Jan. 25, 1949. A. M. CURTIS 2,460,064

MOTOR CONTROL CIRCUIT

Filed May 16, 1945

FIG. 1

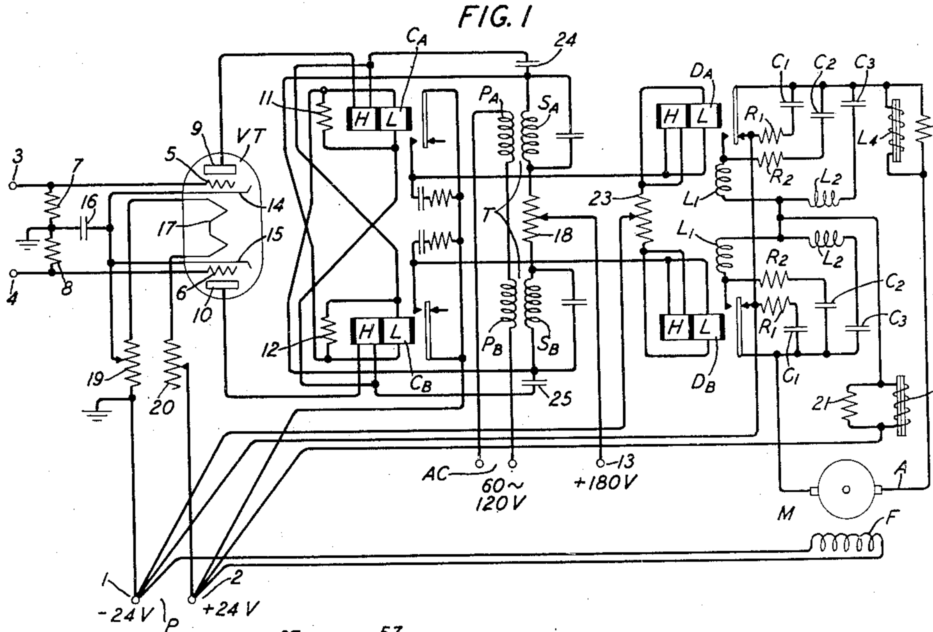
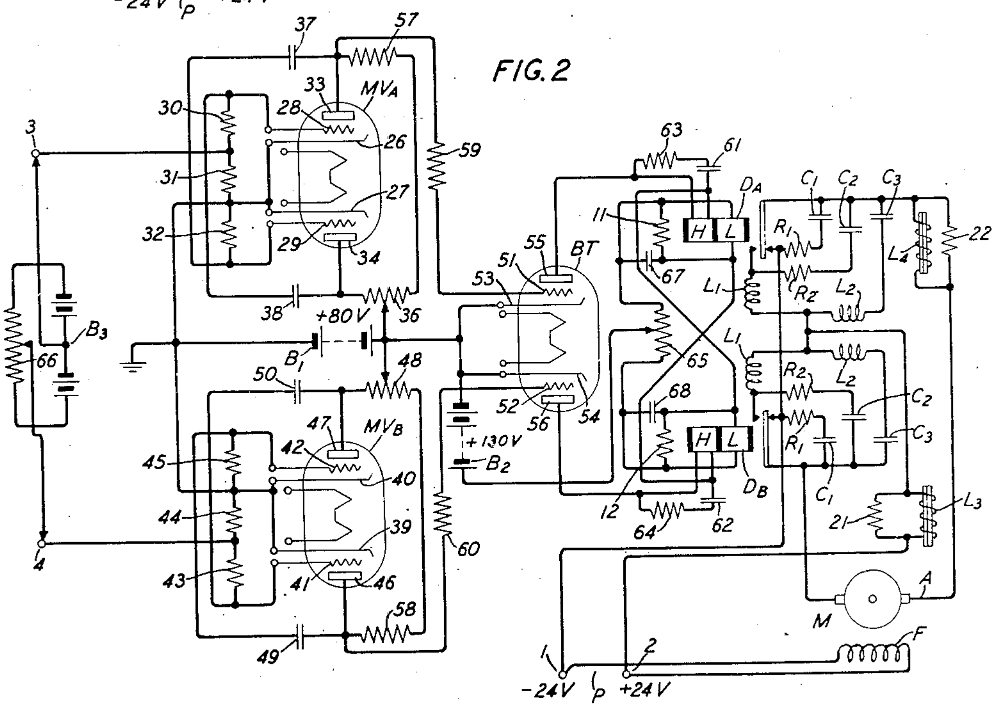


FIG. 2



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Patented Jan. 25, 1949

2,460,064

UNITED STATES PATENT OFFICE

2,460,064

MOTOR CONTROL CIRCUIT

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Application May 16, 1945, Serial No. 594,063

16 Claims. (Cl. 318—257)

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This invention relates to an amplifier circuit and more particularly to a motor control circuit having a vacuum tube amplifier stage, a relay stage and a motor stage.

The simplest relay control circuit which will permit a motor to be driven in either direction and at a speed dependent upon a weak control signal, employs two relays which are vibrated continuously by an external alternating current source of power at a periodicity of 20 to 60 cycles per second. The circuits through the motor over the contacts of the relay are such that when the relays in vibrating close their swing contacts to their front and back contacts for equal periods, no power is supplied to the armature of the motor if the motor is of the direct current type or to the control phase winding if the motor is of the two-phase alternating current type.

