Dec. 14, 1948. W. S. CRAKE 2,455,917

DRILLING CONTROL SYSTEM

Filed Feb. 9, 1946 2 Sheets-Sheet 1

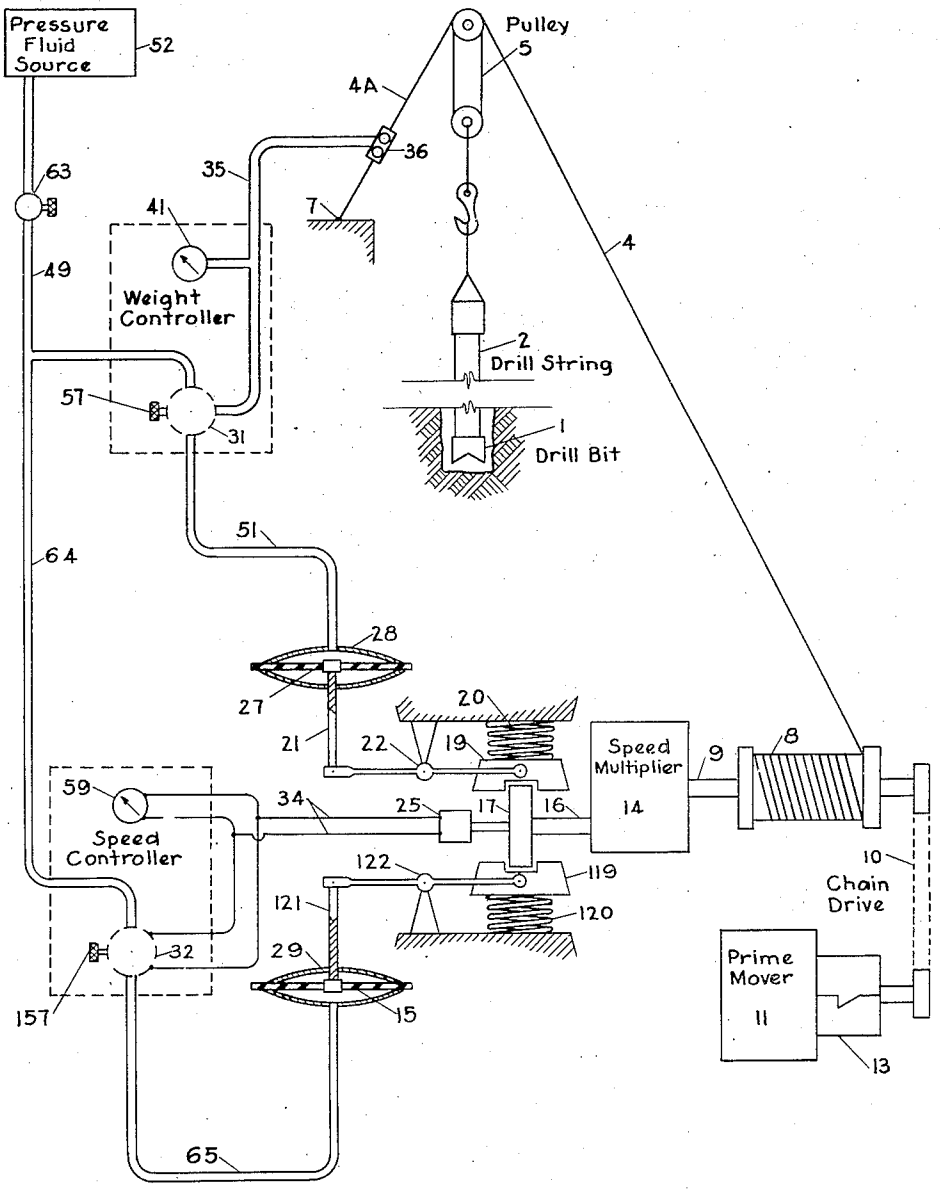


FIG. 1

Inventor: Wilfred S. Crake

By his Attorney: A. M. Alexander

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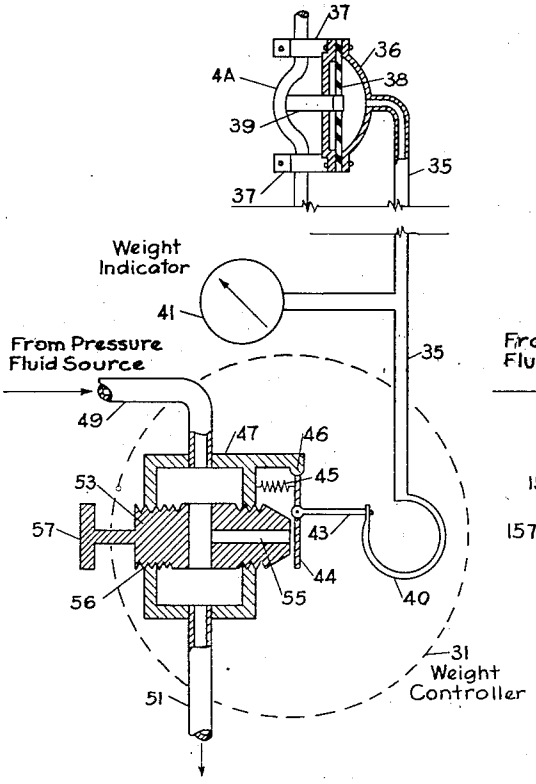


FIG. 2

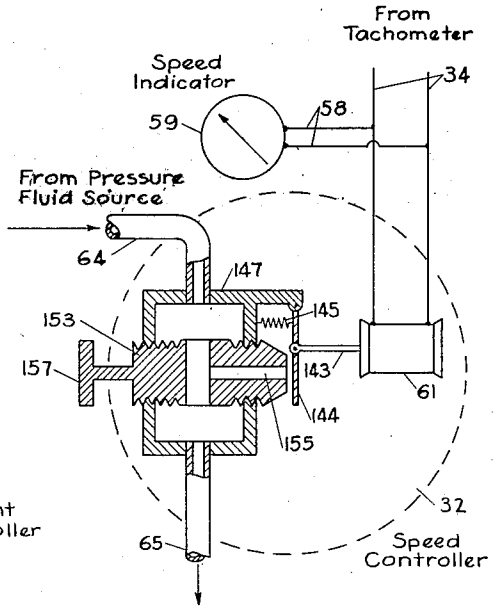


FIG. 3

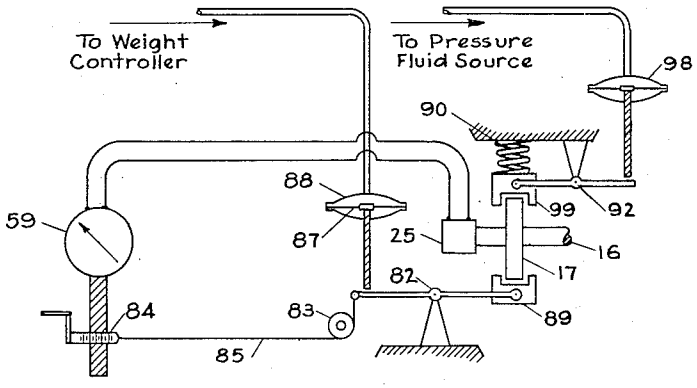


FIG. 4

Inventor: Wilfred S. Crake

By his Attorney: [signature]

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UNITED STATES PATENT OFFICE

2,455,917

DRILLING CONTROL SYSTEM

Wilfred S. Crake, Houston, Tex., assignor to Shell Development Company, San Francisco, Calif., a corporation of Delaware

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1 Claim. (Cl. 255—19)

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This invention relates to the drilling of boreholes, such for example as oil and gas wells, and refers in particular to an automatic control system for maintaining the rate of feed of the drill bit, and the load or weight applied to the bit, at predetermined values.

The rate of penetration of the drill bit into the ground depends generally on the hardness of the ground formation. The rate of feed of the drill bit, or in other words the rate at which the cable supporting the drill string is permitted to unwind from the cable drum, must be adjusted to conform to the rate of penetration. By properly adjusting the feed rate with regard to the penetration rate, load or weight applied to the bit, that is, the force exerted by the bit against the bottom of the borehole, may be controlled between desired limits, and may be maintained at a desired or optimum value.

The feed rate is usually controlled by the operator by means of a brake applied to the cable drum in accordance with the indications of gages showing, for any given instant, the feed rate (for example, in feet per hour), and the weight on the drill bit (for example, in points or thousands of pounds).

