

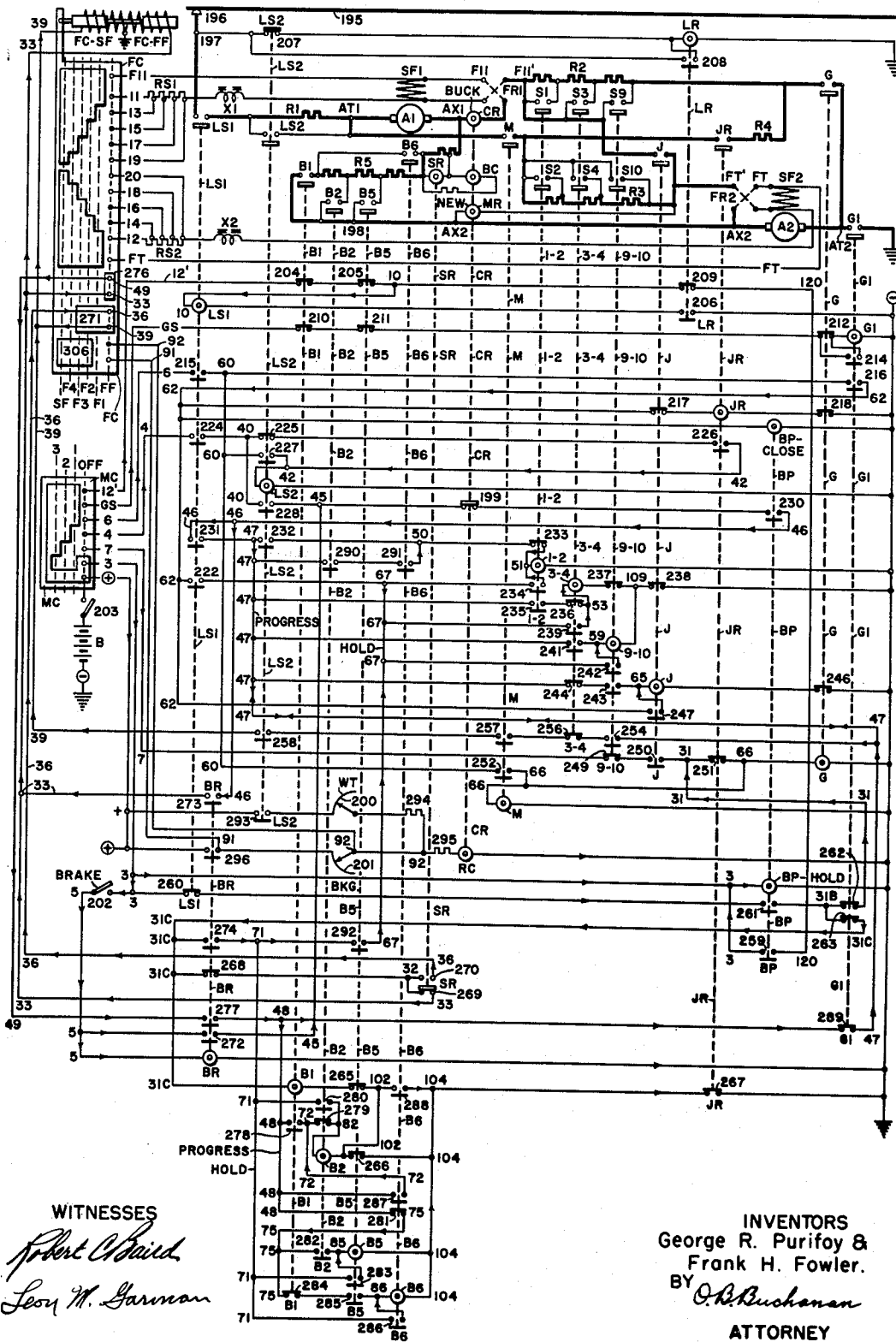
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TRACTION-MOTOR CONTROL

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TRACTION-MOTOR CONTROL

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Our invention relates to direct-current electrically propelled railway-vehicles, and it has particularly relation to electrical control-systems therefor, in which provision is made for obtaining a smooth acceleration during motoring, and also for obtaining a smooth buildup of dynamic brake. Smooth operation is important, not only for the comfort of the passengers in the vehicle, but also for protecting the motors against flashing, particularly during high-speed dynamic-braking conditions, when high voltages are likely to be obtained across the motor-armatures. Our invention is an improvement over the motor-protection system shown in the patent of George R. Purifoy and William L. Barclay, Jr., No. 2,653,284, granted September 22, 1953, in which a so-called kick-coil, or step-up current-transformer, was required, to additionally energize a rate-coil, which did not produce the main current-responsive operating-reflux of the limit-relay. This increased the cost, weight, and space-requirements of the control-equipment.

In particular, we obtain improved results, usually at less expense, by providing a shunt relay-coil on the limit-relay, and by connecting this shunt relay-coil across one or more of the series main-field windings of the motor or motors, or across some alternative serially connected inductive-impedance means in a portion of the motor-circuit which is common to both the power-operating motoring-conditions and the dynamic-braking conditions. (If the series main-field winding is not used as a voltage-source for energizing the shunt relay-coil, it is preferable that the alternatively used serially connected inductive-impedance means shall have a long time-constant, similar to that of the series main-field winding of the motor.) Our shunt relay-coil produces the main or a substantial current-responsive operating-flux of the limit-relay.

Preferably, in addition to our new shunt relay-coil, the limit-relay is provided with a conventional series coil, or a coil similar to the conventional series coil, except that its connections are reversed, so that it bucks some of the ampere-turns of the shunt coil. In this way, we accentuate the kicks which are obtained in the shunt coil, and we have an easier job in matching the temperature characteristics of the limit-relay to the temperature characteristics of the motor-field, so as to avoid material changes in the limit-relay calibration as a result of thermal changes in the resistance of the field-winding.

Shunt relay-coils have been used before, on the limit-relays of traction-motor controls, with these shunt coils energized from the motor-fields, as shown in the patent of Norman H. Willby, No. 2,663,835, granted December 22, 1953, and variations of the therein-illustrated connections. Our invention consists in the use of such a limit-relay in the control of progression during both motoring and dynamic braking, in connection with a traction motor having no shunt field; in the reversal of the series-coil connections of Willby's limit-relay; and in the application of our modified limit-relay to a motor-protecting control-

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system having other individually-known features, in combination, as will be hereinafter described.

With the foregoing and other objects in view, our invention consists in the circuits, systems, apparatus, combinations, parts, and methods of design and operation, hereinafter described, and illustrated in the accompanying drawing, the single figure of which is a simplified circuit-diagram of the parts of one car, which are necessary to illustrate our present invention, omitting many parts which are known to be needed in a successful railway-control equipment of the type to which our invention is applied, but which are not necessary to be discussed in setting forth the nature and operation of our present improvement.

