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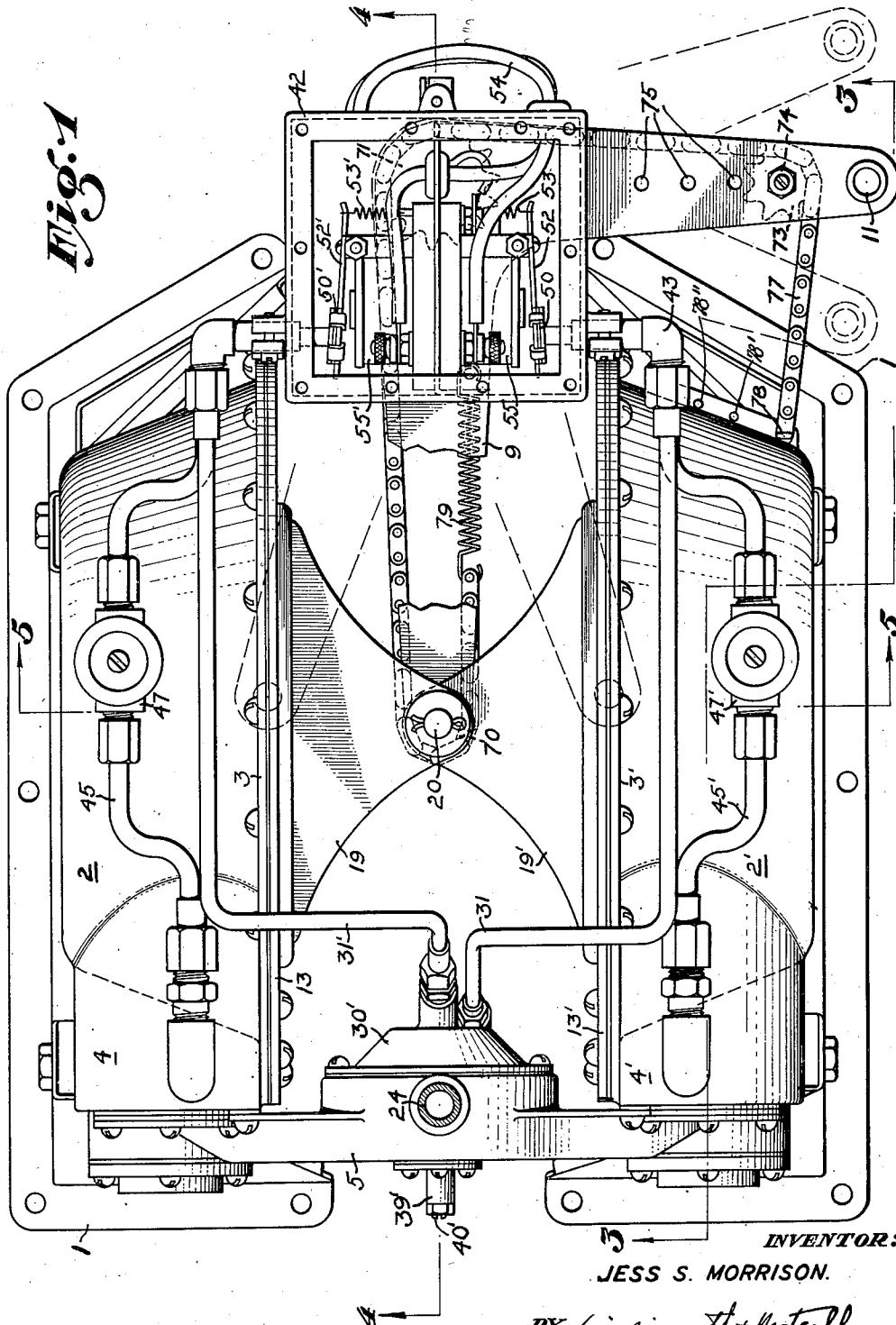
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2,347,837

