May 5, 1970 R. FIDLER 3,510,107

MULTIPLE HOIST SYNCHRONIZATION SYSTEM

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FIG. 2

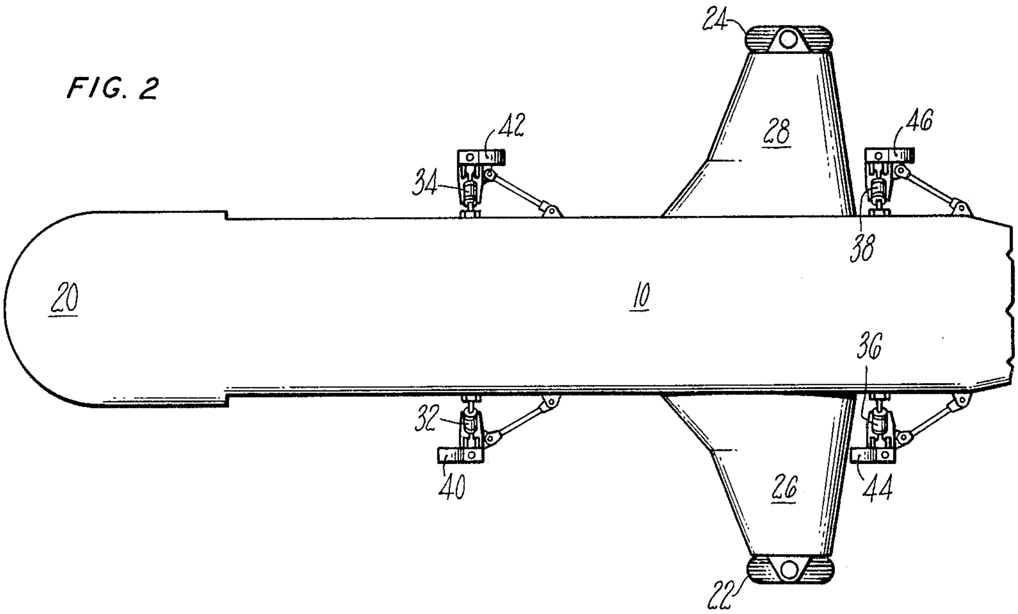
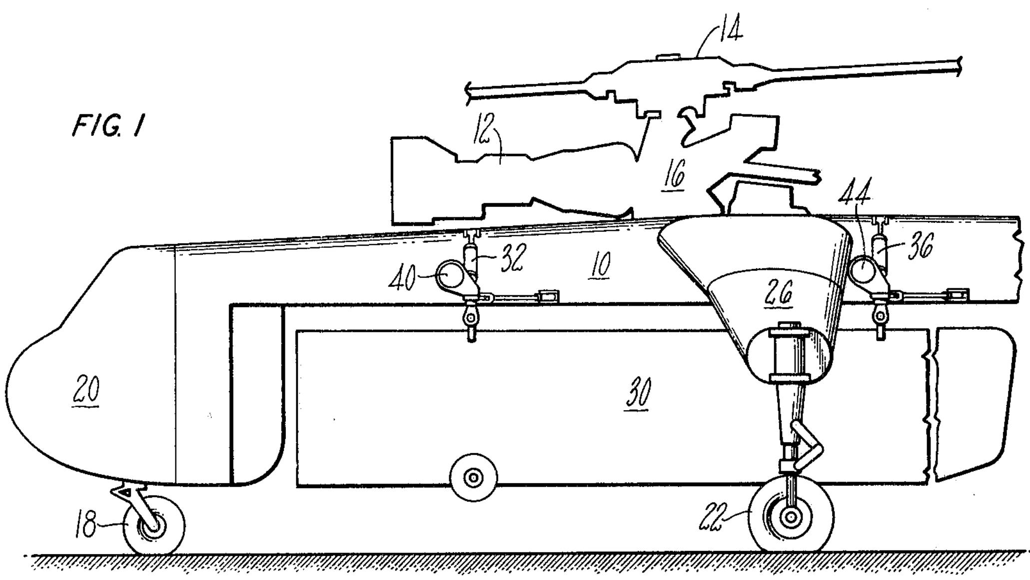