This method of control, involving the human element, leaves much to be desired, especially in view of abrupt changes in the rate of penetration likely to occur during drilling. These changes, as to which the operator receives no direct indications, may occur, for example, when the bit passes from a soft to a hard formation, or encounters a cavity, or is subject to rapid wearing out in a hard formation, etc.

If, under these conditions, the feed rate becomes too high with regard to the penetration rate, there occurs a slack in the supporting cable and the weight on the bit rises to an excessive value, causing a premature dulling of the bit, a deviation of the drill bit from the vertical, a slowing down of the rotary speed of the drill string, etc., and in general a lowering of the drilling efficiency and a loss of drilling time.

If, on the other hand, the feed rate is too low with regard to the penetration rate, the load applied to the drill bit decreases to a value below that of good drilling practice, thus again slowing the drilling operations, causing crooked boreholes, and bringing other undesirable effects.

It is therefore an object of this invention to provide a drilling control system whereby the drill bit or cable feed rate, and the weight applied to the drill bit may be automatically controlled to conform with the actual penetration rate of the drill bit.

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It is also an object of this invention to provide a control system whereby the drill bit feed rate and the weight applied to the bit may be preset and maintained at desired predetermined values, and are not permitted to exceed predetermined maximum values.

It is also an object of this invention to provide a system comprising a speed or feed rate controller and a weight controller operating jointly to maintain the cable drum feed at a proper rate, each of said controllers being however capable of assuming sole and independent control of said cable drum feed rate when the limiting maximum value to which said controller has been pre-set is reached.

It is also an object of this invention to provide a system wherein the control of the cable feed rate and of the weight on the drill bit is effected by pressure fluid, pneumatic, mechanical or electrical means, or by a combination of said means.

It is also an object of this invention to provide an automatic drilling control system provided with safety means for stopping the feed or preventing the drop of the drill string in case of the failure of the medium, such as pressure fluid or electric power, used for control purposes.

These and other objects of this invention will be understood from the following description taken with reference to the attached drawings wherein:

Fig. 1 is a diagram schematically showing the general arrangement of the component parts of the present automatic control system.

Fig. 2 is a diagram illustrating the weight responsive controller of Fig. 1.

Fig. 3 is a diagram illustrating the speed or feed rate responsive controller of Fig. 1.

Fig. 4 shows a modification of a part of the diagram of Fig. 1.

Referring to Fig. 1, a drill bit 1 and drill string 2 are supported in a borehole by means of a cable 4 passing over a block or pulley arrangement 5 attached to the top of a derrick, not shown.

The dead end 4A of the cable is attached to a fixed point 7 of the derrick structure, while the other end is wound on a cable drum 8 rotating on a shaft 9. The cable drum may be wound up, for example, by means of a chain drive 10 and any desired prime-mover 11, provided with a clutch 13, which is released when it is desired to unwind the cable drum, said unwinding or feed action being thus effected solely by the pull of the drill string 2 on the cable 4.

The shaft 9 is connected to a speed multiplier 14, whose high speed shaft 16 carries a brake drum 17. Due to the extremely high ratio between the speeds of the shafts 16 and 9, for example five hundred or more to one, a relatively small force applied to the brake drum 17 is sufficient to restrain the rotation of the cable drum 8 against the relatively very high force or pull exerted by the drill string 2.

A restraining force is applied to the brake drum 17 in any suitable manner, for example by means of shoe, band or disk brakes, as diagrammatically indicated in the drawing by brake means 19 and 119.

The brake means 19 and 119 are urged against the brake drum 17 by means of powerful springs 20 and 120, capable of applying sufficient pressure to stop the rotation of the drum 8. The brakes are released against the action of the springs by means of a lever arrangement diagrammatically shown at 22 and 122.

The lever 22 is controlled by an arrangement involving a motor valve or diaphragm mechanism 28, responsive to a weight controller 31, and the lever 122 is controlled by a fluid motor or diaphragm mechanism 29, responsive to a speed or cable feed controller 32.

A tachometer 25 is actuated by the high speed shaft 16 or another suitable element of the speed multiplier, and may be made, for example, as a small generator adapted to produce a current proportional to the rotating speed of the shaft 16 and therefore of the cable drum 8.

The tachometer 25 is electrically connected by leads 34 to the speed controller 32.

Connected to the cable 4, and preferably to the dead-end 4A thereof is a weight-indicating device 36 connected by means of a conduit 35 to the weight controller 31.