The drawing represents some of the equipment which is carried by a single electrically propelled railway-car embodying our invention. Direct-current power is supplied to the car from a third rail 195, or a trolley wire, which is engaged by a third-rail shoe 196, or a trolley pole, pantograph, or other current-collecting equipment, carried by the car. The third-rail shoe 196 energizes a line 197 which constitutes a supply-circuit for the car. The traction-motors for the car are series motors, which are indicated, by way of a simple example, in the drawing, as comprising two motor-armatures A1 and A2, each being associated with its own series field winding SF1 and SF2, respectively. Two series-motor means, or circuits, are shown. The first series-motor means comprises, in series, an armature-terminal AT1, a motor-armature or armatures A1, an intermediate connection-point AX1, a series relay-coil CR of a limit-relay which is also commonly designated CR, a field-reverser FR1, a series main-field winding or windings SF1 for supplying the field-excitation for said armature or armatures A1, a field-terminal F11, the field-reverser FR1 again, and an auxiliary field-terminal F11'. The corresponding parts for the second series-motor means are indicated at AT2, A2, AX2, FR2, SF2, FT, FR2 again, and FT', noting that the series relay-coil CR is not present in this second series-motor means.

A series-parallel motor-control arrangement is shown in the drawing, in which a line-switch or relay LS1 and a ground-switch G1 are used as power-switch means for establishing a power-circuit for energizing the motors, by connecting the first armature-terminal AT1 to the supply-circuit 197, and connecting the second armature-terminal AT2 to ground. For completing the series-circuit connections, a switch JR is closed in addition to the power-switches LS1 and G1. For parallel-motor operation, two switches M and G are closed in addition to the power-switches LS1 and G1. The parallel-motor switch M provides a circuit-connection between the armature-terminal AT1 of one series-motor means and the auxiliary field-terminal FT' of the other series-motor means; while the other parallel-motor switch G provides a circuit-connection between the other armature-terminal AT2 and the other auxiliary field terminal F11'. During an intermediate transition-period, a switch J is closed. These motor-controlling connections are all in accordance with a well-known switching-system.

Dynamic-braking circuits are established by opening the two power-switches LS1 and G1 and closing a braking-switch B1 in addition to the two parallel-connection switches M and G, also in accordance with a well-known system or arrangement. The braking-switch B1 provides a common dynamic-braking circuit-connection 198 between the respective intermediate connection-points AX1 and AX2 of the two series-motor means, thus providing two dynamic-braking circuits wherein the motor-armature or armatures of each of said series-motor means are loaded by the field winding or windings of the other one of said series-motor means, respectively.

A suitable number of series-connected accelerating

resistances are used, as indicated at R1, R2, R3 and R4. The resistance R1 is disposed between the supply-line 197 and the first armature-terminal AT1, and is shorted out by means of a second line-switch LS2. The resistance R2 is in series with the first auxiliary field-terminal F11', and is progressively shorted out by means of switch-contacts S1, S3 and S9. The resistance R3 is in series with the second auxiliary field-terminal FT', and is progressively shorted out by switch-contacts S2, S4 and S10. The resistance R4 is in the series-motor connection which is made by the switch JR, and this resistance is finally shorted out by the transition-switch J, for obtaining the full-series power-circuit connection of the motors.

During parallel motor operation, the switch-contacts S3, S4 and S9, S10 are successively or progressively closed, during the acceleration of the motor, and after all of the accelerating-resistances R2 and R3 have been cut out, the field-strengths of the motors are progressively reduced, to provide short-field operating-conditions.

In accordance with a usual arrangement, the motor-fields are reduced by equipping each of the series field windings SF1 and SF2 with a field-shunt, comprising an inductive reactor X1 or X2, as the case may be, and a variable resistor RS1 or RS2, respectively. The field-shunts X1—RS1 and X2—RS2 are first connected in parallel relation to their respective field-windings SF1 and SF2, by means of contact-terminals F11—11 and FT—12, respectively, of a progressively or sequentially operating field-controlling means, which is herein illustrated as an electrically operated drum-type field-controller FC. After the respective field-shunts have been connected into operation, the field-shunt resistances RS1 and RS2 are then progressively shorted out by successive controller-points 13, 15, 17 and 19, for RS1, and 14, 16, 18 and 20, for RS2, as the field-controller FC is moved from its initial full-field position FF, through its intermediate positions F1, F2, F3 and F4 to its short-field position SF, at which point the field-winding currents are reduced to about fifty per cent of their unshunted values.

During dynamic braking, the two motors are connected by the common dynamic-braking circuit-connection 198, which contains the braking-switch B1 and a braking-resistance R5. This resistance R5 is used, in addition to the previously mentioned accelerating-resistances R2 and R3, in establishing the complete dynamic-braking circuit. The braking-resistance R5 is progressively shorted out by means of braking-switches B2, B5 and B6, during dynamic-braking operations, after which the acceleration resistances R2 and R3, or portions thereof, are progressively shorted out, as by the switch-contacts S3, S4, and S9, S10.

The progressive operation of the various resistance-shortening switches, during both motoring operation and dynamic braking, is under the automatic control of a suitable limit-relay or relays, which are energized to be responsive to conditions which accompany excessive torque in the motors. Such a limit-relay is illustrated in the form of the previously mentioned current-relay CR, which, according to our present invention, is provided with a motor-coil MR, which is a shunt relay-coil, connected in shunt across the terminals FT' and AX2 of the series main-field winding SF2 of the second motor. This shunt relay-coil MR produces the main, or at least a substantial, current-responsive operating-flux of the limit-relay CR, thus taking over the function which was previously performed by the series relay-coil CR in the control-system of the Purifoy-Barclay Patent 2,653,284. In our present limit-relay CR, the series relay-coil CR is preferably, but not necessarily, still used; and when it is used, it is reversed with respect to the polarity of its previous connections, in said Purifoy-Barclay patent, so that it now bucks some of the ampere-turns of the shunt coil MR; and this shunt coil MR is given enough ampere-turns to be operative in spite of said bucking.

Further details of the design of our limit-relay CR will be given hereinafter, when the operation of the illustrated equipment is being reviewed.

This current-relay CR also has a back-contact 199 (also marked CR), which is normally closed, that is, which is closed in the non-actuated or low-current position of the relay.

The current-relay CR is also provided with certain recalibrating-means. In accordance with previous practice, this relay is provided with a brake-coil BC, which has long been a part of the standard equipment of limit-relays on this type of control-equipment. This brake-coil BC acts cumulatively with respect to the main shunt coil MR, and it is connected in the common brake-circuit connection 198, so that it recalibrates the limit-relay in response to the braking-current, which in turn varies with the speed of the vehicle.

The limit-relay or current-relay CR is further provided with a well-known rate-coil RC, which now acts cumulatively with respect to the main shunt coil MR. This rate-coil RC, in accordance with a known practice, is energized through a weight-responsive rheostat 200, during accelerating operations, and it is energized through a braking-responsive rheostat 201 during dynamic-braking conditions. The switch-responsive rheostat 200 is automatically adjusted according to the variable weight or live load carried by the car, so that the rate-coil RC is the most strongly excited during light-load conditions, thus reducing the minimum-current setting at which the limit-relay CR picks up and opens its back-contact 199. The braking-responsive rheostat 201 is automatically changed in response to the position of a brake-handle 202, which will be subsequently described, so that the rate-coil RC has its maximum excitation when a low braking-rate is called for, thus providing a low minimum-current setting at which the limit-relay CR picks up and opens its back contact 199, and also providing a limit-relay calibration which is different for braking and power-operating conditions. Further details of the rate-coil energizing-circuits will be described hereinafter.