FIG. 1



INVENTOR
RIDLEY FIDLER

BY John C. Lindeman

AGENT

FIG. 3

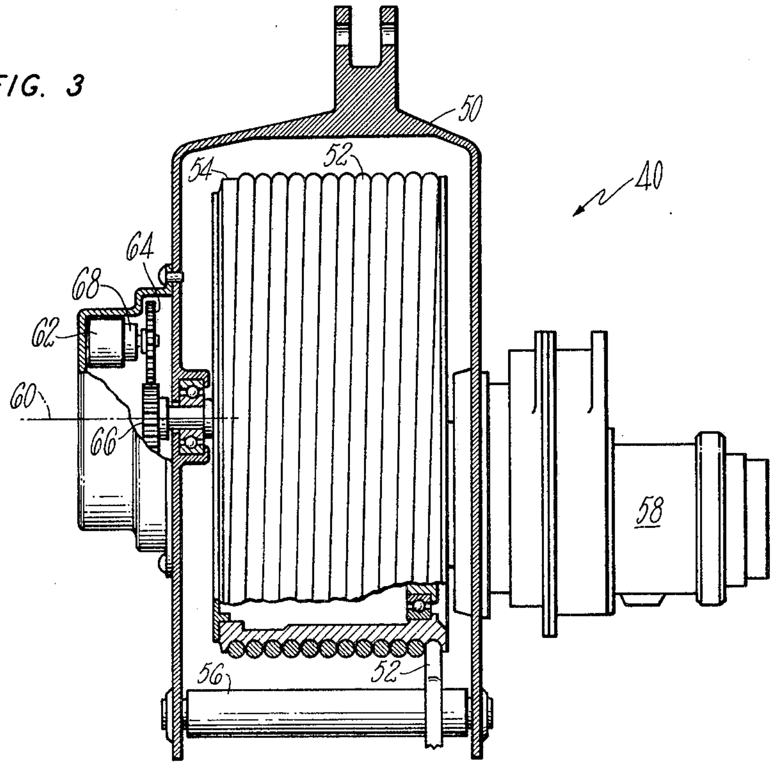

50
52
54
40
64
68
62
60
66
58
56
52

FIG. 5

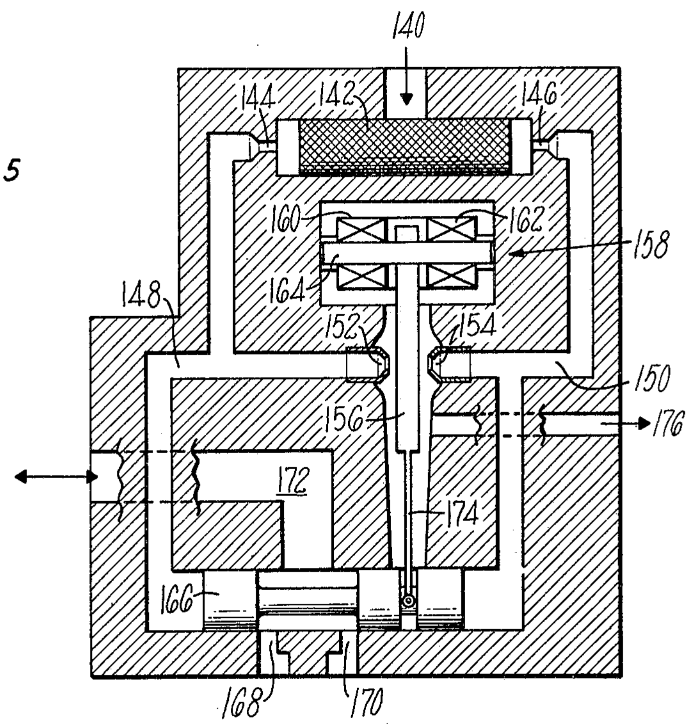
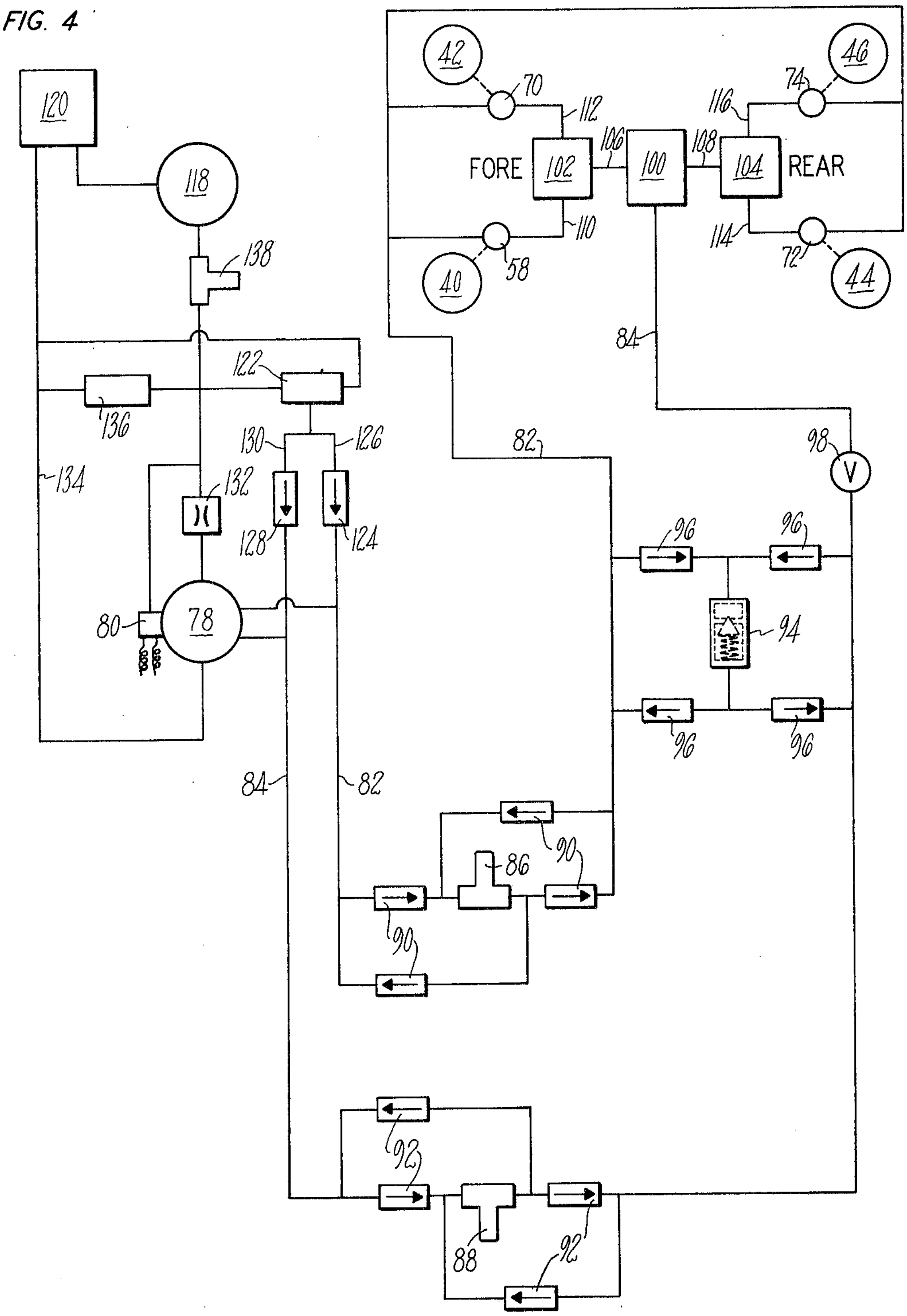

140
144
142
146
160
162
158
164
148
152
154
150
156
176
172
174
166
168
170

FIG. 4


120
118
138
122
136
134
130
126
132
128
124
80
78
84
82
86
90
88
92
42
70
112
46
74
116
FORE
102
106
100
108
104
REAR
110
114
40
58
72
44
98
V
96
94

MULTIPLE HOIST SYNCHRONIZATION SYSTEM

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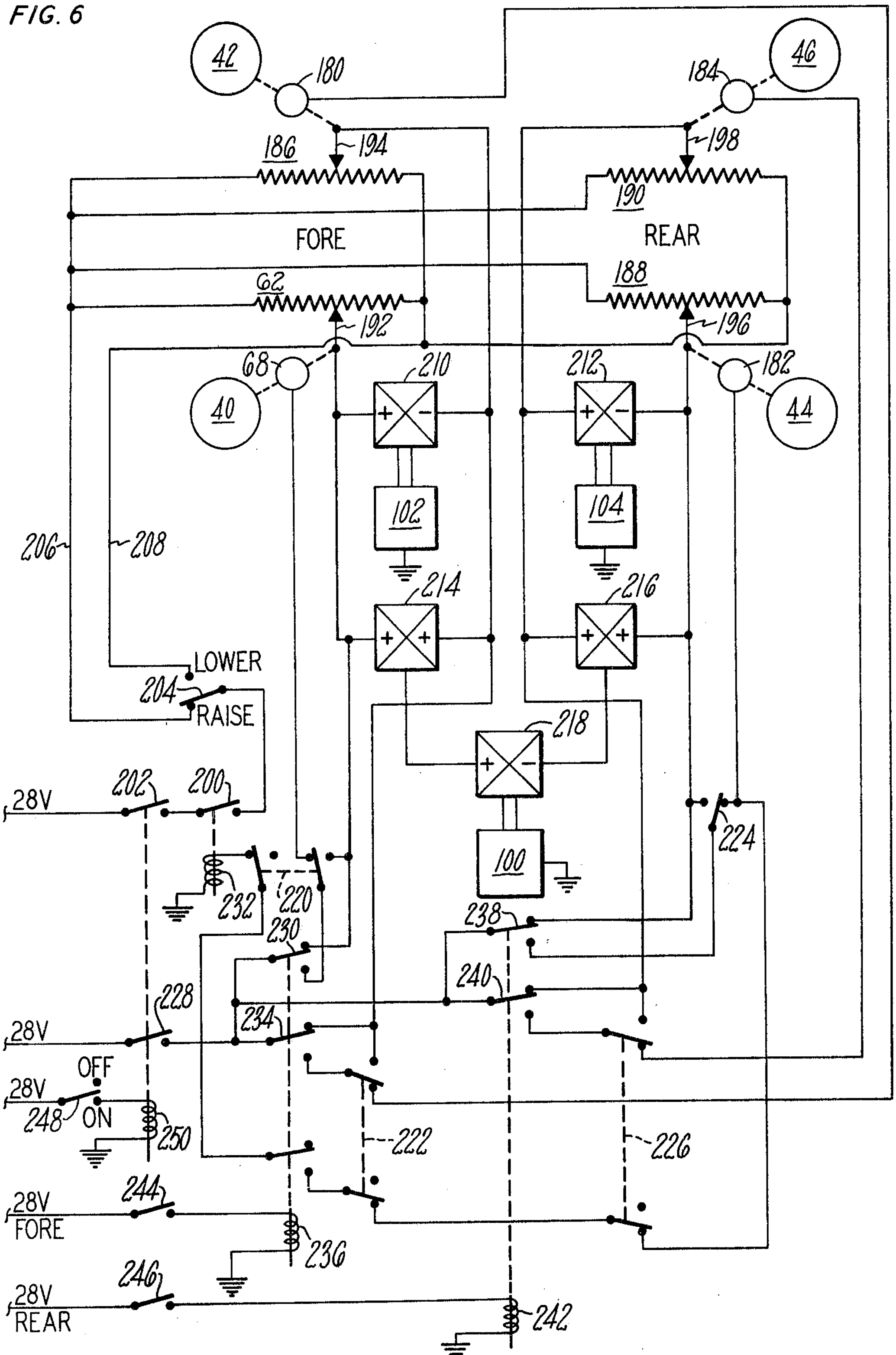
FIG. 6