The percentage of time during which the swing contact of each relay is in its front or back contact closure position is controlled by a direct current through a second winding on the relay. This current serves both as a bias and as a signal and is preferably derived from a stage of tube amplification interposed between the signal input circuit and the relays. The direction of rotation of the motor is then dependent upon whether the signal or control current is above or below the normal bias value which controls the polarity of the power applied by the relays to the motor and the strength of the signal or control current above or below the normal bias value determines the duration of the impulses of power and thus the speed to which the motor will attain. A motor control circuit of this type is disclosed in the application of J. T. L. Brown and C. E. Pollard, Jr., Serial No. 594,048, filed May 16, 1945.

While this simple circuit gives a satisfactory performance for small motors it does not operate as well with larger motors. Part of the difficulty is that the relays found best adapted for use in such circuits, that is relays of the mercury contact reed armature type which are disclosed in the application of E. T. Burton, Serial No. 545,985 filed July 21, 1944, operate with a single contact transfer in which all three contacts are joined together for one or more milliseconds during each operation. Under some circumstances this bridging period may last longer particularly if the relays have been in service for a long time or become damaged. The current which the contacts will handle during these transfer periods without being damaged is about 12 amperes at 28 volts. This leads to the circuit arrangements in which the bridging of all three relay contacts will short-circuit the power supply and it is necessary to protect against this by an inductance which prevents a significant current from being drawn during the normal brief bridging and also by a resistance which limits the maximum current during a long flash and prevented damage to the contacts. This necessary protection limits the power which can be handled to about 30 watts at 28 volts direct current. The maximum length of impulses which can be applied to the armature of the motor during stable controlled operation of both relays is about equal to a quarter of the drive period. During the inactive part of the relay cycle of operation the motor armature is short-circuited and a large proportion of the applied power is wasted in heating the armature of the motor.

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The performance of this and all other direct current motor control circuits is improved by inserting between the relay contacts and the motor armature an inductance comparable in value to the inductance of the motor which stores energy during the applied power period of the operation of the relays and returns it to the armature during the braking period. If properly proportioned to the motor, load and drive frequency this prevents dynamic braking of the motor itself during the brief periods when the relays are centered and much improves the efficiency and smoothness of the torque developed by the motor.

But even with the added armature circuit inductance the operation of the balanced relay circuit is not as desirable for a large motor as the circuit which has been developed in accordance with the present invention. If the two relays do not match each other rather closely in dynamic operating characteristics there are likely to be inequalities in the curve of power versus control current and the contact protection problems become more difficult.

It is the object of the present invention to improve a motor control circuit of the type just described whereby motors of larger power may be controlled over the contacts of the control relays in response to a control or input signal, whereby the requirement that the relays should be substantially matched in their operation response is obviated and whereby impulses of a character best adapted for the most efficient mode of operation are delivered to the relays which control the motor.

In accordance with the present invention the relays may be caused to operate and release in alternation by a sine wave current applied to the exciting windings of the relays from an external source having a frequency from 20 to 60 cycles per second or the relays may be operated in by current applied to the exciting windings from multivibrator tubes.

If the first method of operation is used it is found convenient to precede the relays with a pair of triode tubes and to transfer the control function of the relays to the tubes. The relays will now function in accordance with the sine wave exciting current as modified by the biasing current applied to their control windings under the control of the triode tubes which in turn are under the control of the input signal. If impulses of power are now transmitted directly to the motor under the control of these relays the wave form of the impulses will not be the best for efficient motor operation and sparking will occur at the contacts of the relay. I have found, however, that if these relays are used merely as control relays to control the operation of an additional pair of drive relays which in turn serve to apply drive impulses to the motor then the drive relays will receive simple current impulses of controlled length and of a wave form more suitable for good operation of the drive relays than are the current impulses from the triode tube plate circuits and also, the motor will then receive drive impulses of a wave form better suited for the operation thereof.

In carrying out this feature of the invention the plate circuits of the triode tubes are supplied with a direct current voltage of about 180 volts on which is superimposed an alternating current voltage of about 120 volts and at a frequency from 20 to 40 cycles per second. The direct current control or signal voltage is applied to the grids of the tubes. With the circuit properly adjusted for balance and with no control voltage both the control and drive relays are vibrated by short impulses and, the drive relays being vibrated in alternation, the pulses transmitted to the motor armature alternate in phase thereby failing to cause the motor to rotate but with sufficient vibration to reduce its inherent static friction. With a control voltage applied to the grids of the tubes so that one grid is made more negative with respect to the associated cathode then at a low control the tube having the negative grid potential becomes blocked and the relay at that side ceases to vibrate and therefore only one side of the circuit operates.

Instead of an external source of alternating current the relay vibrating frequency may be supplied by vacuum tubes. In accordance with this feature of the invention each side of the circuit employs as an oscillating element an unbalanced multivibrator the output impulses from each multivibrator operating a triode tube which functions to operate one of the drive relays. The multivibrators, with no control input, give output waves of about 40 cycles per second frequency and the impulses which reach the drive relays are too short to be effective to cause the relays to operate. When a control signal is applied to the multivibrators, the impulses to one associated drive relay are increased in length and the impulses applied to the other drive relay are decreased in length causing the relay on the strong side of the circuit to transmit driving impulses to the motor. The impulse length increases in proportion to the control voltage until the drive relay on the strong side of the circuit locks up and the motor then runs at full speed. Suitable coupling is provided between the two multivibrators to insure that they will operate at the same frequency when the control signal is weak or entirely absent.