All of the electrically controlled relays and switches which are shown in the drawing are diagrammatically indicated as having vertical switch-stems (indicated by dotted lines), which are biased by gravity toward their lowermost positions, and all of these switches and relays are shown in their deenergized or non-actuated positions. All of the relays and switches are electrically controlled, and they are illustrated as being electrically or magnetically operated, by means of an appropriately numbered or lettered coil or solenoid, represented by a circle, acting magnetically to lift an armature which is represented diagrammatically by a smaller circle inside of the coil-circle. In general, the same switch-designation is applied to any particular switch, its coil, and its contacts, by way of identification of the parts belonging to a given switch or relay.

The various electrical control-circuits for a train are under the control of a number of train-line wires, which extend from car to car, throughout the entire length of the train (not shown). In the simplified circuit-diagram of the drawing, eight of these train-line wires are used, being given their usual designations, namely (+), 3, 4, 5, 6, 7, 12' and GS.

Energy for the various relay-circuits or switch-circuits is provided by means of a battery B on each car. The negative terminal (—) of each battery is permanently grounded, while the positive terminal of each battery is connected through a switch 203, to the positive train-line wire (+).

Each end of each car is provided with a motorman's master controller MC, only one of which is indicated in the drawing. The illustrative master controller MC is indicated as being an accelerating-controller having an off-position and three on-positions 1, 2, 3. In each of the three on-positions of the master-controller, MC, the

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positive control-wire (+) is connected to the train-line wires 12', GS and 6. The train-line wire 12' is the energizing-wire for the operating-coil LS1 of the line-switch LS1; while the train-line wire GS is the energizing-wire for the operating-coil G1 of the ground-switch G1, as will be subsequently described.

In the second and third on-positions of the accelerating-drum of the master controller MC, the train-line wire 4 is energized from the positive bus (+); while in the third on-position of this controller, the train-line wire 7 is energized from the positive bus (+).

In the off-position of the accelerating drum or master controller MC, a connection is made from the positive control-wire (+) to the train-line wire 3. In the master controller MC, in accordance with a known practice, there is an over-lap between the off-position contact which energizes this conductor 3, and the on-position contacts which energize the conductors 12' and GS, so that, during the notching-off of the master-controller MC, the contact at 3 is made before the contacts at 12' and GS are broken.

The first on-position of the accelerating-controller MC, in Fig. 1, is a switching position, in which the control-wires 12', GS, and 6 are all energized. The control-wire 12' energizes a control-circuit wire 10, through interlocks which are provided, by the braking-switches B1 and B5, in the form of back-contacts 204 and 205, respectively; and the control-circuit wire 10 is used to energize the operating-coil LS1 of the line-switch LS1.

In accordance with a usual practice, the exciting-circuit for the line-switch operating-coil LS1 also contains a make-contact 206 of a line-relay LR, which is a voltage-responsive relay which drops out upon a voltage-failure of the supply-line 197. This line-relay LR is shown as an undervoltage relay which has an operating-coil LR which is connected between the supply-line 197 and ground, through a back-contact 207 of the line-switch LS2, said back-contact 207 being paralleled by a make-contact 208 of the line-relay LR.

The control-wire 10 energizes a control-wire 120 through a back-contact 209 of the line-relay LR. This line-relay back-contact 209 thus closes in the event of a power-line voltage-failure, which might result from either a third-rail gap or from any other cause; and if the master-controller MC is, at the time, on any on-position, the conductors 12' and 10 will be energized, and hence the line-relay back-contact 209 will energize the control wire 120, which we use as an auxiliary holding-circuit for the protective relay or brake-power relay BP, which we will subsequently describe in more detail.

The train-line wire GS energizes the operating-coil G1 of the ground-switch G1, through interlocks which are provided by back-contacts 210, 211 and 212, which are carried by the braking-switches B1 and B5, and by the parallel-operation switch G, respectively. The back-contact 212 is paralleled by a make-contact 214 of the ground-switch G1.

The train-line wire 6 is connected, through an LS1 make-contact 215, to a relay-circuit 60, which is connected, through a G1 make-contact 216, to a circuit 62 which constitutes a hold-circuit for the switch-progression for the accelerating - resistance short - circuiting switches S1 to S10 and J. This hold-circuit 62 is used to energize the operating coil JR of the series-motor circuit switch JR, through interlocks on the switches J and G, in the form of back-contacts 217 and 218, respectively. The said hold-circuit 62 is also used to directly energize the close-coil or actuating-coil BP-close of the braking-operation protective-relay BP.

The result of the master-control energization in the No. 1 on-position of the master-controller MC, is thus to close the main-circuit or power-circuit contacts of the traction-motor switches LS1, G1 and JR, thereby completing a series-connection motor-circuit for causing a

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slow movement of the train, for so-called "switching" purposes, with all of the accelerating-resistances in series with the motors. This circuit can be traced from the supply-circuit 197, through the main LS1 contact, the resistor R1, the armature A1, the series coil CR of the limit-relay, the series field SF1, the resistance R2, the resistance R4, the main JR contact, the resistance R3, the series field SF2, the motor armature A2, and the main G1 contact, to ground.

At the same time, the energization of the braking-operation protective-relay BP paves the way for the subsequent energization of the dynamic-braking circuits of the motors, and also for the automatic progression-control, under the control of the limit-relay or current-relay CR, both for the motoring progression during acceleration, and for the dynamic-braking progression during an application of the brake-lever 202, as will be subsequently described.

The hold-circuit 62, which is energized in the No. 1 on-position of the master-controller, is also connected, through an LS1 make-contact 222, to a hold-circuit 67, which is used in the subsequent progression-control.

The No. 2 position of the accelerating-controller MC is the first of two running-positions 2 and 3. It initiates the accelerating progression of the series-motor connections, by energizing the trainline wire 4, which is connected, through an LS1 make-contact 224, to a conductor 40. The conductor 40 is connected, through an LS2 back-contact 225, and a JR make-contact 226, to a conductor 42, which energizes the operating-coil LS2 of the second line-switch LS2, which acts as the first acceleration-progression switch, by short-circuiting the first accelerating-resistor R1. This LS2 switch has a make-contact 227 which picks up and serves as a holding-circuit contact between the circuits 60 and 42.

This second line-switch LS2 also has a make-contact 228 which connects the circuit 40 to a circuit 45. The circuit 45 is connected, through the CR limit-relay back-contact 199, and through a BP make-contact 230, to a circuit 46, which constitutes the main limit-relay progression-circuit of the control-equipment. This limit-relay progression-circuit 46 is thus not only under the control of the limit-relay or current-relay CR, which is responsive to excessive motor-currents, but it is also under the control of the braking-operation protective-relay BP, which must be closed (with the protective relay in its actuated position), before there can be any progression during either the motoring operation or the braking operation.