MULTIPLE HOIST SYNCHRONIZATION SYSTEM

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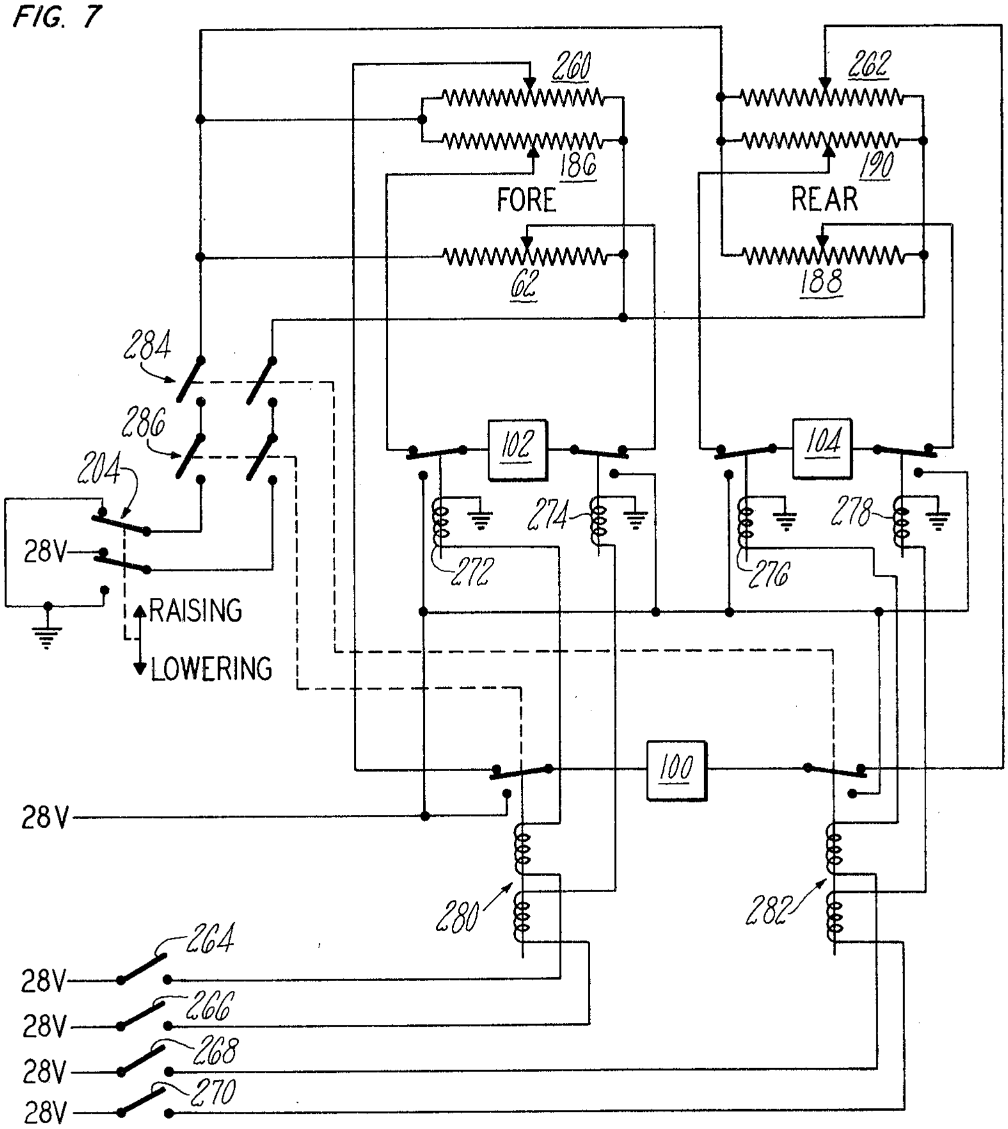
FIG. 7



MULTIPLE HOIST SYNCHRONIZATION SYSTEM

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FIG. 8

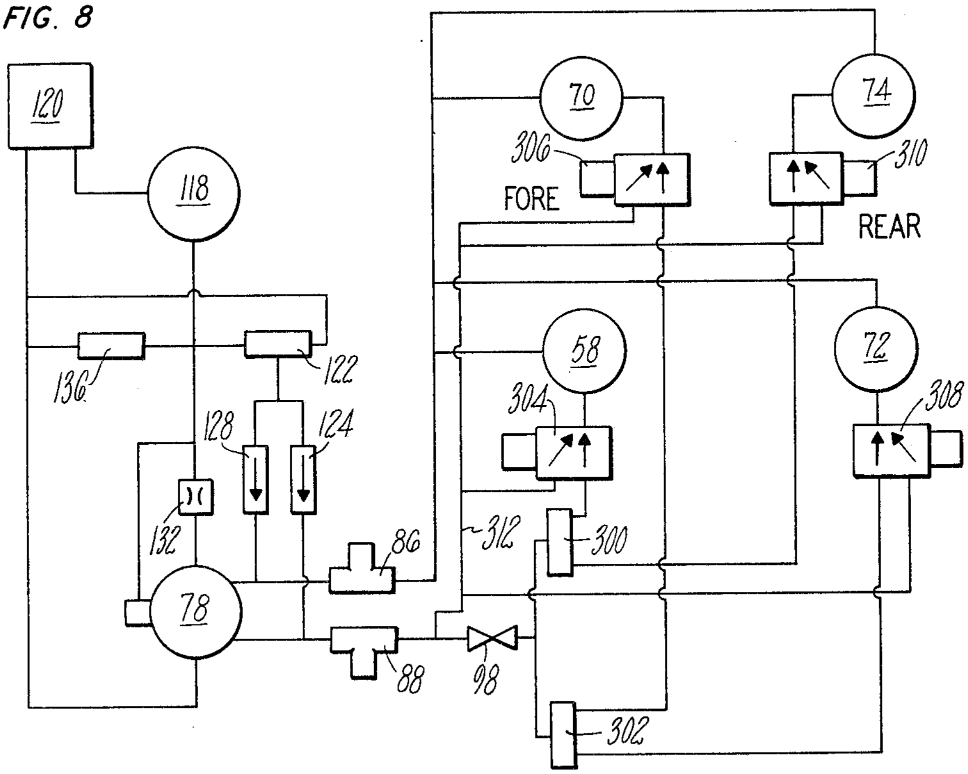
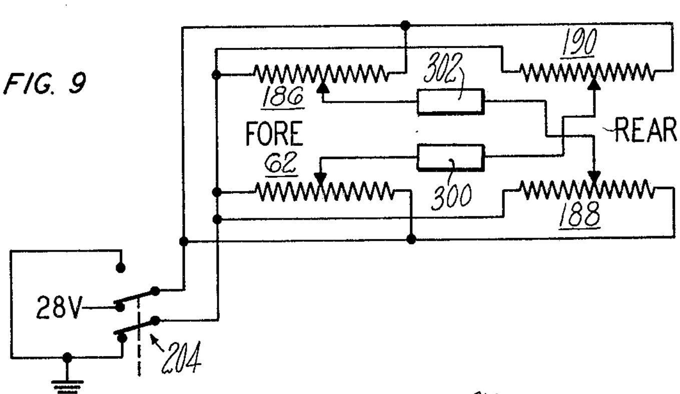


FIG. 9



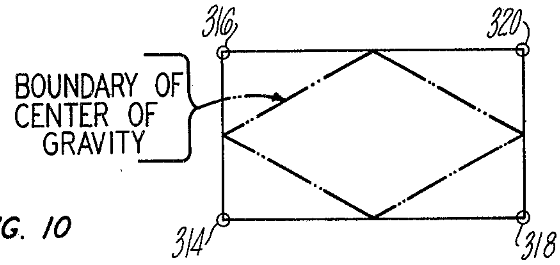


FIG. 10

United States Patent Office 3,510,107
Patented May 5, 1970

3,510,107

MULTIPLE HOIST SYNCHRONIZATION SYSTEM

Ridley Fidler, Milford, Conn., assignor to United Aircraft Corporation, East Hartford, Conn., a corporation of Delaware

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Int. Cl. B66d 1/48
U.S. Cl. 254—173 27 Claims

ABSTRACT OF THE DISCLOSURE

This invention relates to a hoist mechanism in which the speeds of a number of independently driven winch cables are synchronized in order to keep the suspended load in a fixed attitude while it is raised and lowered. Provisions are also made for individually operating the winches or operating the winches in pairs to shorten or extend the cables with respect to one another and change the attitude of the load.

This invention herein described was made in the course of or under a contract or subcontract thereunder with the Department of the Army.

BACKGROUND OF THE INVENTION

This invention relates to a hoist mechanism in which the speeds of a number of independently driven winch cables are synchronized in order to keep a suspended load at a fixed attitude, such as a horizontal attitude, while the load is being raised or lowered.

It is often desirable in cargo-handling systems to employ a hoist mechanism which incorporates a number of winches for moving a bulk cargo load from one place to another. It is generally desirable that the winch cables operate at a uniform speed so that the attitude of the cargo is not changed while the winches are operating in unison. Variations in the cable speed may arise from a number of sources. For example, the different winches may be driven at the same speed but due to the differences in the amount of cable already wound upon the winch drum, the actual radius of one winch drum may be different from that of another and consequently the speed at which the cable is paid in or out may vary. In other instances, different winches or groups of winches may be operated from independent motors and since the motor speeds may vary due to different loads upon the cables, the cable speeds may also vary.

Hoist mechanisms in which a number of cables are driven independently by separated motors are often preferred since they will permit individual operation of the cables. For example, where a load must be suspended with the paid out cable lengths being unequal, the winches at sometime must be operated individually to achieve the desired paid out lengths. Systems with individually driven cables also permit the attitude of the cargo load to be changed while the load is suspended from the cables. In addition, in aircraft systems where weight is a critical factor, it is desirable to employ separate winch motors for remotely positioned winches instead of heavy interconnecting power shafts which might pass through intervening passageways and structural components. In multiple winch systems where the load is only moved a short distance, differences in cable speeds may not prove critical. However, in a system such as the hoist arrangement for raising and lowering a cargo load from a hovering helicopter, a small difference in the speed of the winches may result in a substantial change in the attitude of the cargo load as it is raised or lowered from the hovering helicopter. A number of independently driven winches are often employed in such systems and some form of cable speed control is desirable to keep the cargo load in a level position while it is raised or lowered.