Referring to Fig. 2, the weight indicator may be of any desired type and is shown for purposes of illustration to comprise a housing 36 clamped to the cable 4A by means of members 37. A piston 39, positioned intermediate the clamps 37, extends through the walls of the housing and is attached to a fluid-tight diaphragm 38 fixedly stretched within the housing 34. The resiliency of the diaphragm causes the piston to press against the cable 4A, causing a bend in said cable. The housing 36 and the conduit 35 are filled with any desired fluid.

The conduit or pipe 35 extends to the controller 31, which may likewise be of any desired type and is shown for purposes of illustration to comprise a Bourdon type tube 40 and an indicating or recording gage 41, both in communication with the conduit 35.

The end of the Bourdon tube is pivotally connected, for example, by means of a stem 43, to a plate 44, which is likewise pivotally attached to some fixed point 46. The control mechanism comprises further a housing 47, in communication by means of a conduit or pipe 49 with a source of pressure fluid or air 52, and by means of a conduit 51 with the fluid motor 28, as shown in Fig. 1.

Passing through the housing 47 is a stem 53 provided with an internal channel 55. The stem 53 has external screw-threads 56 and an adjusting micrometric screw-knob 57, whereby the stem may be laterally moved with regard to the housing 47, and the distance between the outer end of the channel 55 and the plate element 44 may be accurately adjusted as desired to control the amount of air or pressure fluid escaping through channel 55.

The speed or feed controller 32 may likewise be of any desired type and is shown for simplicity in Fig. 3 as similar to the weight controller of Fig. 2.

The tachometer 25 of Fig. 1 is connected, through wires 34 and 58 to an indicator 59, which may be calibrated in any desired units, to give the feed rate of the cable drum 8 in revolutions per minute, or the cable or bit feed in terms of feet per hour.

A relay or solenoid coil 61 is connected to the wires 34 and serves to actuate, against the action of a spring 145, a stem 143 and a pivoted plate element 144, similar to elements 43 and 44 of Fig. 2. Likewise similar to corresponding elements of Fig. 2 are the pressure housing 147 and the channeled and screw-threaded stem 153 adjustable by means of a knob 157, and having a channel 155.

The housing 147 is in communication, through pipes 64 and 49 with the pressure fluid source 52, and through pipe 65 with the motor valve 29.

The weight controller of the present system should preferably be adapted to handle and to record any weight between zero and 50,000 lbs. on the bit, or between zero and 400,000 lbs. on the hook or cable and the speed recorder any feed rate between zero and 125 feet per hour of vertical drill bit displacement.

The control of the drilling operations by means of the above system is effected as follows:

Assume that at the beginning of the process the drill string 2 is suspended within the borehole with the drill bit at some distance above the bottom thereof. The cable drum is held stationary by the action of the springs 20 and 120 engaging the brake 19 and 119 against the brake drum 17.

The pressure fluid or compressed air, which may be admitted to the weight controller 31 by opening a valve 63, enters the housing 47 (Fig. 2) and is permitted to vent or escape through channel 55. By rotating the adjusting knob 57, the stem is made to advance towards plate 44 and prevent the pressure fluid from escaping through channel 55. The pressure fluid thereupon passes through pipe 51 to the upper side of diaphragm 27 of the fluid motor 28, thus forcing said diaphragm and the rod 21 downwards and causing lever 22 to pivot and release the brake 19 from the brake drum 17 against the action of spring 20.

The brake drum is then held stationary by brake shoe 119 of the speed controller.

The pressure fluid or compressed air, which has been admitted to the speed controller 32 by opening valve 63, enters the housing 147 and is permitted to vent or escape through the channel 155. By rotating the adjusting knob 157, the stem 153 is made to advance against the plate 144, thus gradually shutting off the escape of the pressure fluid through channel 155. The pressure fluid thereupon passes through pipe 65 to the lower side of diaphragm 15 of the motor valve 29, forcing said diaphragm and the rod 121 connected thereto upwards, and thus causing the pivoted lever 122 to release the brake 119 from the brake drum 17 against the action of the spring 120.

As the cable drum thus starts to unwind under the effect of the pull exerted by the drill string, the tachometer 25 and indicator or recorder 59 indicate the rate of feed of the drill bit. When some desired value, such for example as 10 feet per hour is reached, the further adjustment of the controller 32 by means of the screw 157 is discontinued, and the drill string is lowered until the drill bit 1 reaches the bottom.