This limit-relay progression-circuit 46 is connected, through an LS1 make-contact 231, to a progression-wire 47, which is connected through an LS2 make-contact 232 to a control-wire 50. The control-wire 50 energizes the operating-coil 1—2 of a second resistor-shortening progression-switch 1—2, which carries the two main contacts S1 and S2, this energization being effected through a back-contact 233 of this same switch 1—2. Thus, this energizing-circuit from the conductor 50 includes the switch-out interlock 233, a conductor 51, and the coil 1—2. This second progression-switch 1—2 picks up and closes a holding-circuit make-contact 234, which energizes the circuit 51 from the hold-circuit 67. Our present invention is designed, as will be subsequently described, to improve the operation of the limit-relay CR, in controlling this progression through the limit-relay back-contact 199, which is in series with the progression-circuit 46.

The actuation of the second resistance-shortening switch 1—2 also closes a make-contact 235, which energizes a circuit 53 from the progression-circuit 47, through a back-contact 236 of a third resistance-shortening switch 3—4, which is the switch which carries the main switching-contacts S3 and S4. The energizing-circuit for this switch extends from the conductor 53, through the operating-coil 3—4 and a back-contact 237 of a fourth resistance-shortening switch 9—10, thence through a control-circuit conductor 109, and a J-switch back-contact 238, to the ground negative battery-terminal (—). The actuation of the

third resistance-shortening switch 3—4 closes a make-contact 239 which establishes a holding-circuit for the conductor 53 from the hold-wire 67.

The actuation of the third progression-switch 3—4 also closes a make-contact 241, which completes a circuit from the progression-wire 47 to a conductor 59, which energizes the actuating coil 9—10 of the fourth resistance-shortening switch 9—10, which carries the main switch-contacts S9 and S10, the negative terminal of said coil 9—10 being connected to the previously described wire 109. The actuation of this fourth switch 9—10 also closes a make-contact 242 which establishes a holding-circuit for the conductor 59 from the hold-wire 67.

The actuation of the fourth resistance-shortening switch 9—10 also closes a make-contact 243, which is connected between the progression-wire 47 and a circuit 65, through a back-contact 244 of the third resistance-shortening switch 3—4. This circuit 65 energizes the operating-coil J of the transition-switch J, through a G-switch back-contact 246. The transition-switch J then closes its main or power-circuit contact J, which constitutes the last step in series motor-connection for the traction-motors, cutting out the last accelerating-resistance R4. This transition-switch J has a make-contact 247 which establishes a holding-circuit from the conductor 65 back to the hold-line 62. The previously described J-switch back-contacts 217 and 238 are opened, upon the energization of the transition-switch J, thus dropping out the initial series-connection switch JR, and the third and fourth accelerating switches 3—4 and 9—10.

The next step in the acceleration of the traction-motors is accomplished by a movement of the master-controller MC to its No. 3 position, which is a parallel-motor running-position. This position 3 of the master-controller energizes the train-line wire 7, which is connected, through a back-contact 249 of the fourth accelerating or resistance-shortening switch 9—10, and a make-contact 250 of the transition-switch J, so as to energize a control-circuit 31, which is in turn connected, through a JR back-contact 251, to a control-circuit 66 which energizes the operating-coils M and G of the parallel-motor-connection switches M and G. These switches M and G thereupon connect the traction-motors in parallel, between the supply circuit 197 and ground, with only the first two of the resistance-shortening switches energized, in the illustrated form of embodiment of our invention, namely the second line-switch (or first progression-switch) LS2, and the second progression-switch 1—2 which carries the main switching-contacts S1 and S2. The energization of the parallel-connection switch G opens the previously described back-contact 246, which drops out the transition-switch J. The energization of the parallel-connection switch M closes a make-contact 252, which establishes a holding-circuit for the conductor 66 from the line 60.

Responsive to the dropping-out of the transition-switch J, the back-contact 238 of this switch recloses, and re-initiates the switch-progression of the resistance-shortening contacts S3 to S10, under the control of the switches 3—4 and 9—10, through the circuits which have been previously described. This establishes the maximum armature-voltage conditions on the motors, and it completes the connections for the full-field parallel-connection operation of the traction-motors.

As soon as the resistance-shortening switch 9—10 closes, it closes an additional contact 254, which energizes a field-controller actuating-circuit from the progress-wire 47, said circuit extending from the wire 47 through the previously mentioned make-contact 254 of the resistance-shortening switch 9—10, a back-contact 256 of the third progression-switch 3—4, a make-contact 257 of the parallel-connection switch M, and a make-contact 258 of the line-switch LS2, and thence to the short-field wire 39 of the field-controller FC.

The short-field wire 39 of the field-controller FC

energizes the short-field coil FC—SF, or other means which may be used to move the field-controller from its full-field position FF to its short-field position SF. This starts the progressive operation of the field-controller, and it may be brought about in any one of several ways. In the illustrated form of embodiment, since the power for the short-field wire 39 is obtained from the progress-wire 47, which is under the control of the limit-relay CR, the field weakening progression of the field-controller FC progresses under the control of the limit-relay CR, until the short-field position SF is reached. This completes the connections for the short-field parallel-connection operation of the traction-motors, thus completing the acceleration-progression.

If, now, the master-controller MC is returned to its off-position, the car or train being now running at some speed, the master-controller will energize the train-line wire 3, which may be described as the brake-wire 3, because it is used to set up the dynamic-braking circuits for the motors during the coasting operation. When the braking-protective relay BP is used, as shown, the brake-wire 3 is also used to directly energize a hold-coil BP—hold of the braking protective relay BP, and this hold-coil may be regarded as representative of any holding-means which is effective only after the protective relay BP has previously been moved to its actuated position. When a separate holding-coil, BP—hold, is used as such a holding-means for the BP relay, said coil will be made so as to be too weak to pick up the BP relay if the relay is in its non-actuated position when the hold-coil is energized, but the hold-coil BP—hold has enough energy to hold the relay actuated or closed, once it has been actuated.

The BP—hold coil is also provided with a second energizing-circuit, which is independent of the brake-wire 3, and is thus operative in any of the three on-positions of the master-controller MC. This second hold-coil energizing-circuit includes a make-contact 259 of this brake-protective relay BP, and this make-contact 259 is used to energize the brake-wire 3 from the previously described control-circuit 120, which is under the control of the line-relay LR, so that the control-circuit 120 is energized whenever there is a failure of the line-voltage, at a time when the train-line wire 12' is energized, that is, at a time when the master-controller is on any one of its three on-positions, as previously described. In this way, we not only maintain the energization of the BP—hold coil under the no-voltage conditions just described, thus making sure that the brake-protective relay BP remains in its actuated condition, but we also immediately energize the brake-line 3, without waiting for the master-controller MC to be returned to its off-position, which establishes the coasting braking-circuit connections, as will now be described.