SUMMARY OF THE INVENTION

This invention relates particularly to a hoist mechanism employing a number of independently driven winches in which the speeds of the cables are synchronized to keep the suspended load in a fixed attitude while it is being raised or lowered.

In particular, each winch is driven by a hydraulic motor in a system in which the hydraulic power is distributed in accordance with the power demanded by the motors to keep the winches operating at a constant speed in spite of differences in the loads on each winch and motor. The proportioning of hydraulic power is first made to different groups of winches and from different groups of winches to the various winches themselves. This proportioning is accomplished by hydraulic flow-dividing valves each of which include a torque motor operating a spool valve. The flow-dividing valves are in turn controlled by a feedback mechanism which includes a paid-out cable length transducer for each cable to produce a feedback signal varying as a function of the paid-out length of the cable. The signals from the transducers are combined in an appropriate manner to proportion the proper amount of hydraulic power to the appropriate winches.

In particular, an electrical feedback signal representative of the paid-out cable length from one group of winches is compared with a feedback signal representative of the paid-out cable length from another group of winches. In one embodiment of the invention the representative cable length signal is the average of the paid-out lengths from the group and in another embodiment, the representative signal is the actual paid-out length of one of the winches in the group. A primary hydraulic flow-dividing valve is driven by the difference in the representative signals to proportion the hydraulic power between the group of winches. Within each group the flow is proportioned by secondary flow-dividing valves to the appropriate subgroups of winches in response to the difference in the representative paid-out cable lengths of the subgroups. At the lowest stages of distribution, the hydraulic flow-dividing valves distribute the hydraulic power between the winches themselves in response to the differences in the paid-out cable lengths of the winches. A high gain in the control system permits a small difference signal to operate the valves so that a fixed attitude will be maintained while the load is raised or lowered.

In still another embodiment of the invention, the requirement for a representative paid-out cable length signal is eliminated by providing only two hydraulic flow dividing valves which operate independently. The valves drive four winches which are positioned at the corners of a parallelogram. Each of the flow dividers operates one of the diagonal pairs of winches. In order to beep the individual winches, three-way valves are provided which connect the hydraulic motors directly with a hydraulic power source exclusive of the flow dividing valves.

Another feature of the invention is the provision for operating, or beeping, any of the winches individually or for operating selected pairs of the winches without interfering with the speed balancing system. This operation of the winches permits a change of attitude of the load while the load is suspended from the winches or permits an oddly shaped load to be picked up with the actual paid-out cable lengths of the several winches being unequal. Clutches are included between the paid-out cable length transducers in the feedback mechanism for each cable in order to prevent any unbalance of the biasing adjustment established by the feedback mechanisms for equalizing the speed of the winches. To prevent this adjustment from interfering with the beeping operation, the transducers are also deenergized when the clutches are disengaged.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a winch-supported cargo load under a crane-type helicopter in which the hoist speed synchronization apparatus may be employed.

FIG. 2 is a plan view of the crane-type helicopter showing the position of four hydraulically driven winches.

FIG. 3 is a detail drawing of one of the winches including a hydraulically driven motor and paid-out cable length potentiometer.

FIG. 4 is a diagram of the hydraulic system which drives the winch motors.

FIG. 5 is a schematic of the hydraulic flow-dividing valves in the hydraulic system of FIG. 4.

FIG. 6 is an electrical diagram of the control system which achieves speed synchronization of the four winch motors in FIG. 4.

FIG. 7 is an electrical diagram of a simplified control system which achieves speed synchronization of the four winches in FIG. 4.

FIG. 8 shows the hydraulic system which employs only two flow-dividing valves for a four-point hoist system.

FIG. 9 is a simplified electrical diagram of the control system which achieves speed synchronization of the four-point hoist system in FIG. 8.

FIG. 10 depicts the load C.G. limitations imposed by the hoist system of FIG. 8.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

With reference to FIGS. 1 and 2, a crane-type helicopter is seen having a fuselage **10**, a motor **12** driving a rotor **14** through a transmission **16**. A forward landing gear **18** is connected to cockpit **20** and since the helicopter is of the crane-type, it has an elongated rear landing gear **22** and **24** projecting downwardly from laterally extending struts **26** and **28**. Suspended between the rear landing gear from the fuselage is a cargo load **30**. The cargo load may be a pallet having a load fastened thereon, or a bulk container, or a passenger pod for transporting personnel.

Cargo load **30** is suspended from the fuselage **10** by means of isolators **32, 34, 36** and **38** and winches **40, 42, 44** and **46**. For a further description of the isolators and the pod positioning and supporting means, reference may be had to U.S. Pats. Nos. 3,176,939 and 3,176,940. The winches employed in the present invention have been modified slightly from those described in the above-referenced patents; however, the isolators and the supporting lengths may be the same.

It will be noted that there are four winches for raising and lowering the cargo load from the fuselage **10** of the helicopter. In such an embodiment, it would be important that the winches operate at essentially the same speed so that when the helicopter is raising or lowering the cargo load while in a hovering condition, the altitude of the cargo would not change as the distance between the helicopter and the ground is traversed. It would also be important that provisions be included to individually operate the winches so that all loads can be drawn close to the fuselage at an altitude most suitable for high speed flight under the helicopter.

FIG. 3 shows a detail configuration of the winch **40**

which is the same for all four winches. The winch **40** has a housing **50** which would be supported through the isolators in the helicopter embodiment. A winch cable **52** is wound upon the winch drum **54**. The winch drum **54** has an external helical groove in which the paid-in portion of the cable is nested. The one end of the cable **52** is firmly attached to the drum and the other end of the cable **52** has an appropriate attaching device such as a hook (not shown) hanging pendantly over a scrub roller **56**. The roller serves as a guide for the cable **52** as it is paid in or out from the drum **54**. A hydraulic motor **58** is connected to the winch housing and since such motors generally operate at a high speed, a suitable gear reduction unit may be incorporated within the drum **54** to reduce the operating speed of the drum on the axis **60** and increase the driving torque. If desired, a self-actuated brake may be incorporated in the drive train between the hydraulic motor **58** and the drum **54** in order to lock the drum at a fixed position whenever the motor is not operating.

The hydraulic motor **58** is a conventional, reversible, fixed displacement hydraulic motor. In such motors, the rotational displacement of the motor is directly proportional to the quantity of fluid displaced by the motor and the direction of rotation is reversed when the direction of flow is reversed. If constant motor speeds are to be maintained, a larger load on a motor will require more hydraulic power than a small load. Conversely, a small load on the motor will require less hydraulic power. With motor rotation proportional to fluid displacement, motor speed remains proportional to fluid flow rate. At constant motor speed, therefore, the power must be varied by changing the pressure differential across the motor.

Mounted within a section of the housing **50** is a cable length potentiometer **62**. The potentiometer **62** is connected to a gear **64** which is driven from a gear **66** connected to and rotating with the drum **54**. The potentiometer is a conventional high precision linear transducer of the type shown in U.S. Pat. 3,331,047 which, when excited by DC voltage, produces an electrical signal varying in proportion to the length of cable paid in or out. A suitable potentiometer might have a ten-turn rotary wiper, a total resistance error of $\pm\frac{1}{2}\%$, a linearity error of .03% and resolution error of .03%.

Interposed between the gear **64** and potentiometer **62** is a conventional magnetic particle clutch **68**. The clutch **68** is engaged when an electrical signal is applied and disengaged when the electrical signal is removed. The potentiometer **62**, therefore, will be connected to rotate with the drum **54** when the clutch **68** is engaged. The potentiometer will produce an electrical signal which varies linearly as the drum **54** rotates and cable is paid in or out. When the clutch is disengaged, the drum may rotate and pay cable in or out without changing the signal generated by the potentiometer.

It will be noted that there is only a single layer of cable wound upon the drum. It may be desirable in certain embodiments of the invention to include several more layers of cable upon the drum. In such cases, the output signal of the potentiometer **62** driven from the drum **54** would deviate slightly from the actual paid-out cable length of the winch due to the fact that the effective radius of the drum **54** would change as the layers of cable were paid in or out. If a number of layers of cable are necessary, the accuracy of the system may be improved by attaching the potentiometer **62** to the roller **56** instead of the drum **54** so that a direct reading of the cable length paid in or out is obtained rather than a reading of the drum revolutions.

Reference to FIG. 4 will show the hydraulic system by which the four remotely positioned winches are powered. The hydraulic motors **58, 70, 72** and **74** are connected respectively to the winches **40, 42, 44** and **46**. Hydraulic power in the form of pressurized hydraulic fluid is produced by the winch pump **78**. The winch pump **78** normally delivers a constant flow of hydraulic fluid at a variable pressure but the rate of flow and direction of flow can be varied through an electrically actuated control valve **80**. The pump **78** supplies hydraulic fluid to the motors **58, 70, 72** and **74** through either conduit **82** or **84** depending on the direction of flow established by the control valve **80**. Since the hydraulic motors **58, 70, 72** and **74** are the reversible fixed displacement type, the direction of operation of the motors, and therefore the winches, will be determined by the control valve **80**.

