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CONTROL SYSTEM

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Fig. 1.

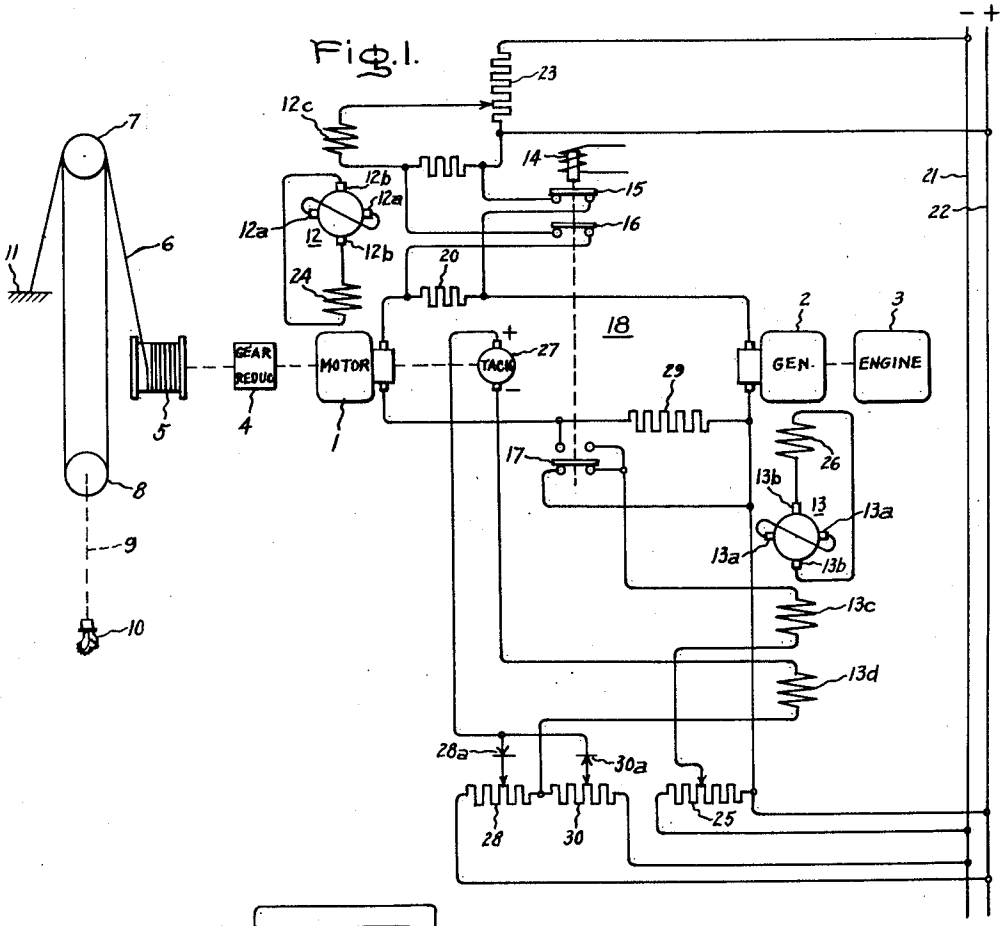
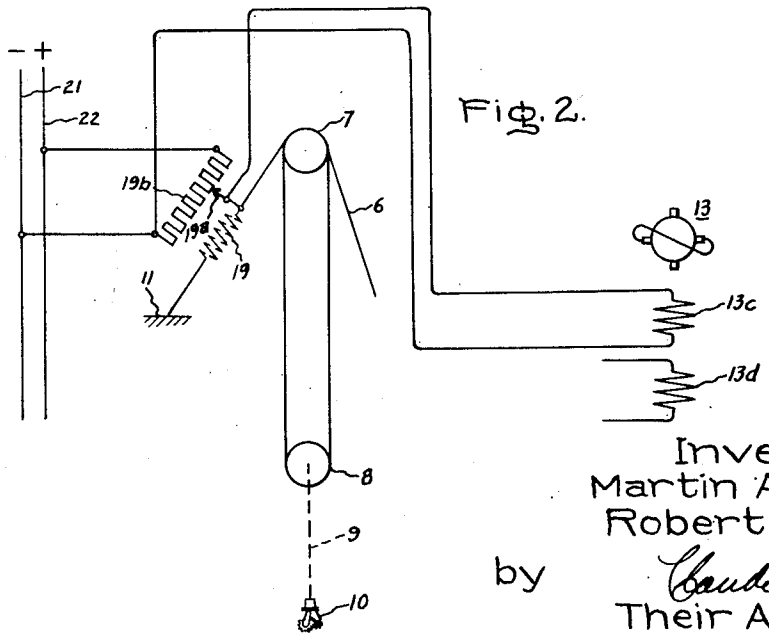


Fig. 2.