The brake-wire 3 is connected, through an LS1 back-contact 260 and a BP make-contact 261, to a control-circuit 31B. This control-circuit 31B is connected, through a G1 back-contact 262, to the previously described control-circuit wire 31, which energizes the previously described parallel-motoring switches M and G through the JR back-contact 251 and the control wire 66. The control-conductor 31B is also connected, through a G1 back-contact 263, to a control-wire 31C, and thence to the positive terminal of the braking-switch coil B1, the negative terminal of which is connected in a circuit which includes a B5 back-contact 265, a conductor 102, another B5 back-contact 266, a conductor 104, and a JR back-contact 267, and thence to the grounded negative battery-terminal (—). The closure of the switches M, G and B1 completes the establishment of a weak coasting-operation dynamic-braking circuit-connection for the traction-motors, with all of the available dynamic-braking resistances R5, R2 and R3 in circuit, this dynamic-braking resistance being large enough so that the braking tractive-effort is usually quite weak, at moderate motor-

speeds, thus permitting the train to coast, with little or no sensible or perceptible braking-effect, as long as the field-controller FC remains in its short-field position.

A connection is also provided, for controlling the field-controller FC during the coasting-operation. In accordance with a known practice, we provide a circuit extending from the control-wire 31C, through a back-contact 268 of a previously known brake-relay BR, to a control-circuit 32, and thence through the back-contact 269 of a spotting-relay SR, to the full-field wire 33 of the field-controller FC. The spotting-relay SR is a previously used relay, having an operating-coil SR which is included in the common brake-circuit connection 198, so that this relay is responsive to the braking-circuit current. Actually, the spotting-relay coil SR, and the brake-coil BC of the limit-relay CR, are both connected, in separate parallel circuits, across a small portion of the braking-resistance R5, as is shown in a patent of George R. Purifoy, No. 2,669,679, granted February 16, 1954. The spotting-relay SR is adjusted to have a low-current pickup-value, so that it can hold the braking-circuit current to a small value suitable for spotting purposes, during the coasting operation of the traction-motors, as is well understood in the art.

The full-field wire 33 of the field-controller FC energizes a full-field coil FC—FF, or other means for causing the field controller FC to move or progress from its short-field position SF to its full-field position FF. This energization of the full-field coil FC—FF under the control of the spotting relay SR thus progressively adjusts the field-controlling means FC toward its full-field position, as spotting-conditions require.

In accordance with a known control-method, the spotting-relay SR has a make-contact 270 which connects the circuit 32 to a circuit 36, which goes to a field-controller contact-segment 271, which is closed only during certain early points in the progressive movement of the field-controller FC from its full-field position FF toward its short-field position SF. This field-controller segment 271 is preferably opened at a certain point near the short-field position SF, preferably before the field-controller reaches this short-field position SF. As shown, we prefer to have this field-controller segment 271 closed at the positions FF through F3 of the field-controller FC. This field-controller segment 271 is used to connect the wire 36 to the short-field wire 39 of the field-controller FC. In this way, when the spotting current is too large, that is, large enough to pick up the spotting-relay SR, the spotting current is reduced by adjusting the motor-field toward a weaker condition, by making the field-controller FC progress in the direction towards its short-field position, but this progression is usually arrested before the field-controller returns all of the way back to its original short-field position SF, which is occupied before the spotting-control commenced to operate.

A service braking-application is made by the closure of the brake-lever 202, which energizes the full-brake wire 5 from the brake-wire 3. This full-brake wire 5 is connected directly to the coil BR of the brake-relay BR. The brake-relay BR has a make-contact 272, which connects the full-brake line 5 to the conductor 45 which leads up to the limit-relay progression-circuit 46, thus putting the braking progression under the control of the back-contact 199 of the limit-relay or current-relay CR, as well as under the control of the BP make-contact 230, both of which are in circuit between the conductor 45 and the limit-relay progression-circuit 46. At the same time the opening of the back-contact 268 of the now-actuated brake-relay BR takes the braking progression out of the control of the spotting relay SR.

Whenever a braking-application is called for, the energization of the brake-relay BR closes a BR make-contact 273, which is used in the initiation of the dynamic-braking progression. Thus, the BR make-contact 273 is used to make a connection from the limit-relay progres-

sion-circuit 46 to the full-field wire 33 of the field-controller FC. This causes a progression of the field-controller FC until it reaches its full-field position FF, under the control of the limit-relay CR. Our present invention is designed to improve the operation of the limit-relay at this time, as will be subsequently described.

The closure of the brake-relay BR also closes a make-contact 274 which makes a connection from the control-wire 31C to a braking-operation hold-wire 71, in readiness for use in the subsequent brake-progression operations.

When the braking-controlling progression has proceeded to the point at which full-field conditions are restored in the traction-motors, the field-controller FC closes a full-field contact member 276, which closes a circuit from the full-field wire 33 to a conductor 49, and thence through a BR make-contact 277 to a braking-progression circuit 48.

The energization of the braking-circuit progression-wire 48 immediately serves, through a B1 make-contact 278, which is already closed, to energize a circuit 72, which is connected, through a B2 back-contact 279, to a circuit 82 which is connected to the positive terminal of the B2 actuating-coil, the negative terminal of which is connected to the previously described conductor 102. The B2 switch thus picks up and closes its main contact B2 which shorts out a part of the braking-resistance R5 in the common dynamic-braking circuit 198 of the traction-motors. The actuation of the B2 switch also closes a make-contact 280 which establishes a holding-circuit for the wire 82 from the hold-wire 71.

A circuit is next established from the lower end of the progression-wire 48, through a B6 back-contact 281, to a conductor 75, and thence through a B2 make-contact 282, which has just been closed, to a conductor 85 which is connected to the positive terminal of the B5 actuating-coil, the negative terminal of which is connected to the previously mentioned wire 104. The B5 switch closes its main-circuit contact B5, which shorts out more of the braking-resistance R5 in the common dynamic-braking circuit 198 of the traction-motors. At the same time, the B5 switch closes a make-contact 283 which establishes a holding-circuit from the conductor 85 back to the hold-wire 71.

The energization of the braking-progression switch B5 opens its previously mentioned back-contacts 265 and 266, thus dropping out the switches B1 and B2, the main contacts of which are both short-circuited, now, by the main contact B5. The dropping-out of the B1 switch closes its lowermost back-contact 284, which completes a circuit from the conductor 75 to a B5 make-contact 285, and thence to a wire 86, which is connected to the positive terminal of the B6 coil, the negative terminal of which is connected to the wire 104. The B6 switch thus closes, and closes its main contact B6 which further shorts out some of the braking-resistor R5, thus still further reducing the effective braking-resistance in the dynamic-braking circuits. At the same time, the actuation of the B6 switch closes its make-contact 286, which establishes a holding-circuit for the wire 86 from the wire 71.

The actuation of the B6 switch also closes a make-contact 287, which connects the progression-wire 48 to the previously described conductor 72, thereby reenergizing the B2 switch, the negative circuit of which is now completed from the wire 102, through a B6 make-contact 288, to the wire 104.