One difficulty which has been found with the multivibrator circuit is that the relay on the weak side of the circuit might not stop vibrating unless a very careful adjustment of each multivibrator is made so that with no control voltage the relays will not operate from their back contacts otherwise the relay on the strong side when locked up could not apply full power to the motor and the

weak side relay would tend to vibrate and chop up the impulses. Also this condition causes some flashing of the relay contacts. When the multivibrators are so adjusted that this condition could not possibly happen the width of this part around zero control was made undesirably wide. To overcome this difficulty it is proposed as a further feature of the present invention to cross-connect the windings of the drive relays into the plate circuits of the control tubes so that the high resistance winding of one relay is connected in series with the low resistance winding of the other relay with the two windings of each relay connected in opposition so that when the control voltage goes in one direction and the pulsating current component of the plate circuit on the active side of the circuit causes the relay in the active side of the circuit to operate, the steady component of this current, (the pulsating component being by-passed by a condenser) biases the relay on the inactive side of the circuit to oppose the effect of any pulsating current which may be transmitted to the high resistance or control winding of the latter relay to thereby stop it from vibrating. This arrangement is also effective in a circuit in which the control relays are vibrated from an external source of alternating current.

For a clearer understanding of the invention reference may be had to the following detailed description when read in connection with the accompanying drawing, in which:

Fig. 1 shows a motor control circuit in accordance with the present invention in which both control and drive relays are employed and in which the alternating current excitation of the control relays is provided from an external source; and

Fig. 2 shows a modified form of a motor control circuit in which only drive relays are employed which are vibratable under the control of signal controlled multivibrator tubes.

The relays illustrated in the drawing are preferably of the reed armature mercury contact type disclosed in the application of E. T. Burton hereinbefore referred to. It is to be understood however that relays of other types could be used if such relays are sensitive and fast in operation and are capable of handling current of considerable wattage transmitted over their contacts. Each of these relays comprises an envelope of glass or other suitable material through the bottom of which an armature terminal is sealed and through the top of which two other terminals are sealed. Secured to the inner end of one of the upper terminals is a front contact of magnetic material and secured to the inner end of the other upper terminal is a back contact of non-magnetic material. Secured to the lower terminal by a reed is an armature of magnetic material which is normally biased against the back contact and is attractable towards the front contact. A pool of mercury is placed in the bottom of the envelope from which mercury is conducted by wick action to the upper contact portions. Surrounding the envelope are two coils or windings, one of which is of high resistance, for example, of 3300 ohms and the other of which is of lower resistance, for example, of 700 ohms.

Referring first to Fig. 1 which shows one embodiment of the invention, a direct current control signal is applied over terminals 3 and 4 to the control grids of the dual triode tube VT. The control signal applied between the terminals 3 and 4 may for example be derived from the output circuits of amplifier tubes which proceed the tube VT. The grids 5 and 6 of tube VT are also connected through equal grid leak resistors 7 and 8 to ground. The plate 9 of tube VT is connected in circuit through the high resistance winding H of control relay C_A, thence through the low resistance winding L of control relay C_B shunted by resistance 12 and condenser 24, through the secondary winding S_A of transformer T and through rheostat 18 to a source of plate potential connected to terminal 13, which source may, for example, be of 180 volts positive potential. Similarly, the plate 10 of tube VT is connected in a circuit through the high resistance winding H of control C_B, thence through the low resistance winding L of control relay C_A shunted by resistance 11 and condenser 25, through the secondary winding S_B of transformer T and through rheostat 18 to the source of plate potential connected to terminal 13. By the adjustment of the slider of rheostat 18 the inequalities in the two halves of the tube VT may be substantially compensated by the adjustment of the plate potential applied to the two plates. The cathodes 14 and 15 of tube VT are connected together and through condenser 16 to ground and through rheostat 19 to ground, the rheostat 19 serving to adjust the cathode to grid potentials. The filament 17 of the tube is heated by current conducted therethrough, through the winding of rheostat 19 and through the rheostat 20 from the terminals 1 and 2 of the 24-volt direct current source P. The filament current may be adjusted by the rheostat 20.

The motor M is of the shunt field type the field F of which is excited from the 24-volt power source P connected to terminals 1 and 2 and the armature circuit A of which is connected between the swing contacts or armatures of the drive relays D_A and D_B. The back contacts of relays D_A and D_B are connected to the terminal 1 of source P and the front contact of each of these relays is connected through an inductance coil L_1 and thence through the inductance coil L_3 shunted by resistance 21 to the other terminal 2 of the source P. The inductance coil L_3 and resistance 21 serve to protect the power source P from becoming short-circuited during the intervals of one or more milliseconds when the three transfer contacts of either drive relay will be interconnected. For contact protection a resistance R_1 connected in series with condenser C_1 is bridged between the swing and back contact of each drive relay, a resistance R_2 connected in series with condenser C_2 is bridged between the swing and front contact of each drive relay and inductance coils L_1 and L_2 connected in series with condenser C_3 are also bridged between the swing and front contacts of each relay. The contact protection is essentially the same as disclosed in the application of E. T. Burton, hereinbefore referred to.

For smoothing the operation of the motor M in response to power impulses transmitted through the armature circuit A under the control of relays D_A and D_B the inductance coil L_4 shunted by resistance 22 is connected in series with the armature circuit. The inductance of the coil L_4 is comparable in value to the inductance of the motor and stores energy during the applied power periods of the operation of the drive relays and returns it to the armature circuit during the periods when the relays do not apply power to the armature circuit.

The swing contacts of control relays C_A and C_B are both connected to terminal 2 of power source P. The front contact of relay C_A is connected to the H and L windings of drive relay D_A connected in parallel, and through the rheostat 23 to the terminal 1 of the source P and similarly the front contact of relay C_B is connected to the H and L windings of drive relay D_B connected in parallel, and through the rheostat 23 to the terminal 1 of source P whereby when relay C_A operates, it in turn causes the operation of relay D_A into its front contact closure position and when relay C_B operates it in turn causes the operation of relay D_B into its front contact closure position.