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CONTROL SYSTEM

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11 Claims. (Cl. 318—154)

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This invention relates to control systems, and more particularly to systems for controlling the operation of electric motors and it has for an object the provision of a safe, reliable and improved control system of this character.

More particularly, the invention relates to electric motor control systems for oil well drilling rigs and the like in which the motor is used to supply power to hoist the drill stem out of the drill hole. It is an object of the invention to reduce to a minimum the time required for such a hoisting operation. In this type of drive, the load is subject to great variation. At the time the hoisting operation starts with the entire drill stem or pipe in the hole, the full weight of the drill stem must be raised. At the end of the hoisting operation, the load approaches zero. The drill bit, which is attached to the bottom of the long drill pipe, has to be changed periodically—in some cases, every few hours, and it is necessary to withdraw the entire length of drill pipe each time it is necessary to change the drill bit. The drill pipe is withdrawn from the hole by raising it a short distance and removing a section of it, usually 90 feet in length, from the top of the drill pipe. This operation is repeated and sections are removed from the top until the drill pipe is completely out of the hole. Since some wells are drilled to great depths, some as much as 20,000 feet, it is very important that the hoisting cycle be held to the minimum possible time.

Another problem connected with the drilling of oil wells and other wells where rotary drilling rigs are used is the holding of proper pressure on the drill bit during the actual drilling operation and it is another object of our invention to provide means for holding this pressure constant. When drilling a deep well, it is necessary to support at least part of the weight of the drill stem in order to reduce the pressure on the drill bit. If the entire weight of the drill stem is allowed to rest on the drill bit, the rate of progress of the hole may be so great that the drilling chips are not removed from the hole, or it may result in the hole being drilled crooked, or it might even result in the crushing of the drill bit in the case of a very long and heavy length of drill pipe.

Another object of our invention is to limit the speed of travel of the drill stem and its attached drill bit to a safe value in both the hoisting direction and when drilling.

In carrying out our invention in one form, we provide a direct current motor electrically coupled to a direct current generator which is driven by

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a suitable prime mover. The motor is connected to the drill pipe hoisting mechanism through a gear speed reducer. The motor acts as a motor in the hoisting direction and as both a drag generator and motor in the lowering or drilling direction. The excitation of both generator and motor is variable and under the control of cross armature reaction excited dynamo-electric machines.

For a better and more complete understanding of our invention, reference should be had to the following description and to the accompanying drawing, Fig. 1 of which is a simple diagrammatical illustration of one embodiment of our invention, while Fig. 2 illustrates a modification thereof.

Referring to Fig. 1 of the drawing, a direct current electric motor 1 is shown connected to a direct current electric generator 2. The generator 2 is driven by a suitable prime mover 3, such as a diesel or steam engine. The motor 1 is connected through speed reducing gears 4 to hoist drum 5. On drum 5 is wound a cable 6 which passes around multi-groove sheaves 7 and 8 and raises and lowers a drill stem 9 and a drill bit 10 attached to the bottom thereof, as cable 6 is wound or unwound from drum 5. One end of cable 6 is anchored at a suitable point 11.

