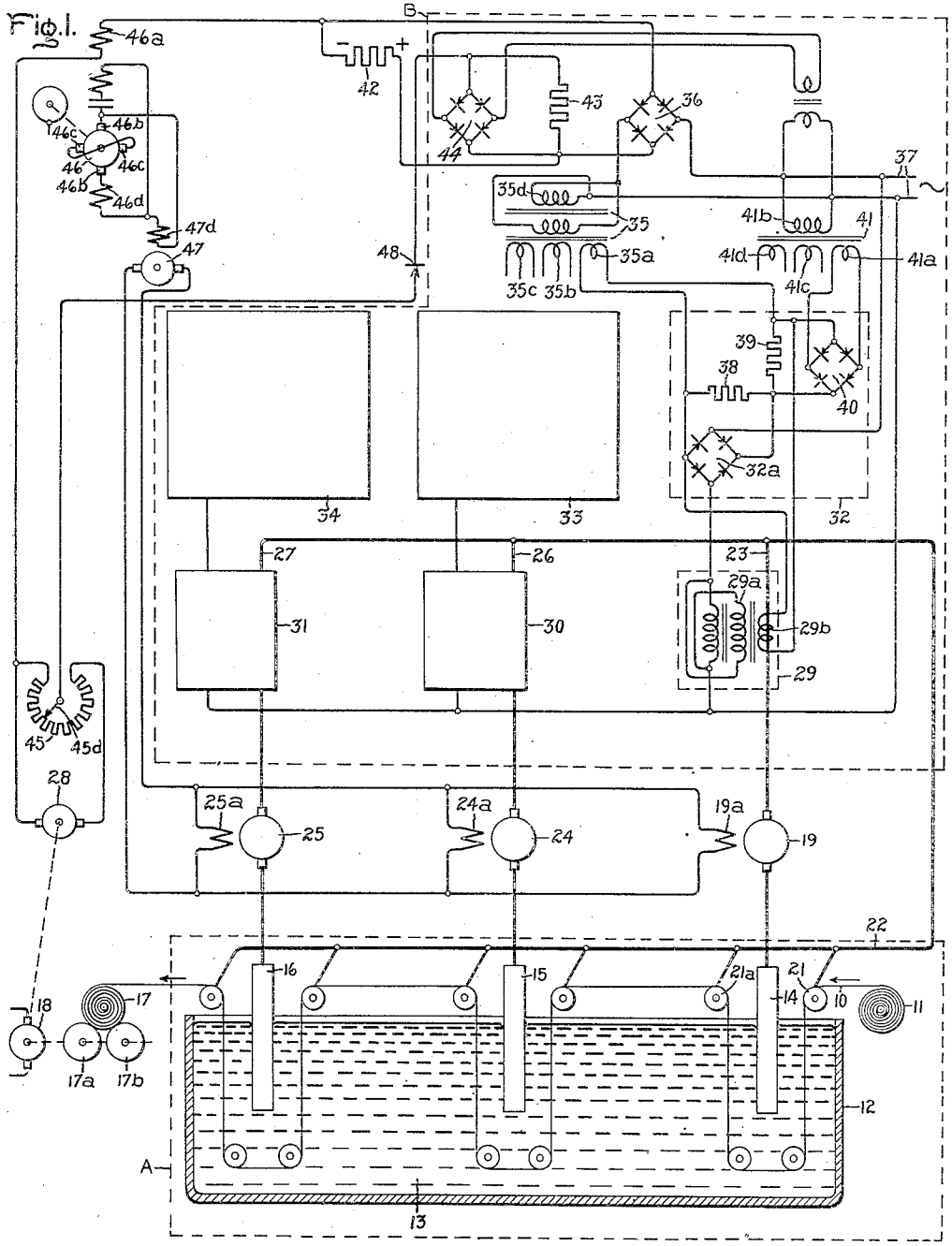
March 1, 1949. M. A. EDWARDS ET AL 2,463,254

ELECTROPLATING CONTROL SYSTEM

Filed Dec. 16, 1943 2 Sheets-Sheet 1

Fig. 1.