It will be understood that all of these braking-progression operations are under the control of the limit-relay progression-circuit 46, which interrupts the progression whenever an excessive motor-current causes an opening of the current-relay back-contact 199, which is connected in the energizing circuit for said wire 46, thus interrupting the progression until the motor-current subsides to a desirable value.

The braking-circuit progression-wire 48 is also connected, through a G1 out-contact or back-contact 289, to the accelerating-resistance progression-wire 47.

After the second closure or actuation of the B2 switch, so that the B2 and B6 switches are now both closed, a circuit is made, from the accelerating-resistance progression-wire 47, through a B2 make-contact 290 and a B6 make-contact 291, to the previously described conductor 50, thus reinitiating the progression of the switches 1—2, 3—4, and 9—10, which progressively close the accelerating-resistor switches S1 to S10, thereby cutting out the accelerating resistors R2 and R3 which are in the individual portions of the respective dynamic-braking circuits of the traction-motors, this progression being also under the same limit-relay control.

Ever since the actuation of the B5 switch, a B5 make-contact 292 has been energizing the accelerating-resistance hold-circuit 67 from the wire 71, in readiness for this progression of the accelerating-resistor switches S1 to S10. The braking-progression thus continues until substantially all of the braking-resistance is removed from the dynamic-braking circuit, thus resulting in the completion of the dynamic-braking operation, during which the speed of the car or train has been reduced from the initial speed at which the dynamic brake was applied, down to a low speed at which the dynamic brake fades out.

If a braking-operation is to be discontinued, after once having been started, the braking-circuit switches are released by an opening of the brake-handle 202, without requiring the establishment of a (perhaps momentary) power-circuit (or MC on-position), in order to deenergize the braking hold-wire 71. This is accomplished by the BR-contact 274, which is in series with the hold-wire 71. The opening of the brake-handle 202 deenergizes the brake-relay BR and opens its contact 274, without requiring an on-position of the master controller MC to release the brake-wire 3, in order to deenergize the conductor 31C and hence the hold-wire 71.

It has long been customary to automatically adjust the calibration or setting of the limit-relay CR, in order to cause this relay to drop out in response to various accurately controlled desirable minimum motor-current values, during both the acceleration-progression and the dynamic-braking progression. This is conveniently done by various controls for the energization of the rate-coil RC of the limit-relay CR, and also (during braking) by the previously mentioned brake-coil BC. In the drawing, we have shown two previously known circuits for the rate-coil control or calibration. One such rate-coil circuit involves the weight-responsive rheostat 200, and is traceable from the positive control-power line (+) through an LS2 make-contact 293, the aforesaid weight-responsive rheostat 200, a resistance 294, a conductor 92, a resistance 295, and the rate-coil RC.

A second old or known rate-coil energizing-circuit for the rate-coil RC involves the braking-responsive rheostat 201, which automatically operates, in a known way, from its zero-resistance position to its full-resistance position, and finally to an open-circuit position, at a rate which is dependent upon the degree of application of the brake-handle 202, as is shown, for example, in the previously mentioned Purifoy patent. This second rate-coil energizing-circuit is traceable from the positive bus (+) through a BR make-contact 296, a conductor 91, and the aforesaid braking-responsive rheostat 201, to the conductor 92.

As described in the aforesaid Purifoy patent, it is usually necessary to provide some sort of over-shooting-preventive means, to prevent the automatically controlled braking-responsive rheostat 201 from too rapidly increasing the calibration of the limit-relay CR (by too rapidly decreasing the excitation of the rate-coil RC), when a full-brake or a heavy-brake application is called for by the brake-handle 202 at a time when the vehicle is operating at a high speed. If the current-setting of the limit-relay CR should be increased too fast, in passing from a spotting-operation to a braking-operation at a high vehi-

cle-speed, the limit-relay CR would not pick up at all, until the field-controller FC had moved, at an unrestrained rate, from its short-field position SF (which it had been occupying during spotting at a high vehicle-speed), to its full-field position FF, thus too quickly setting up a full-field motor-condition, resulting in a rough dynamic-brake application and motor-flashing, as the motor-flux and voltage built up too fast in response to this full-field excitation.

An overshooting-prevention means is provided in our drawing, in the form of a field-controller contact-segment 306, which connects the wires 91 and 92 (thus short-circuiting the braking-rheostat 201), in response to a shortened-field condition of the field-controller FC, as when the field-controller is in any one of its positions F2 through SF, as shown in the aforementioned Purifoy patent. In this way, when a braking-operation is called for, the limit-relay CR is not recalibrated upwardly until the field-controller FC has moved to nearly its full-field position, thus permitting the limit-relay CR to pick up, and open its contact 199, for each of the initial steps of the field-controller movement toward its full-field position FF. When the limit-relay contact 199 opens under these circumstances, it deenergizes the full-field operating-coil—of the field-controller FC, thus arresting the movement of the field-controller until the braking-current subsides, and thus preventing excessive motor-voltages during the opening steps of a dynamic-brake application. It will be recalled, and is evident from the drawing, that the full-field operating-coil FC—FF of the field-controller FC is energized, under these circumstances, from the limit-relay contact 199, through the circuit 230—46 to the brake-relay contact 273, and thence to the full-field wire 33 which energizes the full-field coil FC—FF.

The operation of the simplified illustrated apparatus will be clear from the running comments which have been made during the progress of the description, as well as from the prior art. A few words of added explanation, as to the features which are more particularly related to our novel control-circuit parts, may, however, be helpful.

Our shunt main-coil MR of the limit-relay CR is impressed with the voltage which appears across the series motor-field SF2. The time-constant of the motor-field is of the order of a second, more or less, whereas the time-constant of the MC relay-coil is of the order of 10 or 100 milliseconds. In the early stages of starting the power-operation of the traction-motors, each step or notch of the control produces a current-increase which results in a "kick" or transient increase in the voltage which appears across the motor-field. This "kick" may last for something like 0.5 second. The resistor-switches, such as 1—2, operate in something like 0.1 second, in one form of embodiment of our invention. The speed of pick-up of the limit-relay, required for the movement of the contact 199 from a closed position to an open position, depends upon the strength of excitation of the limit-relay. Without a "kick" or momentary initial increase in excitation, the limit-relay is too slow in picking up, so that the fast-moving accelerating or resistance-shortening switches have sometimes moved uninterruptedly through as many as five sequential steps of acceleration, before the limit-relay CR gets its contact 199 open, thus holding the further progression down to a step-by-step procedure, under the orderly control of the limit-relay, as intended.

Our new limit-relay CR receives a "kick" when the first line-switch LS1 and the ground-switch G1 first close, establishing the power-circuit. This "kick" quickly picks up the limit-relay, and interrupts further progression until either the "kick" or the motor-current, or both, subside sufficiently; except that, in the illustrated embodiment of our invention, the second line-switch LS2 comes in, without being controlled by the limit-switch contact

199, so that, in our illustrated form of embodiment, we can get two quick starting-steps, instead of five, as formerly. After the first few starting-steps, the "kicks" are not as large, but they are not needed, since the limit-relay is able to function properly, even without any "kicks."