The excitation voltages of motor 1 and generator 2 are controlled by special cross armature reaction excited dynamoelectric machines or amplidynes 12 and 13. These dynamoelectric machines differ from a conventinal direct current machine in that they have a pair of auxiliary brushes 12*a* and 13*a* arranged on an axis that is normally displaced substantially 90 electrical degrees from the axis of the main load brushes 12*b* and 13*b*. These auxiliary brushes 12*a* and 13*a* are substantially short-circuited by an external conductor. Control field windings 12*c* and 13*c* and 13*d* are arranged on the axis of the main load brushes and provide a relatively small number of ampere turns. However, the relatively small voltage induced in the armature between the auxiliary brushes by means of the control flux produced by these control fields produces a very large current in the short-circuit and this short circuit current gives rise to a very large cross armature flux in line with the short-circuited brushes and, therefore, across, or at an angle, to the ordinary load current, armature reaction which is normally substantially in line with the main load brushes 12*b* and 13*b*. It is this cross armature reaction flux which provides the main operating flux or excitation for dynamo-

electric machines 12 and 13. By reason of the low inductance and low resistance of the circuit including the auxiliary brushes, a very small change in the control flux will produce a very large and very rapid change in the voltage between the main brushes 12b and 13b.

In order to operate the drilling apparatus in the hoist direction, solenoid 14 is de-energized to close switches 15 and 16 and move switch 17 to the lower position as shown in Fig. 1 on the accompanying drawing. Closing switches 15 and 16 causes a control or signal voltage to be supplied by resistor 20 to the energizing circuit of control field 12c of machine 12. The signal voltage is the voltage drop across resistor 20 caused by the current circulating in the series loop circuit 18 which is shown on the accompanying drawings connecting the armatures of motor 1 and generator 2.

Control field winding 12c is energized by being connected across a constant potential source of direct current from lines 21 and 22 through a manually variable resistor 23. The control or signal voltage from resistor 20 is connected in series with control field winding 12c across this source of electrical energy. The polarity of the supply and reference voltage derived from the constant potential source, and the polarity of the signal voltage from resistor 20 are additive so that an increase in the signal voltage causes an increased current to flow in control field winding 12c.

A small increase in the current in winding 12c causes a very large increase in the voltage between main brushes 12b on machine 12 with a resultant large increase in current in excitation field coil 24 of the main hoist motor 1. The result is that the excitation of motor 1 increases proportionally as the armature current in series loop 18 between motor 1 and generator 2 increases. In a like manner, the excitation of motor 1 decreases proportionally as the armature current in the loop decreases.

By controlling the excitation of motor 1 in this manner during the hoisting operation, motor 1 is made to deliver approximately a constant horsepower output. When the load is heavy, the motor runs slowly, but as soon as the load becomes lighter, the speed of the motor increases and the motor continues to deliver its maximum horsepower. In this way, the accelerating time and hoisting time are reduced to a minimum.

When switch 17 is in its lower position, as illustrated on the accompanying drawing, excitation field winding 13c of cross armature reaction excited dynamoelectric machine 13 is supplied with current from constant potential lines 21 and 22 through a manually variable resistor 25. This resistor is set to provide the desired excitation for machine 13 in conformance with the capacity of the apparatus and is normally left unchanged during the hoisting operation. Machine 13 supplies excitation voltage for field coil 26 of main generator 2.

The excitation of generator 2 remains constant during the hoisting operation unless the speed of motor 1 exceeds a predetermined maximum. A tachometer generator 27 which is directly connected to the shaft of motor 1, supplies a voltage which is proportional to the speed of motor 1. When motor 1 is operating in the hoisting direction, the signal voltage generated by tachometer 27 is compared with a reference voltage of like polarity derived from constant potential buses 21 and 22 through a manually variable resistor 28. However, a rectifier 28a, which may be of the selenium type, in this circuit permits the flow of current in one direction only, this being when the voltage generated by tachometer 27 exceeds the reference voltage. When the latter is the greater, no current flows in either direction through winding 13d which is also in this circuit. If the voltage generated by tachometer 27 during the hoisting cycle exceeds a predetermined reference value, resulting from the manual adjustment of resistor 28, current flows through control field winding 13d to counteract the effect of field 13c on the output of cross armature reaction excited dynamoelectric machine 13. Field 13d is connected with opposite magnetic polarity to field 13c; thus, when current flows through field winding 13d it counteracts the magnetic effect of field 13c and the voltage across main brushes 13b of machine 13 is reduced. This, in turn, reduces the excitation current flowing through field 26 of generator 2, thus reducing the current flowing in the series loop between motor 1 and generator 2. This reduces the torque exerted by motor 1 and its speed is reduced to a safe value.