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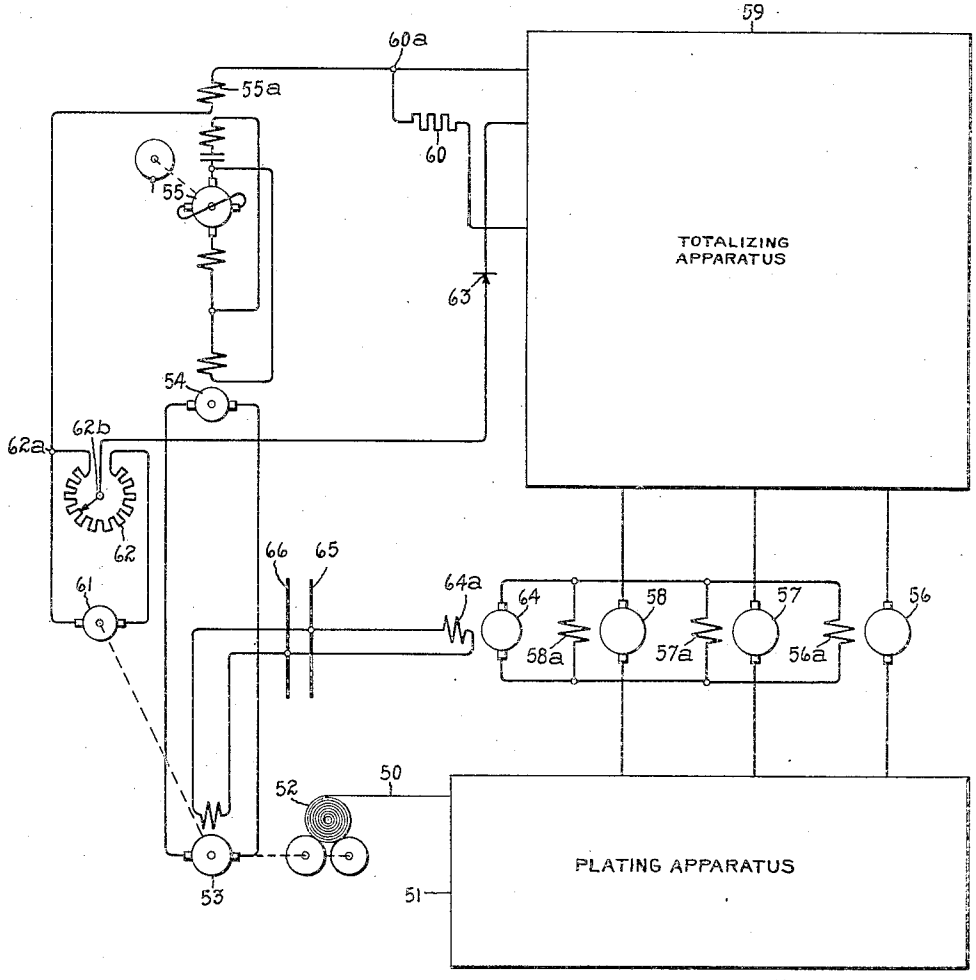
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Fig. 2.



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ELECTROPLATING CONTROL SYSTEM

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1 Claim. (Cl. 204—211)

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This invention relates to apparatus for controlling the electroplating of a moving length of material and it has for an object the provision of a simple, reliable and efficient and improved control apparatus of this character.

A very important application of apparatus of this character is the electrolytic tin plating of a strip of cold steel. Electrolytic tin plating results in a product equal to that produced by the hot dip method with a saving in tin of approximately 50 per cent. Although economics alone is sufficient justification for the electrolytic process, the present strategic value of tin is the more important consideration.