Filters **86** and **88** are included in the conduits **82** and **84**. Check valves **90** surrounding the filter **86** and the check valves **92** surrounding the filter **88** ensure that the hydraulic flow will always pass in the same direction through the filters to avoid back-washing the filters when the direction of the hydraulic flow is reversed. A pressure-reducing valve **94** is also included between the conduits **82** and **84** to bypass excessive pressure from the high pressure side to the low pressure side of the hydraulic system. The check valves **96** connecting the pressure-reducing valve **94** between the conduits **82** and **84** ensure that the valve **94** will experience a positive pressure differential in the proper direction for actuation of the valve. A shutoff valve **98** is included in conduit **84** to shut off the motors.

Interposed between the shutoff valve in conduit **84** and the motors **58, 70, 72** and **74** are flow-dividing valves **100, 102** and **104**. It is important to note that the hydraulic valve **100** controls the flow in the two conduits **106** and **108**. The valve **102** in turn controls the flow through conduits **110** and **112** while the valve **104** controls the flow through conduits **114** and **116**. The total flow in conduits **110** and **112** passes through the valve **100** and conduit **106**. The total flow through conduits **114** and **116** passes through valve **100** and conduit **108**. The distribution of the flows through these valves and conduits is controlled by the valves regardless of the direction of flow through the motors **58, 70, 72** and **74** and the conduits **82** and **84**.

The hydraulic system between the winch pump and the motors is a closed hydraulic system and since there is no reservoir in this system it may be necessary from time to time to add additional hydraulic fluid lost through leakage. This is accomplished through a replenishing pump **118** which draws fluid from a reservoir **120**. This pump may be any suitable pump and in the helicopter installation it can be a pump which supplies utility pressure for operating the landing gear and other auxiliary devices on the aircraft. In order to add fluid to the hydraulic system driving the winches, fluid is taken through a pressure reducer **122** which reduces the pressure to approximately 50 p.s.i. and directs the fluid either through check valve **124** in replenishing line **126** or check valve **128** in replenishing line **130** to the conduits **82** or **84**, respectively. The check valves are incorporated in lines **126** and **130** so that the high pressure fluid from the winch pump **78** will not be lost through the replenishing system. When the pressure on the return side of the winch pump drops below the 50 p.s.i. pressure established by the pressure reducer **122**, fluid will be added to the hydraulic system powering the winches. It will be noted that since the winch pump **78** will reverse the flow to the motors, either one of the conduits **82** or **84** may serve as the return line to the pump **78**, and consequently the two replenishing lines **128** and **130** are necessary.

The replenishing pump **118** can also supply the control pressure for the control valve **80** which varies the flow delivered by the winch pump **78**. In addition, the replenishing pump **118** can also supply fluid through a flow reducing orifice **132** and drain line **134** to the reservoir **120** for cooling the winch pump **78**. A pressure reducer **136** between the high pressure side of the replenishing pump **118** and the drain line **134** prevents excessively high pressures from damaging the winch pump. A filter

138 is also included to prevent contamination from affecting either the control valve **80** or the orifice **132** and also prevents dirt from entering the hydraulic system for the winches.

The hydraulic flow-dividing valves **100, 102** and **104** ensure that the hydraulic flaws through each of the hydraulic motors **58, 70, 72** and **74** remain the same regardless of the power demanded by each of the motors. The valves are similar in construction to the conventional electro-hydraulic servo valves which have a torque motor operating a flapper valve to control a spool valve. The flow-dividing valve is seen in greater detail in FIG. 5. In the upper portion of the valve, hydraulic control fluid from the replenishing pump **118** of FIG. 4 enters a port **140** and pases through a filter **142**, through the orifices **144** and **146** and into control ducts **148** and **150**, respectively. These control ducts direct the fluid through nozzles **152** and **154** against a flapper **156** which is positioned in close relationship to each of the nozzles **152** and **154**. Fluid which passes through the nozzles **152** and **154** is returned to the low pressure side of the replenishing pump **118** through conduit **176**. The flapper **156** is caused to move closer to one nozzle or the other by a torque motor **158** which includes two electromagnetic coils **160** and **162** operating upon an armature **164** to which the flapper **156** is connected. When the flapper **156** moves closer to one of the nozzles, for example nozzle **152**, the flow passing through that nozzle will decrease and consequently the pressure drop across the orifice **144** will decrease to increase the control pressure in duct **148**. A corresponding decrease in the control pressure in duct **150** will occur because the flow will increase through the nozzle **154** and cause a corresponding increase in the pressure drop across orifice **146**. The increase in the pressure in duct **148** and the decrease in the pressure in duct **150** will develop a pressure differential across the spool valve will restrict hydraulic flow for the winch motors passing between the dual ports **168** and **170** and the single port **172**. The summation of the flow through ports **168** and **170** will equal the total flow through the port **172**. This relationship remains true regardless of whether the flow enters the valve through single port **172** and is divided between dual ports **168** and **170** or if the flow is in the reverse direction from ports **168** and **170** to port **172**. As the spool moves toward duct **150**, it will close off the flow through the port **168**. Essentially, the spool acts as a variable orifice for the ports **168** and **170** which biases the hydraulic power converted by the winch motors to maintain constant speeds in spite of differences in the loads on the winches. In this regard, it will be noted that the spool shown in the schematic of FIG. 5 is slightly underlapped in that the lands of the spool **166** do not obstruct any portion of the ducts **168** or **170** when the spool is in the normally centered position. Hydraulic flow will only be reduced in one of the ports **168** or **170** when the spool moves away from its centered position. Those skilled in the art will recognize that the valve could be constructed with overlapping lands and ports so that a displacement of the spool from the normally centered position will not only reduce the flow through the one port but will also increase the flow through the other port. The disadvantage of the overlapped valve is that a greater power loss will occur when the valve is in its normally centered position due to the restrictions on each of the ports in the centered condition.

A feedback spring **174** connects the valve spool **166** to the flapper **156**. The spring **174** ensures that the position of the spool **166** will vary in direct proportion to the position of the flapper valve between the nozzles **152** and **154**. The position of the flapper **156** when it is centrally located between the nozzles **152** and **154** should correspond with a central position of the spool **166** on the two ports **168** and **170** in which case the flow through each of these ports will be balanced. This balanced flow condition through the ports **168** and **170** in turn corresponds approximately with balanced control currents through the electromagnetic coils **160** and **162** of the torque motor **158**.

The control system by which the flow-dividing valves **100**, **102** and **104** are operated in response to the cable length potentiometers on the winches is shown in FIG. 6. The winches **40**, **42**, **44** and **46** are shown in positions which correspond generally to the positions of the winches in FIG. 2 where the helicopter is viewed from above. The forward pair of winches **40** and **42** are located to the left of FIG. 6 and the rear pair of winches **44** and **46** are located on the right. The clutch **68** described in FIG. 3 connects the winch **40** to the cable length potentiometer **62**. In a similar manner, clutches **180**, **182** and **184** connect the winches **42**, **44** and **46** to potentiometers **186**, **188** and **190**, respectively. The potentiometers are transducers which have wipers **192**, **194**, **196** and **198** varying the resistance of the potentiometers to develop voltages for controlling the flow-dividing valves **100**, **102** and **104**. The excitation for the potentiometers is a 28 volt power source in the helicopter, and is transmitted through switches **200**, **202** and **204**. The conductors **206** and **208** lead from the separate contacts of switch **204** to opposite ends of the resistive elements in the potentiometers in order to reverse the excitation of the potentiometers. Switch **204** when in one position, therefore, will energize the one end of the potentiometers while the opposite end is floating. When the switch **204** is in the other position, the energized and floating ends are reversed. The reason for this reversible excitation will be explained in greater detail below.

The wipers **192** and **194** of the potentiometers **62** and **186** are operated respectively by the forward pair of winches **40** and **42**. The signals from the potentiometers **62** and **186** are applied to a large, grounded input impedance in comparator **210** in order to obtain a phase-sensitive difference signal representative of the difference in the voltages from the two potentiometers **62** and **186**. The plus and minus signs indicate that the positive value of the signal from the potentiometer **62** is compared with the negative value of the signal from potentiometer **186**. Those skilled in the art will recognize that the input impedance to the comparator should be high compared with the total impedance of the potentiometer in order to maintain a linearity of the input signals with the position of the wiper. In an alternate embodiment, linearity could also be ensured by exciting the potentiometers with a 28 volt signal across the full resistor of the potentiometers rather than having one end of the potentiometers floating. The comparator **210** therefore produces a null signal when the values of the voltages from potentiometers **62** and **186** are the same and this null signal is impressed upon the coils of flow-dividing valve **102** which proportions the flow between the hydraulic motors for the forward pair of winches **40** and **42**. If the signals from the potentiometers **62** and **186** were not exactly equal, the comparator **210** would produce an unbalanced electrical signal representing the difference in the voltages derived from the potentiometers **62** and **186** and bias the hydraulic power applied to the winches **40** and **42** by moving the valve spool to increase or decrease the openings of the dual ports of the flow-dividing valves in accordance with the magnitude of the unbalanced signal.