The primary windings of transformer T are connected in series and supplied with alternating current from the source AC which, for example, may be of 120 volts potential and 60 cycles per second frequency.

With no signal present and therefore no signal potential applied between terminals 3 and 4 and with the biases of tube VT adjusted so that both units of tube VT are substantially equally conductive, current will flow from the positive 180-volt source through rheostat 18, secondary winding S_A of transformer T, through the L winding of relay C_B in parallel with resistance 12, through the H winding of relay C_A and over the plate-cathode path through the upper unit of tube VT to ground through rheostat 19; and also through rheostat 18, through the secondary winding S_B of transformer T, through the L winding of relay C_A in parallel with the resistance 11, through the H winding of relay C_B and over the plate-cathode path through the lower unit of tube VT to ground through rheostat 19. The H and L windings of relays C_A and C_B are connected in opposition so that the direct biasing currents flowing through the two windings of each relay tend to oppose each other but, under the zero signal condition assumed, the current through the H winding being much greater than the current through the L winding of each relay, each of the relays will be so biased as to be operable during each positive half wave of the alternating current from the source AC applied through their H windings.

The alternating current from the source AC of 60 cycles is impressed through the windings P_A and S_A of transformer T through condenser 24, which is connected in shunt of the L winding of relay C_B and resistance 12, thence through the H winding of relay C_A, over the plate-cathode path through the upper unit of tube VT and through rheostat 19 to ground and is similarly impressed through the windings P_B and S_B of transformer T, through condenser 25, which is connected in shunt of the L winding of relay C_A and resistance 11, thence through the H winding relay C_B, over the plate-cathode path through the lower unit of tube VT and through rheostat 19 to ground.

Due to the poling of the secondary windings of transformer T the alternating current components of the currents flowing through the H windings of relays C_A and C_B will be 180 degrees apart in phase and consequently relays C_A and C_B in response to the superposed direct current biasing and the alternating current exciting currents will operate and release in alternation at the periodicity determined by the periodicity of the alternating current source AC.

Each time that relay C_A operates to its front contact closure position a circuit is established from terminal 1 of the power source P, over the upper portion of rheostat 23 through the wind-

tinued energization of drive relay D_A will be continuous.

It will be obvious that if the control signal had been applied in the opposite sense to the input terminals **3** and **4** then as the signal strength increased from zero the direct current component of the current applied through the lower unit of tube VT would have increased and the direct current component of the current applied through the upper unit of tube VT would have decreased resulting in the operation of relays C_A and C_B, and D_A and D_B in such a manner as to cause the motor to run in the reverse direction and at a speed commensurate with the magnitude of the input signal.

From the foregoing discussion of the circuit of Fig. 1 it is apparent that at zero signal input the control relays C_A and C_B operate alternately and in turn cause the alternate operation of the drive relays D_A and D_B so that the motor does not turn but merely vibrates to reduce its static friction. That as the signal increases from zero in either direction both control relays C_A and C_B operate and the unbalance between the length of the impulses transmitted to the motor by the operation of the drive relays D_A and D_B increases so that the motor will gradually pick up speed as the signal strength increases and turn in a direction dependent upon the polarity of the signal. That as the input signal further increases the control relay on the weak side of the circuit will cease operating and the entire control will then be exercised by the control relay on the strong side of the circuit. By this arrangement the range on either side of zero control is made much narrower and linearity of the entire range is improved. Furthermore the control of the motor is improved by the interpolation of the control relays C_A and C_B. If relays C_A and C_B were used to drive the motor directly the slow rate of change of the drive and control flux of the relays C_A and C_B near the point at which they lock up would contribute to the flashing of the contacts of such relays, especially as in this region the contact pressure is practically nil. The addition of the relays C_A and C_B helps to improve this condition since now the relays C_A and C_B are used as control rather than drive relays and supply square or nearly square waves to the drive relays D_A and D_B which gains something over the just operate flux even on the shortest impulse.

The stopping of one of the control relays and the corresponding drive relay when the value of the control signal is increased from the zero value materially increases the life of the relays since most of the time only two of the four relays will be functioning.

If an external source of alternating current for exciting the control windings of the relays is not available, the relays may be operated periodically by impulses of current supplied under the control of multivibrator tubes as has been disclosed in Fig. 2. For this purpose a pair of tubes interconnected to act as a pulse generator of a substantially square-topped wave, is used in each side of the circuit, the output of one pair of such tubes being applied to the input of one unit of a buffer tube, the plate circuit of which is connected through the H winding of one of the drive relays B_A and the output of the other pair of tubes being connected to the input of the other unit of the buffer tube, the plate circuit of which is connected through the H winding of the other drive relay D_B. Each multivibrator functions in the general manner described on page 294 of the

book by A. V. Eastman entitled "Fundamentals of Vacuum Tubes."

More specifically the multivator tube MV_A has its cathodes **26** and **27** connected together and to ground, has its control grid **28** connected through grid leak resistances **30** and **31** to ground and has its control grid **29** connected through grid leak resistance **32** to ground. The plate **33** of the upper unit of this tube is connected through the resistance **57**, of approximately 5100 ohms, and through the right portion of rheostat **36** to the positive terminal of plate battery B_1 and the plate **34** of the lower unit of this tube is connected through the left portion of rheostat **36** to the positive terminal of battery B_1 and thus upon the adjustment of the rheostat **36** unbalanced plate potentials are applied to the plates of this tube. For producing an oscillatory condition between the two units of this tube the plate **33** of the upper unit is connected through condenser **37** to the grid **29** of the lower unit and the plate **34** of the lower unit is connected through condenser **38** to the grid **28** of the upper unit. The condensers **37** and **38** are of equal capacitance, preferably .03 microfarad, and with resistance **31** substantially short-circuited over the control circuit connected between terminals **3** and **4**, the discharge paths for the condensers are equal or substantially so through the equal resistances **30** and **32**.