To operate the apparatus to control the weight on the drill bit during the drilling operation, solenoid 14 is energized to open switches 15 and 16 and raise switch 17 to the upper position. This causes motor 1 to act primarily as a drag generator while generator 2 acts as a motor and engine 3 as a power absorption device. It is assumed for purposes of this description that engine 3 can absorb the amount of power which is returned to it, either to make up its own losses or to be passed on to another load (not shown) being supplied by the engine. In a case where the engine cannot absorb sufficient power for any reason, a power dissipating resistor may be inserted in series loop circuit 18 between motor 1 and generator 2 to absorb excess power.

In order to maintain a constant predetermined pressure on drill bit 10, machine 1 is made to exert a constant torque on gear speed reducer 4 and drum 5, thus providing a constant tension on rope 6 and through it a predetermined constant tension on drill stem 9. The tension on drill stem 9 is the difference between the total weight of drill stem 9 and the drilling pressure that it is desired to maintain on drill bit 10. Therefore, if the friction of the speed reducing gears and the rope and pulley system is ignored the desired drilling pressure may be maintained on drill bit 10 by causing machine 1 to exert a constant torque on its output shaft. Constant torque is achieved on motor 1 by providing it with constant excitation and then holding its armature current constant regardless of changes in speed or direction of rotation of motor 1.

To maintain the armature current in the series loop circuit between dynamo 1 and dynamo 2 at a constant value, a signal or control voltage is derived from a resistor 29. This voltage, which is proportional to the current flowing in series loop 18, is compared with a predetermined reference voltage derived from constant potential lines 21 and 22 through manually variable resistor 25. The polarities of the two voltages are additive so that an increase in the voltage drop across resistor 29 causes an increase in the current flowing in control field winding 13c of machine 13. This increase in excitation is greatly amplified by machine 13 and the resultant amplified signal voltage is transmitted to main field winding 26 of generator 2. The increase in excitation of dynamo 2, which is operating now as a motor,

causes the current in the armature series loop between machine 1 and machine 2 to decrease until the voltage drop across resistor 29 is reduced to the desired value, returning the control and excitation circuits of machine 13 and dynamo 2 to a balanced condition. For a decrease in the current flowing in the series loop circuit between dynamo 1 and dynamo 2, the apparatus functions in the opposite manner to increase the series loop current and return it to the predetermined value.

Another method of maintaining the current in the series loop 18 at a value which will maintain the desired drilling pressure on drill bit 10 is by the use of a strain gage in the dead side of rope 6, as illustrated in Fig. 2 on the accompanying drawing. It will be understood that this eliminates the effect of the friction in gear speed reducer 4 and most of the friction in the drum and in the remainder of the rope and pulley system and provides a signal producing arrangement which is more nearly directly responsive to the tension on drill stem 9. In some cases the effect of the friction of these components of the system may be sufficient to have a detrimental effect on the operation of a system such as that shown in Fig. 1 of the drawing in which a control signal is derived from the current in the series loop. The strain gage is composed of a spring 19, pointer 19*a*, and resistor 19*b* which is connected across constant potential lines 21 and 22. In this modification, if the tension on rope 6, which is very nearly proportional to the tension on drill stem 9 and roughly proportional to the current in loop 18, increases, spring 19 is lengthened. This moves pointer 19*a* on resistor 19*b* toward connection 21 and increases the voltage drop across the section of resistor 19*b*, which has control field 13*c* of amplidyne 13 connected across it. The resulting increase in voltage supplied to field 13*c* causes a reduction in the current in series loop 18 in the same manner as described in the preceding paragraph. For a decrease in the length of spring 19, the apparatus functions in the opposite manner to increase the current in series loop 18. Thus, the current in series loop 18 is held at a value which maintains the strain gage 19 stationary and the tension on drill pipe 9 is maintained at the predetermined value. It will be understood that the loop current in this modification is not constant as in the previous circuit but varies somewhat to compensate for the friction of the speed reducing gear and the cable and pulley system, the amount of current variation depending upon the amount of friction present in these elements. It will be further understood that our invention is not limited to the strain gage arrangement in the dead side of cable 6 as illustrated in Fig. 2, and that other means for deriving a control signal responsive to the tension on drill stem 9 for controlling the current in series loop 18 may be utilized instead. For example, a strain gage or other suitable means may be used to provide an indication of the stress in the cable or other member (not shown) which supports sheave 7, or in one leg or some other portion of the tower (also not shown) from which sheave 7 is suspended, such signals being responsive to the tension in drill stem 9.