During dynamic braking, we are interested in securing a contact-opening operation of the limit-relay CR, but only after the braking relay VR is actuated as a result of an operation of the brake-lever 202. This is because, during spotting, the control is responsive to the spotting-relay SR, and the limit-relay contact 199 is entirely disconnected from the control. During a braking-operation, we are more particularly interested in the effect of the "kicks" on the operation of the limit-relay CR, only at high vehicle-speeds, as at low speeds the braking progression is not too fast, even without the "kicks."

Upon an application of the brake-lever 202 during the high-speed operation of the vehicle, the field-controller FC is usually initially in or near its short-field position SF. The limit-relay CR lets the full-field coil FC—FF pull the field-controller FC only one step toward its full-field position FF, whereupon the limit-relay CR quickly picks up, aided by the above-described "kick," thus opening the limit-relay contact 199 and interrupting the progression of the field-controller until the braking-current subsides somewhat. In this way, the field-controller is moved one step at a time, so as to require two or three seconds to move from its short-field position SF to its full-field position FF, whereas, without a step-by-step interrupting-operation of the limit-relay CR, the field-controller might have completed this full movement in something like one second. At high vehicle-speeds, an application of full-field excitation to the motors in one second would take place before the sluggishly responding motors (now operating as series generators), could build up their voltage; so that, with full field established, the voltage would build up too fast, and too late to let the limit-relay hold back the progression-steps which had already been made. Our "kicks" enable the limit-relay CR to prevent this uninhibited progression of the field-controller at the beginning of a dynamic-braking operation at a high vehicle-speed, the limit-relay being aided, in this operation, by the full excitation of the rate-coil RC through the field-controller segment 306. By the time full field is reached, in such a step-by-step braking-operation of our invention, at high vehicle-speeds, the "kicks" would still be present, in diminishing amounts, with each new progression-step, to make sure of a sufficiently quick opening of the limit-relay contact 199, with each current-increment; but the "kicks" would not usually then be needed, to insure the continued step-by-step control of the braking-progression.

Under some circumstances, even during the high-speed operation of the vehicle, it is possible that the field-controller FC might be momentarily in or near its full-field position FF at the moment when the brake-lever 202 is moved, to call for dynamic braking. In such a case, the "kicks" are important to hold down the progression of the resistance-switches (such as B2, B5, etc.) to a step-by-step progression under the control of successive operations of the limit-relay CR.

Even at intermediate vehicle-speeds, when the spotting-control holds the field-controller FC closer to its full-field position FF than to its short-field position SF, if dynamic braking should be called for by an application of the brake-lever 202, the above-described "kicks" may not be large enough to make the limit-relay CR pick up during the remainder of the movement of the field-controller FC to its full-field position FF; but once full-field conditions have been established, the "kicks" will be stronger and will insure a step-by-step operation of successive resistance-switches during the subsequent progression of the braking-control.

It will be understood that our step-by-step progressions, under the control of our "kick"-responsive limit-

relay CR, provide comfortable riding-conditions for the passengers, and avoid motor-flashings, during both accelerating-control and braking-control.

While we have illustrated our preferred use of a bucking series coil CR, in addition to our field-voltage-responsive main shunt coil MR on our limit-relay CR, we are not limited to such use. The bucking series coil CR bucks down the relay-response to steady-state motor-currents, without bucking the relay-response to "kicks" or transient conditions. In fact, our bucking series coil CR, by requiring the use of additional turns on the shunt coil MR, makes the limit-relay have a stronger response to the "kicks" in the field-winding voltage. Strong "kicks" obviously augment the "kicking" effects in our limit-relay operation. A similar increase in the relative "kick"-response, as compared to the steady-state response of our limit-relay, could be obtained without the bucking series coil CR, by increasing the ratio of resistance to inductance in the circuit of the shunt coil MR.

It is very desirable, from another standpoint, to use both a series coil (such as CR) and a shunt coil (such as MR) on a limit-relay whose current-responsive main operating-flux is supplied by the shunt coil through a shunt connection across the field-terminals of a series direct-current motor. We refer to the variation in the field-resistance of the motor, according to the motor-temperature. A successful design of a limit-relay for such an application requires that considerable attention be given to the matching of the thermal operating-characteristics of the limit-relay to the temperature-characteristics of the motor, as it is rarely acceptable to place the relay on the motor-frame (where it would be directly responsive to the motor-temperature), due to the danger of lead-breakage. In our limit-relay, the series coil CR heats the relay, to a temperature corresponding to the running-temperature of the motor, the two mechanisms being traversed by the same current. Our shunt relay-coil MR is also traversed by a smaller current, which is proportionate to the motor-current except during the transients, which take up only a small percentage of the total operating-time, so that the heating-effects of these two relay-coils CR and MR must be added together, in matching the heating-effects within the motor. Our series coil CR has only two turns, in an exemplary embodiment, and it carries a heavy current, and in this particular design, it produces most of the heating-effect in our limit-relay CR. Our other two limit-relay coils, BR and RC, produce small heating-effects, which may sometimes need to be taken into consideration. By careful attention to such design-details, we avoid any substantial difficulty due to a change in the current-calibration of our limit-relay in response to a change in the operating-temperature of the motor field-winding.

While we have described our invention, and explained its manner of operation, in connection with a particular simplified illustrative form of embodiment, we wish it to be understood that the efficacy of the invention would not be affected by the addition of desired additional features or safeguards, or by the omission of undesired or unnecessary features, or by the substitution of equivalent or alternative forms of various means or elements for performing the essential element-functions which have been described and explained.

We claim as our invention:

1. A motor-controlling assembly, including the combination, with a direct-current series-motor means to be controlled, said series-motor means including a motor-armature and a series main-field winding connected in series therewith, of: (a) a supply-circuit for the series-motor means; (b) a power-switch means, for establishing a power-circuit for energizing the series-motor means from the supply-circuit; (c) a braking-switch means, for establishing a dynamic-braking circuit for the series-

motor means; (d) a progressively operating multi-step accelerating-controlling means, for controlling the accelerating-adjustment of the power-circuit during power-operating conditions; (e) a progressively operating multi-step braking-controlling means, for controlling the braking-adjustment of the dynamic-braking circuit during dynamic-braking conditions; and (f) an electromagnetic limit-relay means, operable at times to stop the progressions of the accelerating-controlling means and the braking-controlling means during power-operating conditions and dynamic-braking conditions, respectively; said limit-relay means comprising: (g) a shunt relay-coil which produces a substantial current-responsive operating-flux of the limit-relay means; (h) an inductive-impedance means, connected in series with a portion of the motor-circuit which is common to both the power-operating conditions and the dynamic-braking conditions; and (i) circuit-connections for connecting the shunt relay-coil in shunt across the inductive-impedance means.