Similarly the cathodes **39** and **40** of tube MV_B are connected together and to ground, the grid **41** is connected through resistances **43** and **44** to ground and the grid **42** is connected through resistance **45** to ground. The plate **46** of the lower unit of the tube is connected through resistance **58** and through the right portion of rheostat **48** to the positive terminal of the plate battery B_1 and the plate **47** of the upper unit of the tube is connected through the left portion of rheostat **48** to the positive terminal of battery B_1 and thus upon the adjustment of the rheostat **48** unbalanced plate potentials are applied to the plates of the tube. For producing an oscillatory condition between the two units of the tube the plate **46** of the lower unit is connected through condenser **49** to the grid **42** of the upper unit and the plate **47** of the upper unit is connected through condenser **50** to the grid of the lower unit. The condensers **49** and **50** are of equal capacitance, preferably .03 microfarad, and with resistance **44** substantially short-circuited over the control circuit connected between terminals **3** and **4** the discharge paths for the condensers are equal or substantially so through the resistances **43** and **45**.

Since unequal plate potentials are applied to the plates **33** and **34** of tube MV_A the condensers **37** and **38** will receive unequal charges due to the firing of the units of the tube and the tube will therefore generate an unbalanced output wave. Similarly with unbalanced plate potentials applied to the plates **46** and **47** of tube MV_B the condensers **49** and **50** will receive unequal charges due to the firing of the units of the tube and the tube will therefore generate an unbalanced output wave. Since the two tubes are tied to the same plate battery, then with the proper adjustment of the rheostats **36** and **48**, the two tubes will generate output waves which will tie together at the same frequency when no control signal or a weak signal is applied between the input terminals **3** and **4** which are in turn connected respectively to the junction point between resistances **30** and **31** and the junction point between resistances **43** and **44**.

The plate **33** of the tube MV_A is connected through resistance 59, of approximately 150,000 ohms, to the grid 51 of the upper unit of the buffer tube BT and the plate 46 of the tube MV_B is similarly connected through resistance 60 to the grid 52 of the lower unit of tube BT. The resistances 59 and 60 serve to eliminate the effects of the output of the buffer tube BT upon the sensitivity of the multivibrator tube to control signals. The cathodes 53 and 54 of tube BT are both connected to the negative terminal of the plate battery B_2 and to the positive terminal of battery B_1. The filaments of all of the tubes may be heated in any well-known manner from a suitable source of current as, for example, from the 24-volt power source P. The plate 55 of the upper unit of tube BT is connected through the H winding of drive relay D_A, the L winding of drive relay D_B shunted by resistance 12 and condenser 68 and through the lower portion of the rheostat 65 to the positive terminal of battery B_2 and the plate 56 of the lower unit of tube BT is connected through the H winding of drive relay D_B, the L winding of drive relay D_A shunted by resistance 11 and condenser 67 and through the upper portion of rheostat 65 to the positive terminal of battery B_2. By the adjustment of the slider of rheostat 65 a balanced output from the two units of tube BT may be secured when there is no control signal applied between the terminals 3 and 4.

The high resistance winding H of drive relay D_A is shunted by a .02 microfarad condenser 61 connected in series with a 1000-ohm resistance 63 to eliminate the induced voltage when the tube BT cuts off the plate current in its upper unit and to make the relay operate into its front contact closure position on slightly shorter impulses than it would without the shunt by using the stored energy to continue to accelerate the relay armature. A similar shunt comprising the condenser 62 and resistance 64 is connected around the H winding of relay D_B. The low resistance winding L of the relays are connected in parallel with resistances 11 and 12 and condensers 67 and 68, respectively and are connected in opposition to the H windings of the corresponding relay. The armature circuit A and the motor M is connected to the armatures or swing contacts of the relays and the same contact, battery and motor protection is provided as is disclosed in Fig. 1 and discussed in connection therewith.

With no control signal present between the terminals 3 and 4 the multivibrator tubes MV_A and MV_B will generate output waves of the same periodicity, the output pulses of which will be tied together occurring either simultaneously or nearly so. Each impulse from the multivibrator tube MV_A is impressed upon the upper unit of buffer tube BT and in response thereto plate current flows from the positive terminal of the plate battery B_2 over the lower portion of rheostat 65, through the L winding of relay D_B in parallel with resistance 12 and condenser 68 through the H winding of relay D_A and over the plate-cathode path through the upper unit of tube BT to the negative terminal of battery B_2. Each impulse from the multivibrator MV_B is impressed upon the lower unit of tube BT and in response thereto plate current flows from the positive terminal of plate battery B_2, over the upper portion of rheostat 65, through the L winding of relay D_A in parallel with resistance 11, through the H winding of relay D_B, and over the plate-cathode path through the lower unit of tube BT to the negative terminal of battery B_2. With the H and L windings of each relay connected in opposition the current flowing through the H and L windings of each relay will set up opposing flows of flux and with the current impulses delivered by the tube BT under the control of the multivibrator tubes MV_A and MV_B short, neither relay will be sufficiently energized to cause its swing contact to move into its front contact closure position and consequently no circuit will be established from the source of power P through the armature circuit A of the motor M.