Assume that the weight of the drill string and bit is 100,000 lbs. and that it is desired that the bit carry a load of 10,000 lbs., that is, a pressure of 10,000 lbs. be exerted by the bit against the bottom of the borehole.

In such case, the cable must support 100,000 lbs. so long as the drill string is completely suspended without touching the formation, and 90,000 lbs. when the drill bit rests against the formation to the whole extent of the load desired, that is, 10,000 lbs.

As the drill bit descends towards the bottom of the borehole, the whole weight of 100,000 lbs. is carried by the cable, and this value is registered or recorded by means of the weight indicating device **36** and gage **41**, this gage being suitably calibrated for any multiple line arrangement used for block **5**, and preferably for indicating or recording the weight on the drill bit rather than the weight on the cable.

The whole weight of the drill string being at this time supported by the cable, the cable exerts a maximum force on the piston **39** of the weight indicating device **36** of Fig. 2, thus applying pressure to the fluid in said device and in conduit **35**.

Under the effect of this pressure, the Bourdon tube **40** expands in well known manner, forcing, through stem **43**, the plate **44** against the orifice of channel **55**. The stem **53** is withdrawn at this time, by manipulating the knob **57** as far back as necessary to permit a full expansion of the tube **40** without allowing the pressure fluid to escape through channel **55**.

As the bit touches the bottom and the continued feeding of the cable causes said bit to rest on the ground with an increasing force, for example, 2,000, 4,000, 6,000, 8,000 and 10,000 lbs. in succession, which weight is indicated or recorded by gage **41**, the weight on the cable correspondingly decreases from 100,000 lbs. to 90,000 lbs.

The decreasing pressure of the fluid within tube **35** causes the Bourdon tube to contract, thus pulling the plate **44** away from the orifice of channel **55**. The stem **53** is however advanced at this time against the receding plate **44** so as not to permit any escape of the pressure fluid until the gage **41** reads the desired weight on the bit, that is 10,000 lbs., at which time the further adjustment of the stem **53** is discontinued.

The present system is now properly adjusted for control operations, and the drilling may be started in the normal manner, involving the use of the rotary table, drilling fluid, etc., with the bit feed rate and the weight on the bit being maintained at predetermined values and without being permitted to exceed the pre-set maximum values selected as described above, the drill bit feed rate being automatically made to adjust itself to the actual drill bit penetration rate.

This automatic method of control can be best illustrated by the following example:

Assume as above that the maximum feed rate is set at 10 feet per hour and the maximum weight on the drill bit at 10,000 lbs., a soft layer having been drilled through under these conditions.

Upon the drill bit encountering thereafter a hard layer where the penetration rate is for example only 4 feet per hour, the feed rate is in excess of the penetration rate, resulting immediately in a slack in the cable and a corresponding increase of the weight on the bit to a value in excess of 10,000 lbs., thus causing an undesirable condition.

The slack on the cable, however, results in a contraction of the Bourdon tube of the weight

controller, which permits the pressure fluid to escape through channel **55**, thereby relieving the pressure on the diaphragm **27** of fluid motor **28**, and applying the brake **19** to slow down the bit feed rate until said feed rate is reduced sufficiently to take off the slack in the cable, whereafter the drilling proceeds as before with the bit feed rate automatically adjusted to the value of the new penetration rate, that is, 4 feet per hour.

If, after passing through the hard layer, the bit encounters an extremely soft formation, or even a cavity in the ground, all weight is momentarily removed from the bit and is carried in the cable. The weight controller acts in this case to disengage the brake **19**, and the drum **8**, under the effect of the heavy weight of the drill string, has a tendency to unwind at a very high rate, thus dropping the drill string to the bottom.

The instantaneous increase of the drum speed, however, as transmitted by the tachometer **25** to speed controller **32**, results in the solenoid or relay coil **61** of Fig. 3 pulling in the plate **144**, releasing the pressure on the diaphragm **15** of motor valve **29** and thus applying the brake **119** so as not to exceed the pre-set rate of the controller **32**.

It will be seen therefore that the two controllers of the present system cooperate with each other in such a manner as to maintain the drill bit feed rate at a value corresponding to that of the drill bit penetration rate, but below pre-set maximum values of weight carried by the bit and of feed rate of said bit, each of said controllers being adapted to take control over the system independently of the other controller as soon as the maximum value, weight or feed rate, to which said controller is pre-set, is exceeded, thereby bringing the system back to operation within normal limits.