The movement of the valve spool will generally open the port of the flow-dividing valve which is passing the smaller of the flow rates. This arises from the fact that the winch which is operating at the slower speed will cause the movement of the wiper connected thereto to fall behind the movement of the wiper on the opposite winch controlled by the same flow-dividing valve. As a result, the difference signal generated by the comparator **210** will increase and cause a further increase in the hydraulic power bias to the winch which is operating at the slower speed. An equilibrium condition will be established when the wipers move along the potentiometers at the

same speed and at a fixed differential, as measured by the comparator **210**. The power bias to the winches will be stabilized and therefore the winches will continue to operate at the same speed. In this condition, the flow rates to the two winches will be the same regardless of the difference in the power demanded by the two winches **40** and **42**.

If the gain of the comparator **210** and the flow-dividing valve **102** is high, the fixed differential of the signals from the wipers **192** and **194** at which the speeds of the winches **40** and **42** are synchronized can be very small. This means that the control system of FIG. 6 will not only synchronize the speed of the winches but will synchronize the speed of the winches at an attitude of the load at which the paid-out cable lengths of the winches are practically equal as sensed by the potentiometers. For example, the suspended load can be held in a level attitude while it is raised or lowered from the helicopter. A very small difference in the paid-out cable lengths will produce a large error signal from the comparator **210** and cause the flow-dividing valve to speed up the lagging winch until the small differential is essentially eliminated.

A brief consideration of this synchronizing operation will reveal that a reversal in the direction of operation of the winches will require a reversal in the direction of the hydraulic power bias when the deviations in the motions of the winches are measured by the potentiometers **62** and **186**. Consequently, the error signal produced by the comparator **210** must also be reversed in phase when the direction of operation of the winches is reversed. This is accomplished by reversing the excitation on the potentiometers through switch **204**.

The proportioning of the hydraulic flow between the rear pair of winches **44** and **46** is accomplished in a manner similar to the proportioning between the forward pair of winches. The winches **44** and **46** operate the potentiometers **188** and **190** having wipers **196** and **198** which drive a comparator **212** and the flow-dividing valve **104**. The switch **204** also reverses the energization of the potentiometers **188** and **190** to reverse the phase of the error signal for the flow-dividing valve **104**. Switch **204** is operated when the direction of operation of the winch motors is changed to raise or lower the cargo load.

The flow-dividing valves **102** and **104** can level the load with respect to the lateral axis of the aircraft. In order to keep the cargo load level with respect to the longitudinal axis of the aircraft, a signal must be derived from the potentiometers to control the flow-dividing valve **100** which proportions the flow between the fore and aft pairs of winches. This is accomplished by deriving representative paid-out cable length signals for the fore and aft cables from the averaging networks **214** and **216** respectively. The averaging network **214** adds the signals from the potentimeters **62** and **186** operatively associated with the forward pair of winches **40** and **42**. The signal derived from the averaging network **214** therefore is proportional to the average paid-out cable length of the forward pair of winches or the average distance between the cargo load and the one pair of winches. In the same manner, a signal proportional to the average paid-out cable length of the rear pair of winches **44** and **46** is derived from the averaging network **216**. These two signals are then fed to comparator **218** which produces a phase-sensitive difference signal for controlling the main flow-dividing valve **100** in the same manner that the comparators **210** and **212** control the flow-dividing valves **102** and **104**. The flow-dividing valve **100**, consequently, proportions the hydraulic power between the forward and rear pairs of winches in accordance with the difference in the averages of the paid-out cable lengths of the forward and rear pairs of winches. This proportioning of the hydraulic power can be thought of as the process for synchronizing the average speed of the forward pair of winches with the average speed of the rear pair of winches in accordance with the difference in the average distance between the cargo load and the forward pair of winches and the average distance between the cargo load and the rear pair of winches. This synchronization occurs in spite of differences in the power demanded by the winches to maintain equal speeds. Also, as with comparators **210** and **212**, a high gain of comparator **218** will operate the flow-dividing valve **100** in response to a small difference in the signals from averaging networks **214** and **216**. Such a gain will keep the cargo load substantially level with the longitudinal axis of the helicopter as the average speeds of the winches are synchronized. The phase of the error signal from the comparator **218** will also be reversed when the switch **204** reverses the energization of the transducers. This operation will be necessary whenever the direction of operation of the winches is reversed as mentioned above.

The operation of the flow dividing valves may be more clearly understood by an explanation of their functions. As shown in FIG. 5, the ports **168** and **170** are always open when the valve is in its neutral position. In this condition, the pressure drops across the ports would be equal. If one of the winch motors must operate at a greater power level in order to maintain synchronous speed, the difference in the cable lengths of the winches developed by a difference in speed will energize the proportioning of valve and cause the ports **168** and **170** to open and close correspondingly and change the pressure drops across the ports until the proper power bias to the respective winch motors or pairs of winch motors is established. At this point the flows through the ports and the winch speeds will be the same. It will be noted that the flow-dividing values control the flow proportioning and the power distribution between the winches regardless of the direction of fluid flow in the hydraulic circuit. Generally then, the ports of the flow divider valves are trimmed to pass balanced hydraulic power and biased by the cable angle transducers to provide balanced hydraulic flows.

Although two stages of hydraulic flow-dividing valves have been shown to distribute the flow between two groups of winches and between the winches of each group, it will be readily apparent that the two stages of flow-dividing valves could also be employed to proportion the hydraulic power between one group of winches and a third winch. Also if systems employ a number of groups of winches for raising the cargo load, additional flow-dividing valves could be added to divide the flow between the various groups in response to the differences in the averages of the paid-out cable lengths of each group. This apparatus, therefore, is not limited to a system having only four winches but can be employed in cargo-handling systems having a number of winches.

It is also an important feature of this invention that the winches may be operated individually or in selected pairs in order to change the attitude of the load while it is suspended from the winches or to extend or retract certain of the winch cables without operating the others. As discussed above, the potentiometers associated with each of the winch cables establish a power bias to the winches which will synchronize the speed of the winches in spite of variations in the load carried by each of the winches. It will be readily recognized that the individual operation of any of the winch cables would unbalance this power bias unless the potentiometers were disengaged from the cables during the individual operation, beeping, of the cables. It is for this reason that the electromagnetic clutches are incorporated between each of the winches and wipers of the potentiometers.

In order to operate the winches individually, switches **220**, **222**, **224** and **226** are included to deenergize the clutches respectively associated with the wipers **192**, **194**, **196** and **198**. In examining switch **220**, which is typical of any one of these switches, it will be noted that when the switch is actuated electrical power derived through switch **228** and switch **230** will be removed from the

clutch **68** to disengage wiper **192** from the winch **40**. In addition, this electrical power will be applied as a 28 volt signal to both the comparator **210** and the averaging network **214** in order to introduce a maximum bias signal to flow-dividing valves **102** and **100**. This maximum bias signal in valve **102** will completely close the port of the valve **102** to the winch **44**. Also, the maximum bias signal applied to the averaging network **214** and comparator **218** will completely close off the port of valve **100** for the rear pair of winches **44** and **46**. Consequently, the only winch which will operate when hydraulic power is turned on will be winch **40**.

It will be noted that the signals from the potentiometers may also interfere with the bias signal derived from switch **220** for beeping the winch **40**. For this reason, a separate set of contacts associated with each of the switches **220**, **222**, **224** and **226** will be broken at the time any one of these switches is actuated to deactivate relay **232** and deenergize all of the potentiometers. It will, therefore, be understood that operation of any one of the switches **220**, **222**, **224** or **226** for beeping the winch motors will electrically deenergize all potentiometers, disengage the wipers from the winches and energize the flow-dividing valves to direct hydraulic fluid to the winch which is to be beeped. The direction in which the winches will operate during beeping will depend solely upon the winch pump which is controlled by the servo valve **80**. It may be desirable to have several fixed flow rates to which this control valve can be set in order to establish a reduced flow from the winch pump when individual winches are beeped and prevent overspeeding of the hydraulic motors receiving the entire output of the winch pump.