It will now be assumed that a negative signal voltage is applied to the input terminal 3 and a positive signal voltage of equal value is applied to the input terminal 4 as for example from the center tapped battery B_3 under control of the rheostat 66. As a result the multivibrator tube MV_A is caused to generate longer impulses. In response to the longer impulses generated by the tube MV_A, relay D_A now operates in response to each impulse but since the impulses generated by the tube MV_B have been shortened relay D_B does not operate. As a result of the operation of relay D_A while relay D_B remains unoperated, impulses of one polarity are transmitted from the source P through the armature circuit A and the motor M and the motor will attain a speed proportional to the length of the impulses delivered to the relay D_A and therefore proportional to the control signal voltage.

To insure that the short impulses delivered by the multivibrator tube MV_B will not cause relay D_B to vibrate its swing contact away from its back contact during each interval that relay D_A is operated to cause the transmission of a driving impulse of the motor, and thus cause the driving impulses to be chopped up, the operating current applied through the H winding of relay D_B in response to the impulses generated by the multivibrator tube MV_B, is opposed by the increasing direct current component of the current delivered through the L winding of relay D_B in response to the impulses generated by the multivibrator tube MV_A which is delivering operating impulses for causing the operation of relay D_A. The current flowing through the L winding of relay D_B under this condition so unbalances the current flowing through the H winding that the swing contact of relay D_B is held firmly in its back contact closure position.

As the signal voltage further increases the length of the impulses generated by the multivibrator tube MV_A increases and as a result the relay D_A will deliver impulses of increasing length to the motor M thereby causing the speed of the motor to increase until when the control voltage as applied to the grid 28 of multivibrator tube MV_A reaches a maximum negative magnitude the upper unit of tube MV_A ceases to fire and the multivibrator ceases to generate impulses. At this time the upper unit of buffer tube BT will conduct continuously thereby locking drive relay D_A in its front contact closure position to cause the motor M to run continuously at its full speed.

As the positive signal potential applied to the grid 41 of multivibrator tube MV_B increases, the lower unit of this tube will lock up in a conducting condition and the multivibrator will then cease to generate further impulses. This condition will be reached soon after the input signal increases to a low value from zero voltage.

If a negative signal voltage is applied to the input terminal 4 and a corresponding positive voltage is applied to the terminal 3, the impulses generated by the multivibrator tube MV_B will increase in length as the signal voltage increases and as a consequence the impulses transmitted to the drive relay D_B will increase in length and at the same time the drive relay D_A will be prevented from operating. Impulses will therefore be transmitted from the source P through the armature circuit of the motor M in such a direction as to cause the motor to run in the opposite direction and at a speed proportional to the voltage of the control signal. Relay D_A will be locked in the back contact closure position and multivibrator tube MV_A will be controlled to cease transmitting pulses as the signal increases from its zero value in the manner previously described in connection with the operation of tube MV_B and relay D_B and tube MV_B will reach a condition in which it ceases to generate impulses and relay D_B will lock in its front contact closure position to cause motor M to run at full speed when the signal voltage reaches its maximum value in the manner previously described in connection with the operation of tube MV_A and relay D_A.

The control of the drive relays by the multivibrators enables the relays to operate on substantially square-topped impulses thereby improving the motor operation without the use of additional control relays as was necessary in the circuit of Fig. 1. Since one of the drive relays is blocked against operation either through the cross-connections between the windings of the two relays or by the blocking of the multivibrator tube on the weak or positive signal voltage side of the input circuit, wear on the relays is reduced by half and steadier impulses are delivered to the motor. Also by blocking the multivibrator tube in the strong or negative voltage side of the input circuit at maximum signal voltage and the consequent locking of the drive relay on that side of the circuit the wear on the relays is further reduced. Both modifications of the circuit enable a much smoother operation of the motor adjacent to the zero control and improves linearity of control over a greater portion of the control range.

What is claimed is:

1. In a motor control circuit, two control tubes, a relay associated with each of said tubes each relay having a high resistance and a low resistance winding connected in opposition, an energizing circuit for each relay including the cathode-plate path of the associated tube, the high resistance winding of such relay and the low resistance winding of the other relay, means for transmitting impulses of current over said circuits, a source of power, a reversible motor, means controlled by said relays for applying power from said source to said motor, and an input circuit for selectively controlling said tubes to apply current to one of the other of said first circuits, whereby one of said tubes is effective to render the associated relay operable and is effective to energize the low resistance winding of the relay associated with the other tube to render the latter relay unresponsive.

2. In a motor control circuit, two control tubes, a relay associated with each of said tubes, each relay having a high resistance and a low resistance winding connected in opposition, an energizing circuit for each relay including the cathode-plate path of the associated tube, the high resistance winding of such relay and the low resistance winding of the other relay, means for transmitting impulses of current over said circuits, a source of power, a reversible motor, circuits controlled when either of said relays is operated and the other of said relays is unoperated for applying power from said source to said motor, and an input circuit for selectively controlling said tubes to apply current to one or the other of said first circuits whereby one of said tubes is effective to render the associated relay operable and is effective to energize the low resistance winding of the relay associated with the other tube to maintain said latter relay firmly in its back contact closure position.

3. In a motor control circuit, two control tubes, a relay associated with each of said tubes, each having a high resistance winding and a low resistance winding connected in opposition, an energizing circuit for each relay including the cathode-plate path of the associated tube, the high resistance winding of such relay and the low resistance winding of the other relay, means for applying direct and superimposed alternating currents to said circuits, a source of power, a reversible motor, means controlled by said relays for applying power from said source to said motor, and an input circuit for selectively controlling said tubes for varying the direct current applied through one or the other of said first circuits whereby the direct current component of the plate current of one of said tubes is effective to render the associated relay operable and is effective to energize the low resistance winding of the relay associated with the other tube to render the latter relay unresponsive.