In carrying the invention into effect in one form thereof, a strip of cold steel is unwound from a coiler, passed through a plating tank in a number of parallel passes and then wound upon a take-up reel. The plating tank contains an electrolyte and a plurality of spaced apart electrodes. The electrodes are included in direct current circuits. For the purpose of producing a uniform coat of minimum thickness, means are provided for correlating the magnitude of the plating current with the speed of the strip. This correlating means comprises current regulating or controlling devices in circuit with the electrodes, a totalizing means for producing a control voltage proportional to the sum of the electrode currents, a device for producing a second control voltage proportional to the speed of the strip together with means for comparing these control voltages and controlling the electrode current controlling devices responsively to the difference of these control voltages to maintain the sum of the separate electrode currents at a value proportional to the speed of the strip.

For a better and more complete understanding of the invention, reference should now be had to the following specification and to the accompanying drawing, of which Fig. 1 is a simple diagrammatical illustration of an embodiment of the invention and Fig. 2 is a modification.

Referring now to the drawing, a length of cold steel strip **10** is unwound from a paying-out reel **11**, passed into a tank **12**, and then through a tin plating bath **13** in a series of vertical passes, the pass lines of which are spaced from the electrodes **14**, **15** and **16**. After passing through the bath, the strip is wound on a take-up reel **17**.

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In passing through the bath **13** in tank **12**, only the top surface of the strip receives a coating of tin from the electrodes **14**, **15** and **16**. Additional electrodes (not shown) are provided for coating the bottom surface.

The take-up reel **17** is driven by any suitable driving means such, for example, as a direct current motor **18**. This motor may be supplied from any suitable source such as an adjustable voltage generator (not shown). Tension may be maintained in the strip between the paying-out reel **10** and the first contact guide roller at the entrance end of the tank by means of a dynamoelectric machine (not shown) which is driven by the paying-out reel. This dynamoelectric machine operates as a generator and returns energy to the supply generator which supplies the take-up reel motor and in thus returning energy to the system, it acts as a braking generator.

Each of the electrodes **14**, **15** and **16** is included in a separate direct current circuit. For example, the circuit for electrode **14** extends from the lower or positive terminal of the direct current generator **19** to the tin electrode **14** which acts as an anode, through the plating bath to the strip and then through contact rollers **21** and **21***a*, conductors **22** and **23** to the negative terminal of generator **19**.

The electrodes **15** and **16** are similarly connected in separate direct current circuits with direct current generators **24** and **25** through conductors **26** and **27**.

In the interest of simplicity, only three electrodes are illustrated in the drawing. In practice a much larger number, such as twelve, and a corresponding number of direct current generators are used.

The generators **19**, **24** and **25** are low-voltage high-current generators. For example, these generators may be designed for 6000 amperes and 12 volts. Since the current flowing in each of the electrode circuits is a high value, e. g., 6000 amperes, the conductors **23**, **26** and **27** preferably are constructed as bus bars.

Instead of the generators **19**, **24** and **25**, other suitable means may be employed for supplying or controlling the value of currents supplied to the electrode circuits. One alternative to the generators is the combination of a rectifier supplied from an A. C. source and a series connected sat-

urable core reactor in circuit with each of the electrodes. A second alternative is a grid controlled mercury arc rectifier connected in circuit with each of the electrodes.

For the purpose of maintaining the total electrode current at a value proportional to the speed of the strip, means are provided for producing a control voltage which is proportional to the speed of the strip and additional means are provided for producing a control voltage proportional to the sum of the electrode currents.

The means for producing control voltage proportional to strip speed is illustrated as comprising a tachometer generator 26 which is driven by the take-up reel driving motor 18. As indicated, the take-up reel 17 is driven by means of contact drums 17*a* and 17*b* which make contact with the coil at the periphery thereof. These drums are driven by the motor 18. Since the coil is driven through contact drums 17*a* and 17*b* at the periphery of the coil, the speed of the strip will be proportional to the speed of the motor 18. Likewise the voltage of the tachometer generator, which is driven by motor 18, is proportional to the speed of the strip.