During the drilling operation, the excitation of machine 1 is maintained at a constant value. This is performed by cross armature reaction excited dynamoelectric machine 12. Excitation field winding 12*c* provides a constant excitation for machine 12 and the latter in turn, supplies a constant voltage for the excitation of machine 1 through its field winding 24. Winding 12*c* is supplied a constant voltage derived from constant potential lines 21 and 22 through manually variable resistor 23.

By maintaining constant excitation and an approximately constant armature current in machine 1, it is made to exert a constant tension on the drill pipe through the supporting apparatus, operating either as a drag generator or as a motor, in accordance with the needs of the system. Machine 1 thus supports a predetermined proportion of the weight of the drill pipe regardless of the speed with which the bit progresses downward. This tension is maintained, even when the drill bit is stationary.

It is necessary to protect motor 1 against overspeeding during the drilling operation, as well as during the hoisting operation, because of the possibility of the drill bit striking a soft place in the earth and starting to go downward very rapidly. This is accomplished by comparing a signal voltage taken from tachometer 27 with a predetermined voltage derived from constant potential lines 21 and 22 through a manually variable resistor 30 and a rectifier 30*a*. During the time the drill pipe is moving downward the signal voltage from tachometer 27 is of opposite polarity to that indicated in Fig. 1. However, the relative polarity with respect to the constant potential lines across which resistor 30 is connected remains the same. When the signal voltage from tachometer 27 increases beyond the value of the reference voltage, derived from resistor 30, current flows in field winding 13*d* in the direction which causes a decrease in the output voltage of machine 13. This decrease in the output voltage of machine 13 decreases the excitation of generator 2 if the speed of motor 1 becomes too great. This, in turn, increases the current circulating in series loop 18 between motor 1 and generator 2 above the value which is maintained during normal drilling operation. The increase in current in the series loop increases the torque output of machine 1 and causes it to exert more upward force on the drill pipe 9, thus reducing the rate of the downward progress of drill pipe 9 to a safe value.

With reference to resistors 20 and 29 in series loop circuit 18 from which signal voltages are derived respectively for machines 1 and 2 it will be understood that the signal voltages are proportional since current of equal value flows through both. A single resistor may be substituted for resistors 20 and 29 provided the elements of the control and excitation circuits are properly selected. Separate resistors are shown for purposes of clarity in explaining the invention but in practice a single resistor is usually used.

While machines 1 and 2 are referred to herein as dynamos in some instances, it is not to be understood from this that these machines operate only as generators. As is explained hereinbefore, each of these machines operates both as a generator and a motor during a complete cycle of operation of the control system. Machines 1 and 2 are referred to as dynamos in order to distinguish them readily from dynamoelectric machines 12 and 13. Machines 1 and 2 would be described more accurately perhaps by the apellation dynamoelectric machines and they would have been so designated except for the possibility of confusion with machines 12 and 13.

While we have illustrated and described one

embodiment of our invention together with one modification, many additional modifications will occur to those skilled in the art and, therefore, it should be understood that we intend to cover, by the appended claims, all such modifications as fall within the true spirit and scope of this invention.

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

1. A control system for rotary oil well drilling rigs and the like comprising in combination, an adjustable voltage direct current electric dynamo having a prime mover and power absorption device coupled thereto, a second reversible direct current electric dynamo having coupled thereto a mechanism to be driven and controlled, said mechanism having a controllable condition, the two said dynamos having their armatures connected in a series loop circuit, strain gage means for deriving a control voltage responsive to said controllable condition, means for selectively maintaining a constant torque on the output shaft of said second reversible dynamo regardless of the rotation of said second dynamo whereby said controllable condition is maintained at an approximately constant predetermined value, said last-named means comprising means for maintaining the field current of said second dynamo at a constant value and simultaneously maintaining the current in said series loop circuit at an approximately constant predetermined value and including a cross armature reaction excited dynamoelectric machine having a control field winding connected to be excited responsively to said control voltage, means for deriving a second control voltage proportional to the speed of said second dynamo and means for limiting the speed of said second dynamo comprising an additional field winding on said dynamoelectric machine connected to be excited responsively to said second control voltage.