4. In a motor control circuit, two control tubes, a relay associated with each of said tubes, each having a high resistance winding and a low resistance winding connected in opposition, an energizing circuit for each relay including the cathode-plate path of the associated tube, the high resistance winding of said relay and the low resistance winding of the other relay, means for applying direct and superimposed alternating currents to said circuits, a source of power, a reversible motor, circuits controllable when either of said relays is operated and the other of said relays is unoperated for applying power from said source to said motor, and an input circuit for selectively controlling said tubes for varying the direct current applied to one or the other of said first circuits whereby the direct current component of the plate current of one of said tubes is effective to render the associated relay operable and is effective to energize the low resistance winding of the relay associated with the other tube to maintain said latter relay firmly in its back contact closure position.

5. In a motor control circuit, two control tubes, a control relay associated with each of said tubes, an energizing circuit for each of said relays including the cathode-plate path of the associated tube, means for applying direct and superimposed alternating currents to said circuits, a motor drive relay operable under the control of each of said control relays respectively, a source of power, a reversible motor, circuits controllable when either of said drive relays is operated and the other of said drive relays is unoperated for applying power from said source to said motor, and an input circuit for selectively controlling said tubes for varying the direct current applied to one or the other of said control relay energizing circuits whereby the direct current component of the plate current of one of said tubes is effective to render the associated control relay

operable to in turn control the associated drive relay to cause said motor to operate at a speed determined by the control exercised over said input circuit.

6. In a motor control circuit, two control tubes, a control relay associated with each of said tubes each having a high resistance winding and a low resistance winding connected in opposition, an energizing circuit for each relay including the cathode-plate path of the associated tube, the high resistance winding of such relay and the low resistance winding of the other relay, means for applying direct and superimposed alternating currents to said circuits, a motor drive relay operable under the control of each of said control relays respectively, a source of power, a reversible motor, circuits controlled when either of said drive relays is operated and the other of said drive relays is unoperated for applying power from said source to said motor, and an input circuit for selectively controlling said tubes for varying the direct current applied to one or the other of said control relay energizing circuits whereby the direct current component of the plate current of one of said tubes is effective to render the associated control relay operable and is effective to energize the low resistance winding of the control relay associated with the other tube to maintain said latter relay firmly in its back contact closure position to in turn control the associated drive relay to cause said motor to operate at a speed determined by the control exercised over said input circuit.

7. In a motor control circuit, two control relays, a vacuum tube multivibrator associated with each of said relays, input circuits connected to the inputs of said multivibrators, means for applying a control signal to one or the other of said input circuits whereby the associated multivibrator is controlled to deliver impulses to the associated relay of a length proportional to the magnitude of the signal, a source of power, a reversible motor and circuits controllable by said relays for applying impulses of power from said source to said motor whereby said motor is operated at a speed proportional to the magnitude of the signal and in a direction determined by the manner of application of the signal.

8. In a motor control circuit, two control relays, a vacuum tube multivibrator associated with each of said relays, input circuits connected to the inputs of said multivibrators, means for applying a control signal to either one of said input circuits and a signal of opposite polarity and of the same magnitude to the other of said input circuits whereby one of said multivibrators is controlled to deliver impulses to the associated relay of a length proportional to the magnitude of the signal and whereby the other of said multivibrators is controlled to deliver impulses to the associated relay which decrease in length as the magnitude of the signal increases, a source of power, a reversible motor, and circuits controlled by said relays for applying impulses of power from said source to said motor whereby said motor is operated at a speed proportional to the magnitude of the signal and in a direction determined by the direction of application of the signal.

9. In a motor control circuit, two control tubes, a control relay associated with each of said tubes, an energizing circuit for each of said relays including the cathode-plate path of the associated tube and a source of direct current, a vacuum tube multivibrator associated with the input circuit of each of said tubes, input circuits connected to the inputs of said multivibrators, means for applying a control signal to one or the other of said input circuits whereby the associated multivibrator controls the associated tube to deliver impulses to the associated relay of a length proportional to the magnitude of the signal, a source of power, a reversible motor and circuits controllable by said relays for applying impulses of power from said source to said motor, whereby said motor is operated at a speed proportional to the magnitude of the signal and in a direction determined by the manner of application of the signal.

10. In a motor control circuit, two control tubes, a control relay associated with each of said tubes, an energizing circuit for each of said relays including the cathode-plate path of the associated tube and a source of direct current, a vacuum tube multivibrator associated with the input circuit of each of said tubes, input circuits connected to the inputs of said multivibrators, means for applying a control signal to either one of said input circuits and a signal of opposite polarity and of the same magnitude to the other of said input circuits whereby one of said multivibrators controls the associated tube to deliver impulses to the associated relay which increase in length as the magnitude of the signal increases and whereby the other of said multivibrators controls the tube associated therewith to deliver impulses to the associated relay which decrease in length as the magnitude of the signal increases, a source of power, a reversible motor, and circuits controllable by said relays for applying impulses of power from said source to said motor whereby said motor is operated at a speed proportional to the magnitude of the signal and in a direction determined by the direction of application of the signal.

