such that winding 20 is tuned somewhat below resonance at the frequency of alternating current employed. As element 17 approaches saturation and the reactance of winding 20 decreases, winding 20 and capacitor 40 approach parallel resonance and the impedance presented by the parallel circuit increases. Thus, current through the right-hand rectifier 23 decreases while current through the left-hand rectifier increases. These currents flow through opposite halves of center-tapped resistor 41 and provide a voltage across the resistor which is proportional to the difference in value of the two currents. Winding 29 is connected in parallel with resistor 41 and is energized by an amount proportional to the voltage across the resistor.

Refer now to Fig. 4, which is a schematic diagram of another modification of the proximity gauge. This modification is similar to the gauge illustrated in Fig. 2, except for the means for providing direct magnetic flux through the unconfined circuit. Instead of a winding linking the unconfined circuit, permanent magnets are used. The permanent magnets may be small bar magnets 42 and 43, arranged at respective ends of element 17, as shown, with their polarities aiding to provide direct magnetic flux, represented by broken lines 44, through the unconfined circuit. Otherwise, operation is the same as in the Fig. 2 circuit.

Somewhat better operation can be obtained if a separate motor is used to draw the steel strip from the pickling tank, instead of relying entirely on the motor which drives reel 9. A further improvement in operation is obtained by additional control means for automatically maintaining substantial equality between the speed at

which strip enters the pickling tank and the speed at which it emerges, so that only small errors need correction by the proximity gauge control. An arrangement of this type is shown in Fig. 5. Referring now to this figure, motor 10 drives reel 9 as hereinbefore explained. Another motor 45 drives roller 8' to draw the steel strip from the pickling tank at a substantially constant speed. Motor 45 is supplied with current through connections 11, and a rheostat 46 is provided for adjusting the speed of this motor to a desired value.

Motors 10 and 45 automatically divide their load, and consequently no special means to maintain a proper speed relation between the two is necessary. If motor 45 should tend to run faster than required for it to keep up with motor 10, motor 45 picks up a larger portion of the load, which tends to reduce the speed of motor 45 and increase that of motor 10, until the correct speed relation is restored.

Two small D.-C. generators 47 and 48 are mechanically coupled to motors 5 and 45, respectively. Generators 47 and 48 are of the type commonly called "D.-C. tachometer generators" which provide direct current proportional in value to the speed at which the generator is driven. Generators 47 and 48 are connected to supply current through magnetic amplifier signal windings 49 and 50, respectively. The current through winding 49 acts upon the control system to decrease the speed of motor 5, while current through winding 50 acts to increase the speed of motor 5. Rheostats 51 and 52 may be provided, in series with the tachometer generators as shown, for adjusting the currents through windings 49 and 50 to equality when the speed of strip entering the pickling tank equals the speed of strip leaving the tank. If motor 5 should momentarily run faster than motor 45, generator 47 supplies more current through winding 49 than generator 48 supplies through winding 50. This tends to reduce the speed of motor 5, and restore the speed equality. But if strip 1 becomes too close, or not close enough, to the bottom of the tank, the proximity gauge operates as hereinbefore described to correct the error. The complete system described is unusually stable and free of any tendency to hunt excessively.

It will be appreciated that other modifications and arrangements which may occur to those skilled in the art, such as feeding the strip into the pickling tank at constant speed and using the proximity gauge to control the withdrawal rate for regulating immersion depth, are within the scope of this invention.

Having described the principle of this invention and the best mode in which we have contemplated applying that principle, we wish it to be understood that the apparatus described is illustrtaive only, and that other means can be employed without departing from the true scope of the invention.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. A proximity gauge for ferromagnetic materials, comprising a confined magnetic circuit and an unconfined magnetic circuit the magnetic element of each of said magnetic circuits consisting of the same saturable element, means to provide direct magnetic flux through the unconfined circuit, a winding linking the confined circuit and a portion only of the unconfined circuit, a rectifier connected in series with said winding, connections to apply alternating voltage across the series connected winding and rectifier, and apparatus responsive to the value of current through said winding.

2. A proximity gauge for ferromagnetic materials, comprising a confined magnetic circuit and an unconfined magnetic circuit both the magnetic element of each of said magnetic circuits consisting of the same saturable element, first and second windings linking the unconfined circuit and the confined circuit respectively, connections for energizing the first winding with direct current, a rectifier connected in series with the second winding, connections to apply an alternating voltage across the series-connected second winding and rectifier, and apparatus responsive to the value of current through the second winding.

3. A proximity gauge for ferromagnetic materials, comprising a two-legged saturable magnetic element, a first winding around both legs of said element connected for energizing the first winding with direct current, second and third windings around respective ones of the two legs, rectifiers connected in series with the second and third windings respectively, connections to apply two alternating voltages in phase opposition across the respective sets of series-connected rectifiers and windings, and apparatus responsive to the value of currents through the second and third windings.

4. A proximity gauge for ferromagnetic materials, comprising a two-legged saturable magnetic element, a first winding about both legs of said element, connections for energizing the first winding with direct current, second and third windings around respective ones of the two legs, a capacitor connected in parallel with said third winding, rectifiers connected in series with the second and third windings respectively, connections to apply two alternating voltages in phase opposition across the respective sets of series-connected rectifiers and windings, and apparatus responsive to a difference in value between the direct currents through the second and third windings respectively.

5. A control system for a D.-C. motor which regulates the position of ferromagnetic material, comprising a booster generator electrically connected in series with the D.-C. motor and having a field winding adapted for external excitation, a confined magnetic circuit and an unconfined magnetic circuit both including a common saturable element and positioned in proximity to the ferromagnetic material the position of which is controlled, first and second windings linking the unconfined circuit and the confined circuit respectively, connections for energizing the first winding with direct current, connections for energizing the second winding with current having alternating components, and a current amplifier connected to provide through the field winding of said booster generator a current dependent in value upon the current through said second winding.

6. In apparatus for pickling steel strip, including a pickling tank, means to draw strip from the tank, and means including a variable-speed D.-C. motor to feed strip into the tank, an improved control system comprising a booster generator electrically connected in series with the D.-C. motor and having a field winding adapted for external excitation, a two-legged saturable magnetic element embedded in the floor of the pickling tank, a first winding around both legs of said element, connections, for energizing the first

winding with an adjustable value of direct current, second and third windings around respective ones of the two legs, rectifiers connected in series with the second and third windings respectively, connections to apply two alternating voltages in phase opposition across the respective sets of series-connected rectifiers and windings, a magnetic amplifier having a signal winding connected in series with both sets of series-connected rectifiers and windings, the depth of immersion of the strip controlling the values of the currents flowing in said sets and the voltage supplied to said signal winding amplidyne having a field winding connected across the output of the magnetic amplifier and having its output connected to the field winding of said booster generator.

7. In a system for controlling the depth of immersion of strip material in a tank, having electric motors for feeding such material into the tank and for withdrawing material from the tank respectively, the combination of a booster generator connected in series with one of such motors for varying the relative speeds of such motors, means including a magnetic amplifier for controlling the voltage generated by said booster

generator, said magnetic amplifier having a plurality of signal windings, gauging means for supplying direct current through a first of said signal windings in amounts related to the depth of immersion of such material, a first tachometer generator mechanically coupled to one of such motors and electrically connected to supply current through a second of said signal windings, and a second tachometer generator mechanically coupled to the other of such motors and electrically connected to supply current through a third of said signal windings.

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