It is understood that the particular structure of the weight or speed indicators, motor valves or diaphragms, weight indicators, etc., which have been described above to define clearly the operation of the control system as a whole, forms no part of this invention, and that any desired types of these devices, whereby the application of the brakes may be effected in response to increase or decrease of the weight of the cable, increase or decrease of fluid pressure on diaphragms, etc., may be equally well used. It is also understood that instead of effecting drilling control according to the present invention by pneumatic or electro-pneumatic ways, as described above for purposes of illustration, such control may be effected by mechanical or electrical means.

Fig. 4 shows a portion of the drilling organization of Fig. 1, wherein the brake drum **17** is engaged by a brake **89** in response to an increase of fluid pressure on the diaphragm **87** of a motor valve **88** transmitted by the weight controller upon an excessive weight being applied to the bit.

Instead of a pneumatic speed controller, there is used however in this embodiment a mechanical speed controller comprising a micrometric screw **84** connected by means of a wire **85**, passing over a pulley **83**, to the lever **82** actuating the brake. The tachometer **25** and the speed or feed indicator **59** are the same as in Fig. 1.

In adjusting the speed controller of Fig. 4 for operation, the drill string is permitted to descend in the borehole above the bottom thereof at a varying rate by varying the adjustment of the micrometric screw **84** and thus the engagement of the brake **89** with the brake drum **17**. As there is no weight on the bit, there is no pressure in

the weight-responsive motor valve 88, and this valve exerts at this time no controlling action. When the gage 59 indicates the desired maximum speed, for example, 10 feet per hour, the further adjustment of the micrometric screw 84 is discontinued, and the weight controller is then adjusted for a desired maximum weight in substantially the same manner as described with regard to Fig. 1.

The operation of the system of Fig. 4 is similar to that of Fig. 1 as will be seen from the following example:

Assuming, as before, that the drill bit reaches a cavity, the removal of pressure on the bit will cause a removal of fluid pressure in the motor valve 88 and a disengagement of the brake 89, the drill string tending to fall down through the cavity. Since, however, the micrometric screw 84 has been adjusted to hold the brake in such engagement with the brake drum that no feed rate in excess of for example 10 feet per hour is permitted, the drill bit will be moved through the cavity at that maximum speed until it touches hard ground again, whereupon the weight controller will again assume control to maintain the weight on the bit below the pre-set maximum value.

A safety brake 99, operated by a lever 92 and motor valve 96, connected to the source of pressure fluid, against the action of a spring 90, may be used with the system as additional protection in case of a failure of the pressure fluid or a mechanical failure of the speed controller.

I claim as my invention:

An automatic control system for a rotary drilling installation comprising a drill string supported on a cable and a cable drum rotating to unwind the cable as the drill string descends, said system comprising a high-ratio speed multiplier driven by the cable drum, said speed multiplier having a high-speed shaft, brake means on said shaft, first and second fluid motor means, leverage means connected to said fluid motor means and said brake means for applying the restraining

force of said brake means to said high-speed shaft, means for supplying to said fluid motor means an actuating pressure fluid, said means comprising a source of fluid pressure, a weight controller and first conduit means connecting said weight controller to said source and the first fluid motor means, a speed controller and second conduit means connecting said speed controller to said source and the second fluid motor means, adjustable means on the weight controller for pre-setting the fluid pressure transmitted thereby to the first fluid motor to a value corresponding to a predetermined weight supported by the cable, adjustable means on the speed controller for pre-setting the fluid pressure transmitted thereby to the second motor fluid to a value corresponding to a predetermined speed of said multiplier shaft, a weight indicator connected to the cable for registering the weight supported thereby, a speed indicator connected to the multiplier shaft for registering the speed thereof, means responsively connecting the weight indicator to the adjustable means on the weight controller for varying the setting of said adjustable means in proportion to the changes of the weight supported by the cable, and means responsively connecting the speed indicator to the adjustable means on the speed controller for varying the setting of said adjustable means in proportion to the changes of the speed of the multiplier shaft, whereby the fluid pressure transmitted to said fluid motors is independently varied in proportion to said weight changes and to said speed changes.

WILFRED S. CRAKE.

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