11. In a motor control circuit, two control tubes, a control relay associated with each of said tubes, an energizing circuit for each of said relays including the cathode-plate path of the associated tube and a source of direct current, a vacuum tube multivibrator associated with the input circuit of each of said tubes, means for unbalancing said multivibrators whereby they normally cause the associated tubes to deliver impulses to said relays of insufficient length to cause their operation, input circuits connected to the inputs of said multivibrators, means for applying a control signal to one or the other of said input circuits whereby the associated multivibrator controls the associated control tube to deliver impulses of sufficient length to operate the relay associated therewith for impulse intervals proportional to the magnitude of the signal, a source of power, a reversible motor and circuits controllable when either of said relays is operated and the other of said relays in unoperated for applying impulses of power from said source to said motor whereby said motor is operated at a speed proportional to the magnitude of the signal.

12. In a motor control circuit, two control tubes, a control relay associated with each of said tubes, an energizing circuit for each of said relays including the cathode-plate path of the associated tube and a source of direct current, a vacuum tube multivibrator associated with the input circuit of each of said tubes, means for unbalancing said multivibrators whereby they nor-

mally cause the associated tubes to deliver impulses to said relays of insufficient length to cause their operation, input circuits connected to the inputs of said multivibrators, means for applying a control signal to either one of said input circuits and a signal of opposite polarity and of the same magnitude to the other of said input circuits whereby one of said multivibrators controls the associated tube to deliver impulses to the associated relay which increase in length as the magnitude of the signal increases and of sufficient length to operate said relay for intervals proportional to the magnitude of the signal and whereby the other of said multivibrators controls the tube associated therewith to deliver impulses to the associated relay which decrease in length as the magnitude of the signal increases, a source of power, a reversible motor, and circuits controllable by said relays for applying impulses of power from said source to said motor whereby said motor is operated at a speed proportional to the magnitude of the signal and in a direction determined by the direction of application of the signal.

13. In a motor control circuit, two control relays, a vacuum tube multivibrator associated with each of said relays, means for unbalancing said multivibrators whereby they normally cause the delivery of impulses to said relays of insufficient length to cause their operation, input circuits connected to the inputs of said multivibrators, means for applying a control signal to either one of said input circuits and a signal of opposite polarity and of the same magnitude to the other of said input circuits whereby one of said multivibrators is controlled to deliver impulses to the associated relay of a length proportional to the magnitude of the signal and whereby the other multivibrator is controlled to deliver impulses to the associated relay which decrease in length as the magnitude of the input signal increases from zero over the lower portion of its range and is controlled to cease delivering impulses to the associated relay as the input signal further increases, a source of power, a reversible motor, and circuits controllable by said relays for applying impulses of power from said source to said motor whereby said motor is operated at a speed proportional to the magnitude of the signal and in a direction determined by the direction of application of the signal.

14. In a motor control circuit, two control relays, a vacuum tube multivibrator associated with each of said relays, means for unbalancing said multivibrators whereby they normally cause the delivery of impulses to said relays of insufficient length to cause their operation, input circuits connected to the inputs of said multivibrators, means for applying a control signal to either one of said input circuits and a signal of opposite polarity and of the same magnitude to the other of said input circuits whereby one of said multivibrators is controlled to deliver impulses to the associated relay of a length proportional to the magnitude of the signal and whereby the other multivibrator is controlled to deliver impulses to the associated relay which decrease in length as the magnitude of the signal increases, said first multivibrator locking up to cause the transmission of a continuous impulse to the associated relay when said signal approaches its maximum magnitude, a source of power, a reversible motor, and circuits controllable by said relays for applying impulses of power from said source to said motor whereby said motor is operated at a sleeve proportional to the magnitude of the signal and in a direction determined by the direction of application of the signal.

15. In a motor control circuit, two control relays, each having a high resistance and a low resistance winding connected in opposition, an energizing circuit for each relay including a source of current, a high resistance winding of such relay and a low resistance winding of the other relay, a vacuum tube multivibrator associated with each of said circuits, a source of power, a reversible motor, circuits controllable when either of said relays is operated and the other of said relays is unoperated for applying power from said source to said motor, input circuits connected to the inputs of said multivibrators, and means for applying a control signal to either one of said input circuits and a signal of opposite polarity and of the same magnitude to the other of said input circuits whereby one of said multivibrators is controlled to deliver impulses to the energizing circuit of the associated relay which increase in length as the magnitude of the signal increases and whereby the other of said multivibrators is controlled to deliver impulses to the energizing circuit of the associated relays which decrease in length as the magnitude of the signal increases and whereby the impulses delivered through the opposing windings of the relay on the weak side of the circuit are effective to maintain said latter relay firmly in its back contact closure position.

16. In a motor control circuit, two control tubes, a control relay associated with each of said tubes, each having a high and a low resistance winding connected in opposition, an energizing circuit for each relay including the cathode-plate path of the associated tube, the high resistance winding of such relay and the low resistance winding of the other relay, a vacuum tube multivibrator associated with the input circuit of each of said tubes, means for unbalancing said multivibrators whereby they normally cause the associated tubes to deliver impulses to said relays of insufficient length to cause their operation, a source of power, a reversible motor, circuits controllable when either of said relays is operated and the other of said relays is unoperated for applying power from said source to said motor, input circuits connected to the inputs of said multivibrators, and means for applying a control signal to either one of said input circuits and a signal of opposite polarity and of the same magnitude to the other of said input circuits whereby one of said multivibrators controls the associated tube to deliver impulses to the energizing circuit of the associated relay which increase in length as the magnitude of the signal increases, whereby the other of said multivibrators controls the associated tube to deliver impulses to the energizing circuit of the associated relay which decrease in length as the magnitude of the signal increases and whereby the impulses delivered through the opposing windings of the relay on the weak side of the circuit are effective to maintain said latter relay firmly in its back contact closure position.

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The following references are of record in the file of this patent:

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Number	Name	Date
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