It is another feature of this invention that the fore or aft pairs of winches can be operated independently. This is accomplished by the ganged switches **230** and **234** operated by solenoid **236** and ganged switches **238** and **240** operated by solenoid **242**. When switch **244** is opened, solenoid **236** is deenergized and the clutches **68** and **180** for winches **40** and **42** are deenergized as well as all of the potentiometers. A beeping signal is applied to the comparator **210** and the averaging network **214**. The application of the beeping signals to the comparator **210** will balance the power bias established by the flow-dividing valve **102**. In addition, the signal produced by the averaging network **214** will bias the comparator **218** so that the aft pair of winches will be shut off and all hydraulic power will be directed to the forward pair of winches **40** and **42**. When solenoid **236** is deenergized, therefore, the forward pair of winches will be operated together and the rear pair of winches will remain stationary. Solenoid **242** together with the switches **238** and **240** perform the identical function for the rear pair of winches so that when the switch **246** is opened and solenoid **242** is deenergized, only the rear pair of winches **44** and **46** will be operated.

Switch **248** actuates solenoid **250** to apply power to the entire speed synchronization system. It may be desirable, for example, if a failure occurs in the speed synchronization system to deenergize the system by opening the switch **248** and deenergizing solenoid **250**. In this case, the feedback springs in the flow-dividing valves tend to position the flappers and spools in their central position so that the ports through the valves are opened and the winches operate at approximately the same speed provided the cargo load has a center of gravity located substantially equidistant from the contact points of all of the winches.

A simplified embodiment of the electrical controls is seen in FIG. 7. In this embodiment the comparators **210**, **212** and **218**, and the averaging networks **214** and **216** have been eliminated. The resistive elements of the potentiometers are excited across their entire length from switch **204**. In place of the comparators, the signals from the cable length potentiometers are fed directly to the coils of the torque motors in the flow dividers. Essentially, the signals comparison is made by the torque motor coils themselves. In order to eliminate the averaging networks and still acquire a representative paid-out cable length signal, potentiometer **260** has been added to one of the forward cable winches and potentiometer **262** has been added to one of the rear cable winches. These potentiometers are used to generate representative cable length signals for driving the primary flow dividing valve **100**. In this case, the representative signal is equal to the cable length signal from only one of the winches. However, since speed synchronization between the forward pair or rear pair of winches is provided by the flow divider valves **102** and **104**, the cable length signal from one of the forward winches and one of the aft winches will be acceptable to synchronize the forward and aft winch speeds. It will be understood that these additional potentiometers would be connected to the winches through the clutches **180** and **184** respectively (FIG. 1) as well as the potentiometers **186** and **190**.

The beeping system includes individual switches **264**, **266**, **268** and **270** which actuate relays **272**, **274**, **276**, and **278**, respectively. The relays disconnect the potentiometers from flow dividers **102** and **104** and apply a 28 volt signal directly to the one coil of the torque motors to fully bias the flow divider toward one of the winch motors. In addition, the switches also actuate one of the double relays **280** or **282** to fully bias the main flow divider valve **100** to the corresponding fore or aft pairs of winches. At the same time the double relay is actuated, the energization of the potentiometers is removed through ganged switches **284** or **286**. In this manner, any one of the winch motors can be operated individually. It will be readily understood that they can also be operated in pairs by ganging the switches **264**, **266**, **268** and **270** or by inserting additional ganged switches in series with the above switches.

Still another embodiment of my invention is shown in FIGS. 8 and 9. In the simplified hydraulic schematic of FIG. 8, two flow dividers **300** and **302** are employed to control the flow rates between the four winch motors **58**, **70**, **72** and **74** previously described with respect to FIG. 4. In this embodiment the flow divider **300** acts as a flow proportioner for the diagonally paired winch motors **58** and **74** while the flow divider **302** acts as a proportioner for the diagonally paired motors **70** and **72**. With the hydraulic power controlled to diagonally paired winches, the flow dividers operate independently but will move the load, within limitations defined below, at a synchronous speed. In order to simplify the hydraulic cut off for beeping the individual winches, three-way valves **304**, **306**, **308** and **310** are interposed between the respective winch motors and the flow dividing valves **300** and **302**. These three-way valves have a passageway connecting the hydraulic motor with its respective flow dividing valve and a passageway which connects the motor to the hydraulic pump **78** through a bypass line **312** exclusive of the flow dividing valves. Each of the three-way valves can be actuated between two positions to correspondingly open and close the respective passages. When any one of the winches is to be operated by itself, the corresponding three-way valve will be actuated to its bypass position to connect the motor with bypass line **312** and the shutoff valve **98** will be closed to prevent any of the other winch motors from operating.

The control schematic for the diagonally paired winches is shown in FIG. 9 in simplified form. It will be understood that the same clutches incorporated with the potentiometers in FIG. 6 would be actuated during the beeping operation described above. It will be readily noticed that no representative paid-out cable length signal is required with only two flow dividing valves connected as shown because each of the valves **300** and **302** operate independent groups of winches. Because of this independence, limitations must be imposed on the location of the load center of gravity (C.G.) within the parallelogram defined by the cables **314**, **316**, **318** and **320** depicted in FIG. 10. The locus of points within which the C.G. of the load can lie is the shaded area between the lines connecting the mid-points of the sides of the parallelogram. This limitation is imposed by the facts that the power expended by each of the independent diagonal pairs must be equal and the speeds of the winches are controlled to be equal. This requires that each of the pairs of winches carries half of the load. This C.G. limitation in the helicopter installation is not unduly restrictive because the limitations of the aircraft itself generally define a C.G. location well within the boundaries established by the winch system.

Although the present hoist synchronization systems are shown in a cargo system for the helicopter, those skilled in the art will recognize that they may be advantageously employed in other multiple-winch hoisting systems where the winches have independent driving means.

It should be understood that the invention is not limited to the particular embodiments shown and described herein, but that various changes and modifications may be made without departing from the spirit or scope of this novel concept as defined by the following claims.

I claim:

1. Apparatus for moving a cargo from one position to another comprising:

(a) a plurality of remotely positioned winches having cables adapted to connect to different points on the cargo;

(b) controllable motor means connected to the winches for individually driving each of the winches;

(c) sensing means for determining the difference in the paid-out cable lengths of the winches; and

(d) control means connected to the controllable motor means for equalizing the speed of the cables in response to the sensing means.

2. Apparatus according to claim **1** wherein:

(a) the controllable motor means includes a hydraulic motor for each winch; and

(b) the control means connected to the controllable motor means includes a plurality of hydraulic flow-dividing valves which distribute hydraulic flow to the motors to equalize the speed of the cables.

3. Apparatus according to claim **2** which includes:

(a) at least two pairs of winches;

(b) a first stage flow-dividing valve in the control means for separating hydraulic flow into a portion for the one pair and a portion for the other pair in response to the difference in representative paid-out cable lengths of each pair; and

(c) a second stage flow-dividing valve in the control means interposed between the first stage flow-dividing valve and the one pair of winches for receiving and distributing the portion of flow for the one pair in response to the difference in the paid-out cable lengths of the one pair.

4. Apparatus for raising and lowering a load at a fixed attitude comprising:

(a) two pairs of winches, each winch having a cable for raising or lowering the load;

(b) cable length sensing means operatively associated with the cables for producing signals varying as a function of the pair-out cable lengths;

(c) first control means for synchronizing the speed of the one pair of winches in response to the sensing means and cables of the one pair of winches;

(d) second control means for synchronizing the speed of the other pair of winches in response to the sensing means and cables of the other pair of winches; and

(e) third control means for receiving signals from the sensing means and synchronizing the speeds of the winches in the one pair with the speeds of the winches in the other pair.

5. Apparatus according to claim 4 and including:
(a) disengageable couplings between the sensing means and the cables of the one pair of winches; and
(b) means for disengaging the couplings without unbalancing the first, second, and third control means whereby the load can be moved by the one pair of winches without disturbing the speed synchronization established by the sensing means and the first, second, and third control means.

6. A speed synchronization control for two pairs of independently and hydraulically driven winches with cables, comprising:
(a) signal generating means connected with the cables for producing a first set of signals proportional to the paid-out cable length of each winch and a second set of signals proportional to a representative paid-out cable length from each of the respective pairs of winches;
(b) a first hydraulic flow distribution valve having a fluid communication with each of the pairs of winches and controllable to vary the hydraulic flow through each pair, the valve being connected to the signal generating means and responsive to the second set of signals;
(c) a second hydraulic flow distribution value interposed in the fluid communication between the first valve and one pair of winches and controllable to vary the hydraulic flow through the winches of the one pair, the valve being connected to the signal generating means and responsive to the signals of the first set corresponding to the one pair of winches.

7. The speed synchronization control of claim 6 wherein the signal generating means produces signals in the second set proportional to the average paid-out cable length from each of the respective pairs.

8. The speed synchronization control of claim 6 wherein the signal generating means produces signals in the second set proportional to the paid-out cable length of one winch from each of the respective pairs.