The means for producing a control voltage proportional to the sum of the electrode currents comprises a plurality of saturable reactor units 29, 30 and 31, one for each of the bus bars 23, 26 and 27, together with a plurality of corresponding rectifier units 32, 33 and 34 and a totalizing reactor 35 and associated rectifier 36.

The impedance of a saturable core reactor to alternating current may be varied by varying the D. C. excitation of its magnetic circuit, and a D. C. exciting coil may be provided for this purpose. However, the core of the reactor 29 is designed to be slipped over the bus bar and thus the ampere turns of saturating current are numerically equal to the amperes flowing in the bus bar.

For the purpose of economy in the amount of iron required for the core member of the reactor, for proper operation at 6000-ampere turns produced by the bus current, a feedback winding 29*b* is wound over the reactance winding 29*a*. The reactance winding 29*a* is connected in series relationship with the full wave rectifier 32*a* of the rectifier unit 32 across a source of alternating voltage which is represented by the two supply lines 37.

The reactance voltage drop across the reactance winding 29*a* decreases as the saturation of the core increases. Thus the output voltage of the rectifier 32*a*, which is the difference between the constant voltage of source 37 and the voltage drop across reactance winding 29*a*, is proportional to the net saturation current. This output voltage of rectifier 32*a* appears across the resistance 38. The feedback winding 29*b* is included in a circuit which is connected across the output of rectifier 32*a* and its polarity is such that its ampere turns oppose the ampere turns of the electrode current. The net saturating ampere turns of reactor unit 29 are the difference of these two ampere turns. The feedback winding may be designed, for example, to produce 5600 ampere turns when the bus bar ampere turns are 6000. With such design the net saturating ampere turns of reactor 29 is 400.

The reactor 29 has a magnetizing current of about 5 per cent. That is to say, when all direct current is removed from the reactor, the voltage across the output terminals of rectifier 32*a* is 5 per cent of the voltage that appears across these terminals when the reactor is saturated. This is the voltage produced by the magnetizing current which flows in the reactance winding when there is no direct current excitation of the reactor. This voltage is applied to the feedback winding. At zero electrode current, this 5 per cent voltage causes a small current to flow in the feedback winding which causes partial saturation and this partial saturation, in turn, causes a greater voltage to appear across the output terminals of the rectifier. The action is cumulative and once begun, the reactor becomes and remains saturated until alternating voltage is removed from the reactance winding. To prevent this cumulative self-excitation, a small opposing bias voltage, slightly in excess of the 5 per cent voltage produced by the magnetizing current, is provided. This opposing voltage is applied across the resistor 39 and is supplied from the rectifier 40 which in turn is supplied from the secondary winding 41*a* of a transformer 41, the primary winding 41*b* of which is connected across the source 37. The resistor 39 is connected in series relationship with the feedback coil 29*b* which is connected across the resistor 38 to which the output voltage of rectifier 32*a* is supplied. The polarities are such that the voltages across the resistors 38 and 39 are in opposition so that at zero electrode current the voltage across the feedback winding 29*b* is zero.

The reactor units 30 and 31 are identical with unit 29 and, accordingly, a description of units 30 and 31 is omitted to avoid repetition. Likewise, the rectifier units 33 and 34 are duplicates of unit 32 and a description is therefore omitted. The bias rectifiers of units 33 and 34, which correspond to the bias rectifier 40 of unit 32, are supplied from the secondary windings 41*c* and 41*d* of transformer 41.