2. A control system for rotary oil well drilling rigs and the like comprising in combination, an adjustable voltage direct current electric dynamo having a prime mover coupled thereto, a second reversible direct current electric dynamo coupled to a mechanism to be driven and controlled, the armatures of the two said dynamos being connected in a series loop circuit, a resistor in said loop circuit from which a control voltage proportional to the current flowing in said loop circuit is obtained by utilizing the voltage drop across said resistor, means providing an adjustable reference voltage comprising a constant voltage source and a manually variable resistor, connected thereto, means for maintaining a constant horsepower output from said second dynamo, said means comprising a cross armature reaction excited dynamoelectric machine connected to be excited by a voltage equal to the sum of said reference voltage and said control voltage, means for deriving a second control voltage proportional to the speed of said second dynamo, and means for limiting the speed of said second dynamo to a predetermined value comprising a second dynamoelectric machine connected to excite the first said dynamo, the said second dynamoelectric machine being connected to be excited by a voltage equal to the difference of said second control voltage and said reference voltage whenever said second control voltage exceeds said reference voltage.

3. A control system comprising a first adjustable voltage electric dynamo, a second adjustable voltage electric dynamo connected to a mechanism to be driven and controlled and having its armature connected in a series loop circuit with the armature of said first dynamo, means for deriving a control voltage responsive to the current flowing in said loop circuit, selective means responsive to said control voltage for controlling the excitation of said second dynamo to operate it as a motor and maintain a substantially constant horsepower output, means for deriving a second control voltage responsive to a controllable condition of said mechanism, and selective means responsive to said second control voltage for controlling the excitation of said first dynamo to maintain said condition at a predetermined value.

4. A control system comprising a first adjustable voltage electric dynamo, a second adjustable voltage electric dynamo connected to a mechanism to be driven and controlled and having its armature connected in a series loop circuit with the armature of said first dynamo, said mechanism having a controllable condition, means including a resistor connected in said series circuit loop for deriving a control voltage proportional to the current flowing in said loop circuit, a source of reference voltage, selective means responsive to the sum of said control voltage and said reference voltage for controlling the excitation of said second dynamo to operate it as a motor and provide a substantially constant horsepower output for the operation of said mechanism over a considerable range of speeds, means for deriving a second control voltage proportional to the current flowing in said loop circuit, a second source of reference voltage, and selective means responsive to the sum of said second control voltage and said second reference voltage for controlling the excitation of said first dynamo to maintain said condition at a predetermined value.

5. A control system comprising a first adjustable voltage electric dynamo, a second adjustable voltage electric dynamo connected to a hoist mechanism to be driven and controlled and having its armature connected in a series loop circuit with the armature of said first dynamo, means for deriving a control voltage responsive to the current flowing in said loop circuit, selective means responsive to said control voltage for controlling the excitation of said second dynamo to operate it as a motor to raise the hoist and provide a substantially constant horsepower output to said hoist mechanism regardless of hoisting speed, strain gage means for deriving a second control voltage responsive to the tension on the hoisting cable of said hoisting mechanism, and selective means responsive to said second control voltage for controlling the excitation of said first dynamo to maintain said tension at a predetermined value regardless of the speed of said hoisting mechanism.

6. A control system comprising a first adjustable voltage electric dynamo adaptable for operation primarily as a motor, a second electric dynamo adaptable for operation primarily as a drag generator connected to a lowering mechanism and having its armature connected in a series loop circuit with the armature of said first dynamo, said mechanism being provided with a load supporting cable, means for deriving a control voltage responsive to the tension in said cable, and means responsive to said control voltage for controlling the excitation of said first

dynamo to maintain said tension at a selected value.