2. A motor-controlling assembly, including the combination, with a direct-current series-motor means to be controlled, said series-motor means including a motor-armature and a series main-field winding connected in series therewith, of: (a) a supply-circuit for the series-motor means; (b) a power-switch means, for establishing a power-circuit for energizing the series-motor means; (c) a braking-switch means, for establishing a dynamic-braking circuit for the series-motor means; (d) a progressively operating multi-step accelerating-controlling means, for controlling the accelerating-adjustment of the power-circuit during power-operating conditions; (e) a progressively operating multi-step braking-controlling means, for controlling the braking-adjustment of the dynamic-braking circuit during dynamic-braking conditions; and (f) an electromagnetic limit-relay means, operable at times to stop the progressions of the accelerating-controlling means and the braking-controlling means during power-operating conditions and dynamic-braking conditions, respectively; said limit-relay means comprising: (g) a shunt relay-coil which produces a substantial current-responsive operating-flux of the limit-relay means; (h) a long-time-constant inductive-impedance means, connected in series with a portion of the motor-circuit which is common to both the power-operating conditions and the dynamic-braking conditions; and (i) circuit-connections for connecting the shunt relay-coil in shunt across the inductive-impedance means; and (j) said inductive-impedance means producing voltage-kicks which at times are of sufficient strength and duration to quickly actuate the limit-relay means after at least one or more of the current-increasing steps in the motor-controlling progression, and to hold the limit-relay means actuated long enough to prevent unwanted step-skipping in the progression.

3. A motor-controlling assembly, including the combination, with a direct-current series-motor means to be controlled, said series-motor means including a motor-armature and a series main-field winding connected in series therewith, of: (a) a supply-circuit for the series-motor means; (b) a power-switch means, for establishing a power-circuit for energizing the series-motor means from the supply-circuit; (c) a braking-switch means, for establishing a dynamic-braking circuit for the series-motor means; (d) a progressively operating multi-step accelerating-controlling means, for controlling the accelerating-adjustment of the power-circuit during power-operating conditions; (e) a progressively operating multi-step braking-controlling means, for controlling the braking-adjustment of the dynamic-braking circuit during dynamic-braking conditions; and (f) an electromagnetic limit-relay means, operable at times to stop the progressions of the accelerating-controlling means and the braking-controlling means during power-operating conditions and dynamic-braking conditions, respectively; said limit-relay means compris-

ing: (g) a shunt relay-coil which produces a substantial current-responsive operating-flux of the limit-relay means; and (h) circuit-connections for connecting the shunt relay-coil in shunt across said series main-field winding.

4. A motor-controlling assembly, including the combination, with a direct-current series-motor means to be controlled, said series-motor means including a motor-armature and a series main-field winding connected in series therewith, of: (a) a supply-circuit for the series-motor means; (b) a power-switch means, for establishing a power-circuit for energizing the series-motor means from the supply-circuit; (c) a braking-switch means, for establishing a dynamic-braking circuit for the series-motor means; (d) a progressively operating multi-step accelerating-controlling means, for controlling the accelerating-adjustment of the power-circuit during power-operating conditions; (e) a progressively operating multi-step braking-controlling means, for controlling the braking-adjustment of the dynamic-braking circuit during dynamic-braking conditions; and (f) an electromagnetic limit-relay means, operable at times to stop the progressions of the accelerating-controlling means and the braking-controlling means during power-operating conditions and dynamic-braking conditions, respectively; said limit-relay means comprising: (g) a shunt relay-coil which produces the main current-responsive operating-flux of the limit-relay means; (h) a series relay-coil which bucks some of the ampere-turns of said shunt relay-coil, said series relay-coil being connected in series with a portion of the motor-circuit which is common to both the power-operating conditions and the dynamic-braking conditions; (i) an inductive-impedance means, connected in series with a portion of the motor-circuit which is common to both the power-operating conditions and the dynamic-braking conditions; and (j) circuit-connections for connecting the shunt relay-coil in shunt across the inductive-impedance means.

5. A motor-controlling assembly, including the combination, with a direct-current series-motor means to be controlled, said series-motor means including a motor-armature and a series main-field winding connected in series therewith, of: (a) a supply-circuit for the series-motor means; (b) a power-switch means, for establishing a power-circuit for energizing the series-motor means from the supply-circuit; (c) a braking-switch means, for establishing a dynamic-braking circuit for the series-motor means; (d) a progressively operating multi-step accelerating-controlling means, for controlling the accelerating-adjustment of the power-circuit during power-operating conditions; (e) a progressively operating multi-step braking-controlling means, for controlling the braking-adjustment of the dynamic-braking circuit during dynamic-braking conditions; and (f) an electromagnetic limit-relay means, operable at times to stop the progressions of the accelerating-controlling means and the braking-controlling means during power-operating conditions and dynamic-braking conditions, respectively; said limit-relay means comprising: (g) a shunt relay-coil which produces the main current-responsive operating-flux of the limit-relay means; (h) a series relay-coil which bucks some of the ampere-turns of said shunt relay-coil, said series relay-coil being connected in series with a portion of the motor-circuit which is common to both the power-operating conditions and the dynamic-braking conditions; (i) a long-time-constant inductive-impedance means, connected in series with a portion of the motor-circuit which is common to both the power-operating conditions and the dynamic-braking conditions; and (j) circuit-connections for connecting the shunt relay-coil in shunt across the inductive-impedance means; and (k) said inductive-impedance means producing voltage-kicks which at times are of sufficient strength and duration to quickly actuate the limit-relay means after at least one or more of the current-increasing steps in the motor-controlling progression, and

to hold the limit-relay means actuated long enough to prevent unwanted step-skipping in the progression.

6. A motor-controlling assembly, including the combination, with a direct-current series-motor means to be controlled, said series-motor means including a motor-armature and a series main-field winding connected in series therewith, of: (a) a supply-circuit for the series-motor means; (b) a power-switch means, for establishing a power-circuit for energizing the series-motor means from the supply-circuit; (c) a braking-switch means, for establishing a dynamic-braking circuit for the series-motor means; (d) a progressively operating multi-step accelerating-controlling means, for controlling the accelerating-adjustment of the power-circuit during power-operating conditions; (e) a progressively operating multi-step braking-controlling means, for controlling the braking-adjustment of the dynamic-braking circuit during dynamic-braking conditions; and (f) an electromagnetic limit-relay means, operable at times to stop the progressions of the accelerating-controlling means and the braking-controlling means during power-operating conditions and dynamic-braking conditions, respectively; said limit-relay means comprising: (g) a shunt relay-coil which produces the main current-responsive operating-flux of the limit-relay means; (h) a series relay-coil which bucks some of the

ampere-turns of said shunt relay-coil, said series relay-coil being connected in series with a portion of the motor-circuit which is common to both the power-operating conditions and the dynamic-braking conditions; and (i) circuit-connections for connecting the shunt relay-coil in shunt across said series main-field winding.

7. The combination, with a direct-current circuit which is subject to sudden current-changes; of a current-responsive electromagnetic relay-means; said relay-means comprising: a shunt relay-coil which produces the main flux which actuates said relay-means; an inductive-impedance means, connected in series with said circuit; circuit-connections for connecting the shunt relay-coil in shunt across said inductive-impedance means; and a series relay-coil which produces a bucking flux which opposes the actuation of said relay-means, said series relay-coil being connected in series with said circuit.

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