The totalizing reactor 35 is provided with a plurality of direct current saturating windings 35*a*, 35*b*, and 35*c*, one for each of the electrodes. The saturating winding 35*a* is connected across the resistors 38 and 39 and thus there is caused to flow in the saturating winding 35*a* a saturating current which is proportional to the current flowing in electrode 14. Similarly, the saturating windings 35*b* and 35*c* are connected across resistors in rectifier units 33 and 34 which correspond to resistors 38 and 39 in rectifier unit 32. Thus, currents which are proportional to the currents flowing in the individual electrode circuits are caused to flow in the saturating windings 35*a*, 35*b* and 35*c*.

The reactance winding 35*d* of the totalizing reactor is connected in series with full wave rectifier 36 across the source 37. A resistor 42 is connected in series relationship with a resistor 43 across the output terminals of rectifier 36. For the purpose of producing zero voltage across the output terminals of rectifier 36, when zero current is flowing in each of the saturating windings 35*a*, 35*b* and 35*c*, a small bias voltage is supplied from rectifier 44 to resistor 43 of such a polarity as to oppose the voltage produced across the resistor 42 by the magnetizing current flowing in reactance winding 35*d*. The reactance of the reactor winding 35*d* decreases and the current flowing therein increases with increased saturation of the core. Thus, a current is caused to flow in resistance 42 which produces a voltage drop across resistor 42 that is proportional to the sum of the separate currents flowing in the saturation windings 35*a*, 35*b* and 35*c* and hence

proportional to the sum of the separate electrode currents.

One terminal of resistor 42 is connected to the slider of a potentiometer 45 which is connected across the tachometer generator. The other terminal of the resistor 42 and the terminal 45d of like polarity of potentiometer 45 are connected to opposite terminals of the control field winding 46a of a special direct current dynamoelectric machine 46. The voltage between the slider and the terminal 45a is derived from the voltage of the tachometer generator 28 and is therefore proportional to the speed of the strip. Thus, there is applied to the control field winding 46a a voltage which is the difference of the voltage across resistance 42, which represents the total electrode current, and the voltage between the slider of potentiometer 45 and terminal 45a which is proportional to the speed of the strip.

A special dynamoelectric machine 46 has a pair of load brushes 46b and a pair of brushes 46c on an axis which is displaced 90 electrical degrees from the axis of the load brushes. The brushes 46c are short-circuited.

The control field winding 46a is arranged on the load brush axis. The armature reaction along the load brush axis is effectively neturalized by the series compensating field winding 46d. The control field winding 46a, which is also arranged on the load brush axis, produces a flux which causes current to flow in the short circuit, and this short-circuit current produces an armature flux which generates a voltage across the load brushes and causes current to flow in the load circuit. The machine is thus a cross armature flux excited, direct armature flux compensated dynamoelectric machine. The important characteristics of this machine are its high speed of response and its high amplification factor, i. e., the ratio of the current in the load circuit to the current in the control field winding.

The dynamoelectric machine 46 thus compares the voltage drop across resistor 42, representing the total electrode current, with a voltage derived from the tachometer generator which represents the speed of the strip, and supplies a current proportional to the difference of these voltages to the field winding 47a of an exciter 47. This exciter 47 supplies excitation current to the field windings 19a, 24a and 25a of the generators 19, 24 and 25 which individually supply currents to the electrodes 14, 15 and 16, respectively. If the combination of saturable reactors and rectifiers were used instead of the generators 19, 24 and 25 as pointed out in the foregoing, the exciter 47 would be connected to supply excitation to the saturating windings of the reactors. In other words, the saturating windings of these separate reactors would be connected in the places of the field windings 19a, 24a and 25a, respectively.

By varying the position of the slider on the potentiometer 45, the total plating current for any given strip speed can be adjusted as desired. A rectifier 48 is included in the connections between the slider 45a and the right hand terminal of potentiometer 42.