9. A four-point hoisting mechanism comprising:
(a) two pairs of power-driven hoists mounted on a cargo support and adapted to be connected to a cargo load for raising and lowering the load;
(b) first means for producing signals proportional to the distances between the connected cargo load and each hoist of one pair;
(c) second means connected to the first means for proportioning power between the one pair of hoists in response to the difference in the signals from the first means;
(d) third means for producing signals proportional to the distances between the connected cargo load and each hoists of the other pair; and
(e) fourth means connected to the third means for proportioning power between the other pair of hoists in response to the difference in the signals from the third means.

10. The hoisting mechanism of claim 9 wherein: fifth means are operatively connected to the first, second, third and fourth means for proportioning the power between the second and fourth means in response to the first and third means.

11. The hoisting mechanism of claim 10 in which:
(a) the hoists are hydraulically driven; and
(b) the second, fourth and fifth means include valves which proportion hydraulic fluid flow between the hydraulically driven hoists.

12. A four-point hoist mechanism for a cargo carrier comprising:
(a) two pairs of hydraulically driven winches on the cargo carrier, each winch having a cable adapted to be connected to a load for raising and lowering the load from the carrier;
(b) a sensor operatively associated with the cable of each winch for producing a signal varying as a function of the paid-out cable length;
(c) first averaging means for receiving the signals produced by the sensors associated with one pair of winches and generating a signal representative of the average paid-out cable length of the one pair of winches;
(d) second averaging means for receiving the signals produced by the sensors associated with the other pair of winches and generating a signal representative of the average paid-out cable length of the other pair of winches;
(e) a hydraulic power source; and
(f) a first adjustable hydraulic flow-dividing valve connected between the hydraulic power source and each of the pairs of winches for proportioning the hydraulic power between the pairs of winches in response to the signals from the first and second averaging means.

13. Apparatus according to claim 12 wherein:
(a) a second controllable hydraulic flow-dividing valve is interposed between the first hydraulic flow-dividing valve and the one pair of winches and connected to the sensors associated with the cables of the one pair of winches, the valve dividing the hydraulic flow between the one pair of winches in response to the signals from the sensors.

14. Apparatus for synchronizing the speeds of two pairs of winch cables, each cable being independently operated by a hydraulically driven winch for lifting a load comprising:
(a) sensors operatively associated with each winch cable, each sensor developing a signal as a function of the paid-out cable length;
(b) first means responsive to the sensors associated with the one pair of winch cables for producing a first control signal as a function of the difference in the paid-out cable lengths of the one pair of cables;
(c) second means responsive to the sensors associated with the other pair of winch cables for producing a second control signal as a function of the difference of the pair-out cable lengths of the other pair of cables;
(d) a hydraulic power source for driving the winches;
(e) a first controllable hydraulic power distribution valve having a fluid communication with the hydraulic power source and connected to the winches operating the one pair of cables for distributing hydraulic power from the source between winches for the one pair, the valve also being connected to the first means and responsive to the first control signal, whereby the power distribution is controlled by the difference in the cable lengths of the one pair;
(f) a second controllable hydraulic power distribution valve having a fluid communication with the hydraulic power source and connected to the winches operating the other pair of cables for distributing hydraulic power from the source between winches for the other pair, the valve also being connected to the second means and responsive to the second control signal, whereby the power distribution is controlled by the difference in the cable lengths of the other pair.

15. Apparatus according to claim 14 wherein:
(a) the four winches are positioned at the corners of a parallelogram; and
(b) the winches for the respective pairs of cables lie on the diagonals.

16. Apparatus according to claim 14 further including:
(a) third means responsive to the sensors associated with each pair of winch cables for producing a third control signal as a function of the difference in representative paid-out cable lengths of each pair;
(b) a third controllable hydraulic power dsitribution

valve interposed between the hydraulic power source and the first and second hydraulic valves for distributing hydraulic power between the first and second valves, the third valve also being connected to the third means and responsive to the third control signal whereby the power distribution is controlled by the difference in the representative cable lengths.

17. Apparatus according to claim **14** wherein:

(a) each sensor is a transducer having a movable element associated with a cable for varying the sensor signal;

(b) disengageable clutches are interposed between the movable elements and the respective cables; and

(c) means are provided for individually disengaging clutches whereby the speed synchronization signals established by the disengaged sensors are unaffected by movement of the respective cables.

18. Apparatus according to claim **17** wherein means are provided for disengaging pairs of the clutches interposed between the cables and sensors.

19. Apparatus according to claim **14** wherein:

(a) each hydraulically driven winch includes a reversible hydraulic motor to operate the winch; and

(b) the hydraulic source includes a reversible flow pump for changing the direction of operation of each motor and the driven winch.

20. Apparatus according to claim **19** wherein:

(a) each sensor is an electromechanical transducer developing an output signal from an excitation voltage in response to the paid-out cable length;

(b) the first means and the second means each employ a signal comparator producing a phase-sensitive difference signal from the output signals of the sensors;

(c) the first and second controllable hydraulic power distribution valves bias the hydraulic power between the winches as a function of the phase of the difference signal from the comparators; and

(d) means are provided for reversing the excitation voltage on the transducers to permit the phase of the difference signal and the hydraulic power bias to the winches to be reversed when the direction of operation of the motors is reversed.

21. In a helicopter, a four-point hoist mechanism comprising:

(a) a first pair of winches mounted at a forward position of the helicopter, each winch being independently driven and having a cable for raising and lowering a load;

(b) a second pair of winches mounted at an aft position of the helicopter, each winch being independently driven and having a cable for raising and lowering the load;

(c) sensors operatively associated with the winches for producing signals varying as a function of the paid-out cable lengths of the winches;

(d) first speed control means connected to the sensors for synchronizing the speeds of the winches within each pair in response to the signals from the sensors within the respective pairs; and

(e) second speed control means connected to the sensors for synchronizing the speed of the first pair of winches with the speed of the second pair of winches in response to sensor signals from both the forward and aft pairs of winches whereby the load can be raised and lowered from the helicopter at the synchronized speed of the winches.

22. Apparatus according to claim **21** wherein:

(a) fixed displacement hydraulic motors are respectively connected to each of the winches for independently driving each winch;

(b) the second speed control means includes a first hydraulic flow-dividing valve which proportions hydraulic flow between the first pair and the second pair of winches; and

(c) the first speed control means includes:

(1) a second hydraulic flow-dividing valve interposed between the first hydraulic flow-dividing valve and the first pair of winches for dividing the proportioned hydraulic flow of the first valve between the hydraulic motors of the first pair of winches; and

(2) a third hydraulic flow-dividing valve interposed between the first hydraulic flow-dividing valve and the second pair of winches for dividing the proportioned hydraulic flow of the first valve between the hydraulic motors of the second pair of winches.

23. Apparatus according to claim **22** wherein each hydraulic flow-dividing valve has two variable and coacting hydraulic flow ports trimmed to pass balanced hydraulic power and biased by the sensors to provide balanced hydraulic flows whereby the fixed displacement hydraulic motors drive the winches at a synchronous speed in spite of the differences in power required to drive the different winches.

24. Apparatus according to claim **23** wherein:

(a) each sensor is an electrically energized transducer having an adjustable element disengageably connected to the winch to vary the sensor signal with movement of the cable; and

(b) means are provided for simultaneously deenergizing all sensors, disengaging the adjustable element of a sensor operatively associated with a selected winch, and energizing the first and second speed control means to operate the selected winch individually without unbalancing the bias adjustment previously established by the sensors.

25. Apparatus according to claim **23** wherein:

(a) each sensor is an electrically energized transducer having an adjustable element disengageably connected to the winch to vary the sensor signal with movement of the cable; and

(b) means are provided for simultaneously deenergizing all sensors, disengaging the adjustable elements of the sensors operatively associated with a selected pair of the winches, and energizing the first and second speed control means to operate the selected pair without unbalancing the bias adjustment previously established by the sensors.

26. A four-point hoist system comprising:

(a) two pairs of winches positioned at the corners of a parallelogram and diagonally opposite winches forming each of the pairs, each winch having a hydraulic motor and a cable for hoisting a load;

(b) transducers connected to each of the cables for generating signals proportioned to the length of cable paid out by the winches;

(c) a hydraulic fluid power source for driving the motors;

(d) a first hydraulic power proportioner connected in series with the source and the two motors for the one pair of winches for proportioning power from the source between the motors of the one pair, the proportioner also being connected to the transducers associated with the cables of the one pair of winches and responsive to the difference in the signals from the transducers; and

(e) a second hydraulic proportioner connected in series with the source and the two motors for the other pair of winches for proportioning power from the source between the motors of the other pair, the proportioner also being connected to the transducers associated with the cables of the other pair of winches and responsive to the difference in the signals from the transducers

27. Apparatus according to claim **26** further including three-way hydraulic valves interposed between each of the hydraulic motors and the respective proportioners each valve having a closable series passage connecting the respective proportioner and the motor and a closable bypass passage communicating the motor with the source exclusive of the proportioner.

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