7. A first adjustable voltage electric dynamo adaptable for operation primarily as a motor, a power absorption device associated with said first dynamo, a second adjustable electric dynamo adaptable for operation primarily as a generator connected to a lowering mechanism and having its armature connected in a series loop circuit with the armature of said first dynamo, said lowering mechanism including a load supporting cable, strain gage means for deriving a control voltage responsive to the tension in said cable, means responsive to said control voltage for varying the excitation of said first dynamo to maintain said tension at a selected value, means for deriving an additional control voltage responsive to the speed of said second dynamo, and means responsive to said additional control voltage for varying the excitation of said first dynamo to limit the downward speed of said lowering mechanism.

8. A control system comprising a first adjustable voltage electric dynamo, a second electric dynamo connected to a hoisting and lowering mechanism and having its armature connected in a series loop circuit with the armature of said first dynamo, said hoist mechanism including a cable for raising and lowering a load, means for deriving a control voltage responsive to the tension in said cable, said means comprising a resistor in said series loop circuit, and means responsive to said control voltage for controlling the excitation of said first dynamo to maintain said tension at a selected value during lowering regardless of the speed of said hoist, and means for limiting the speed of said second dynamo comprising means for deriving an additional signal voltage responsive to the speed of said second dynamo and means responsive to said additional control voltage for affecting the excitation of said first dynamo.

9. A control system for rotary drilling rigs and the like comprising in combination, a first adjustable voltage direct current electric dynamo having a prime mover and power absorption device coupled thereto, a second reversible direct current electric dynamo having coupled thereto a mechanism to be driven and controlled, said mechanism having a controllable condition, said two dynamos having their armatures connected in a series loop circuit, a resistor connected in said loop circuit for deriving a control voltage proportional to the current flowing in said loop circuit, a reference voltage derived from a constant voltage source, means for selectively securing an approximately constant horsepower output from said second dynamo, said means comprising an amplidyne exciter connected to be excited by a voltage equal to the sum of said reference voltage and said control voltage, means for deriving a second control voltage responsive to the controllable condition of said mechanism, and selective means for regulating said system to maintain said controllable condition at a predetermined value, said means comprising means for maintaining the field current of said second dynamo approximately constant and amplidyne exciter means for said first dynamo responsive to said second control voltage.

10. A control system for rotary oil well drilling rigs and the like comprising in combination, an adjustable voltage direct current electric dynamo having a prime mover and power absorption device coupled thereto, a second reversible direct current electric dynamo to which is coupled a mechanism which is to be driven and controlled, the two said dynamos having their armatures connected in a series loop circuit, a first resistor in said loop circuit from which a first control voltage proportional to the current flowing in said loop circuit is obtained by utilizing the voltage drop across said resistor, a first reference voltage derived from a constant voltage source through a first variable resistor, means for selectively maintaining a constant torque on the output shaft of said second reversible dynamo regardless of the rotation of said second dynamo comprising means for maintaining the field current of said second dynamo constant and means for maintaining the current in said series loop circuit constant, said last-named means comprising a cross armature reaction excited dynamoelectric machine having a control field winding connected to be excited by a voltage equal to the sum of said first reference voltage and said first control voltage, a second resistor in said loop circuit from which a second control voltage proportional to the current flowing in said loop circuit is obtained, a second reference voltage derived from said constant voltage source through a second variable resistor, means for selectively securing a constant horsepower output from said second dynamo comprising a second cross-armature reaction excited dynamoelectric machine connected to be excited by a voltage equal to the sum of said second reference voltage and said second control voltage, means for deriving a third control voltage proportional to the speed of said second dynamo, means for limiting the speed of said second dynamo comprising an additional field winding on said first dynamoelectric machine connected to be excited by the difference between said third control voltage and a third reference voltage derived from said constant voltage source, and rectifier means in circuit with said additional field winding permitting current to flow in one direction only through said additional field winding.

11. A control system comprising a first adjustable voltage electric dynamo adaptable for operation primarily as a motor, a second electric dynamo adaptable for operation primarily as a drag generator connected to a lowering mechanism and having its armature connected in a series loop circuit with the armature of said first dynamo, said mechanism being provided with a load supporting cable, means for deriving a control voltage responsive to the tension in said cable, means responsive to said control voltage for controlling the excitation of said first dynamo to maintain said tension at a selected value, and means for limiting the speed of said second dynamo to a predetermined value.

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