In operation, if the total plating current drops below the value set on the plating current adjustment potentiometer 45, the difference voltage applied to the regulating field winding 46a of dynamoelectric machine is increased, which in turn increases the excitation supplied to the field winding 47a of the exciter 47. As a result of its increased excitation, the exciter 47 generates an increased voltage which is supplied to the field windings of the separate electrode generators 19, 24 and 25 and the current supplied by these generators to the electrodes is increased until the total current produces a voltage drop across the resistor 42 such that the difference between the voltage drop across the resistor 42 and the voltage between the slider and the terminal 45a of potentiometer 45 will produce just that excitation of the control field winding 46a which is required to maintain the total electrode current at the value set on the potentiometer 45.

If the total plating current should increase above the value set on the potentiometer 45, a similar but reverse action takes place.

If the speed of the strip increases, the voltage of the tachometer generator 28 increases correspondingly and, as a result, an increased difference voltage is applied to the control field winding 46a of the dynamoelectric machine 46. This causes an increased voltage to be supplied to the field windings 19a, 24a and 25a of the plating generators 19, 24 and 25. As a result, the total current supplied by these generators to the electrodes will increase thereby increasing the voltage drop across the resistor 42 and reducing the difference voltage applied to the field winding 46a until the excitation of the dynamoelectric machine 46 is just sufficient to maintain the total electrode current at the proper value for the increased speed of the strip.

If the speed of the strip decreases, a similar but reverse operation takes place.

If for some reason, the speed of the strip should decrease very rapidly, the voltage across the active portion of potentiometer 45 would become less than the voltage across the potentiometer 42, and the current through field winding 46a would be momentarily reversed. This would tend to reverse the excitation of the plating current generator. During a severe transient, this tendency might actually reverse the plating current. The polarity of the magnetic fluxes produced by the plating current and feedback windings of the reactors 29, 30 and 31 would then be in the same direction, and the reactors would be completely saturated. If this occurred, it would be necessary to shut down the entire equipment before normal operation could be restored.

This undesirable operating condition is prevented by the rectifier 48 which prevents reverse current flow in the field winding 46a. Thus, when the speed of the strip drops suddenly, the excitation of control field winding 46a and the excitation of the plating generators 19, 24 and 25 may decrease to zero until the voltage drop across the potentiometer 42 becomes less than the voltage drop across the active portion of potentiometer 45. This allows the plating current to decrease to a new low value corresponding to the reduced speed of the strip.

In the modification of Fig. 2, the speed of the strip is controlled as a function of the sum of the plating currents flowing in the separate electrode circuits. This is accomplished by utilizing the output of the totalizing apparatus to control the speed of the driving means for the take-up reel.

The length of material 50 after passing through the plating apparatus 51 is wound upon a reel to form a coil 52. The plating apparatus of Fig. 2 is represented conventionally by the rectangle 51

since it is identical with the plating apparatus contained within the dotted rectangle A of Fig. 1.

The take-up reel 52 is driven by a direct current electric motor 53 which corresponds to the take-up reel motor 18 of the modification of Fig. 1. The motor 53 is supplied from a small generator 54 which corresponds to the exciter 47 of Fig. 1. This generator receives its excitation from an armature reaction excited dynamoelectric machine 55 which corresponds to the machine 46 of Fig. 1.

Currents are supplied to the electrode circuits of the plating apparatus 51 by means of individual direct current generators 56, 57 and 58 which correspond to the generators 19, 24 and 25 of the modification of Fig. 1. These electrode currents are totalized by means of totalizing apparatus which is represented conventionally by the rectangle 59. This totalizing apparatus 59 is preferably identical with the totalizing apparatus of Fig. 1 which is enclosed within the dotted rectangle B.

A resistor 60 corresponding to the resistor 42 of Fig. 1 is connected to the output of the totalizing apparatus so that a voltage is produced across the resistor 60 which is proportional to or a function of the sum of the individual electrode currents.

A voltage proportional to the speed of the length of material 50 is generated by means of a tachometer generator 61 which is driven by the reel motor 53. This voltage proportional to strip speed is applied to a potentiometer resistor 62 which is connected across the armature terminals of the tachometer generator. The terminals 62*a* of potentiometer 62 and 60*a* of resistor 60, which have the same polarity, are connected to opposite terminals of the control field winding 55*a*, and the slider 62*b* of potentiometer 62 is connected through rectifier 63 to the opposite terminal of potentiometer 60. As a result of these connections, the voltage drop across potentiometer 60 which is proportional to total electrode current is compared with the voltage drop between the terminal 62*a* and the slider 62*b* of potentiometer 62 which is proportional to the strip speed, and the difference of these two voltages is applied to the control field winding 55*a* of the armature reaction excited dynamoelectric machine 55.

The field windings 56*a*, 57*a* and 58*a* of the individual electrode current supply generators are excited from a suitable source of excitation, such as the exciter 64 which is driven at a substantially constant speed by suitable means, such as an induction motor (not shown). The field winding of exciter 64 is excited from a suitable D. C. source which is represented by the two supply lines 65 and 66.

The slider 62*b* is adjusted to a position on the potentiometer 62 which corresponds to the strip speed which is to be held for a predetermined normal value of total electrode current.

In operation, when this speed is reached, a balanced condition exists in the system with the difference between the voltage drop across the potentiometer 60 and the voltage drop across the active portion of the potentiometer 62 being just sufficient to maintain the speed of motor 53 at the desired value for the predetermined normal value of total electrode current.

If the total electrode current decreases below this normal value, the voltage drop across potentiometer 60 will decrease, thereby reducing the difference voltage applied to control field winding 55*a*. This results in decreasing the speed of the reel drive motor 53 until a new condition of balance is established at a somewhat lower speed, which corresponds to the reduced electrode current. Similarly, if the total electrode current increases above the predetermined normal value, the difference of the voltage drops across potentiometer 60 and the active portion of potentiometer 62 is correspondingly increased. As a result, the speed of motor 53 is increased to effect a corresponding increase in the speed of the strip. A new condition of balance is established at a higher value of strip speed which corresponds to the increase total electrode current.

Although in accordance with the provisions of the patent statutes, this invention is described as embodied in concrete form and the principle thereof has been described together with the best mode in which it is now contemplated applying that principle, it will be understood that the apparatus shown and described is merely illustrative and that the invention is not limited thereto, since alterations and modifications will readily suggest themselves to persons skilled in the art without departing from the true spirit of this invention or from the scope of the annexed claim.

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

Apparatus for controlling the electroplating of a length of material in a tank containing an electrolyte and a plurality of electrodes comprising in combination, an electric motor for moving said length of material through said electrolyte, a plurality of direct current circuits each including a different one of said electrodes thereby to cause a direct current to flow through each of said electrodes and said electrolyte to said material, a separate supply generator connected in each of said circuits provided with a field winding for controlling the current flowing therein, a tachometer generator driven by said motor for producing a control voltage proportional to the speed of said length of material, a plurality of saturable reactors each provided with a saturating winding excited by the direct current of a corresponding one of said direct current circuits, a reactance winding and a feedback winding, a separate rectifier for each of said reactors, each having its input terminals connected in circuit with the reactance winding of a corresponding reactor and its output terminals connected in circuit with the feedback winding thereof, a source of constant direct voltage and electrical connections from said source to said feedback winding for supplying a bias voltage to said feedback winding to counteract the output voltage of said rectifier resulting from the magnetizing current of said reactance winding at zero electrode current, a totalizing saturable reactor having a plurality of saturating windings each connected to be excited by the output voltage of a corresponding one of said rectifiers and having a reactance winding, a rectifier having its input terminals connected in circuit with said reactance winding of said totalizing reactor for producing in its output circuit a control voltage proportional to the sum of said electrode currents, and a dynamoelectric machine excited by the difference of said control voltages and having electrical connections from its armature to the field windings of said supply generators for supplying exciting current to said field windings of said supply generators to maintain the ratio between the speed

of said length of material and the sum of said electrode currents substantially constant.

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