SERVOMOTOR

Filed Dec. 31, 1940

6 Sheets-Sheet 1



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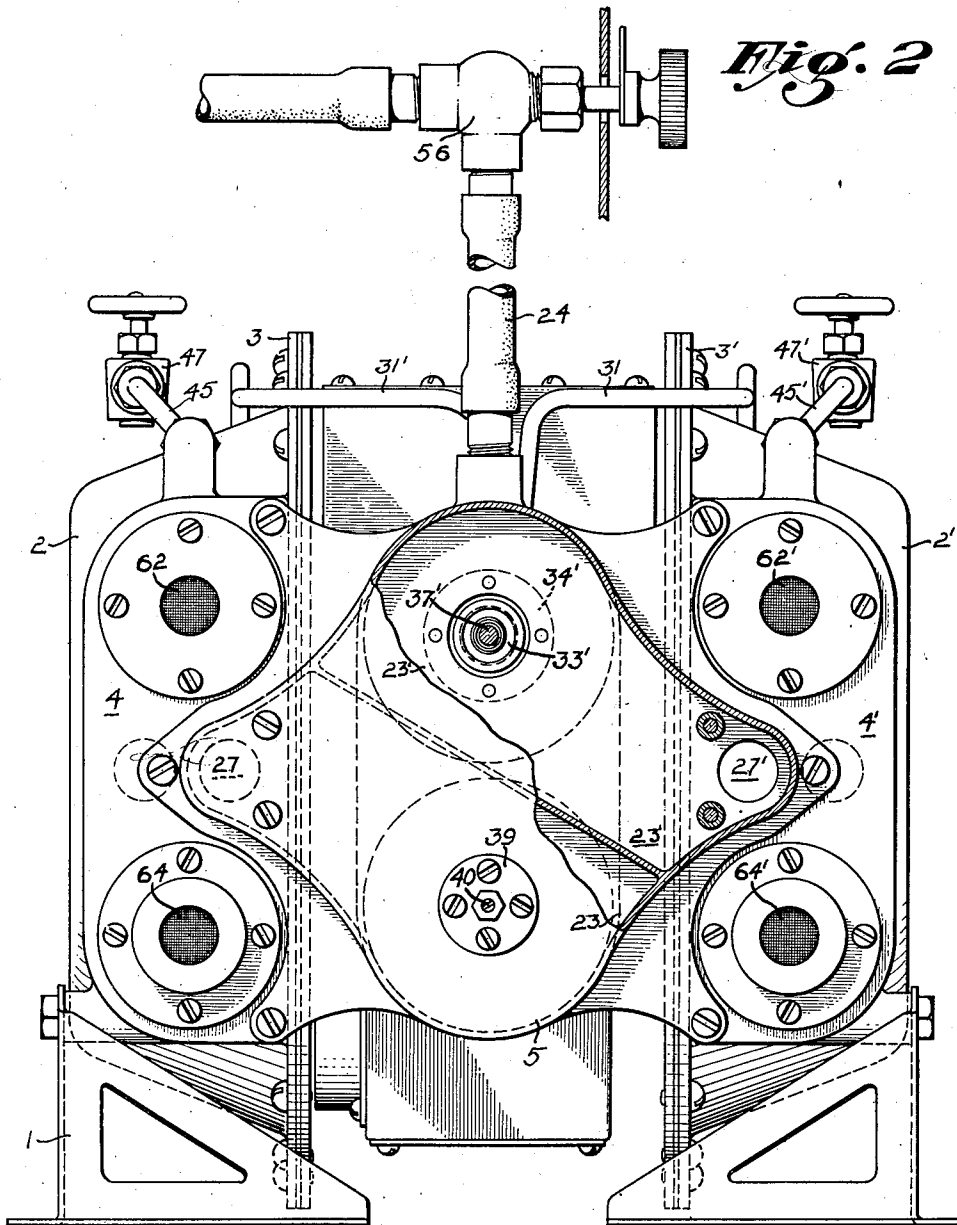
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6 Sheets-Sheet 2



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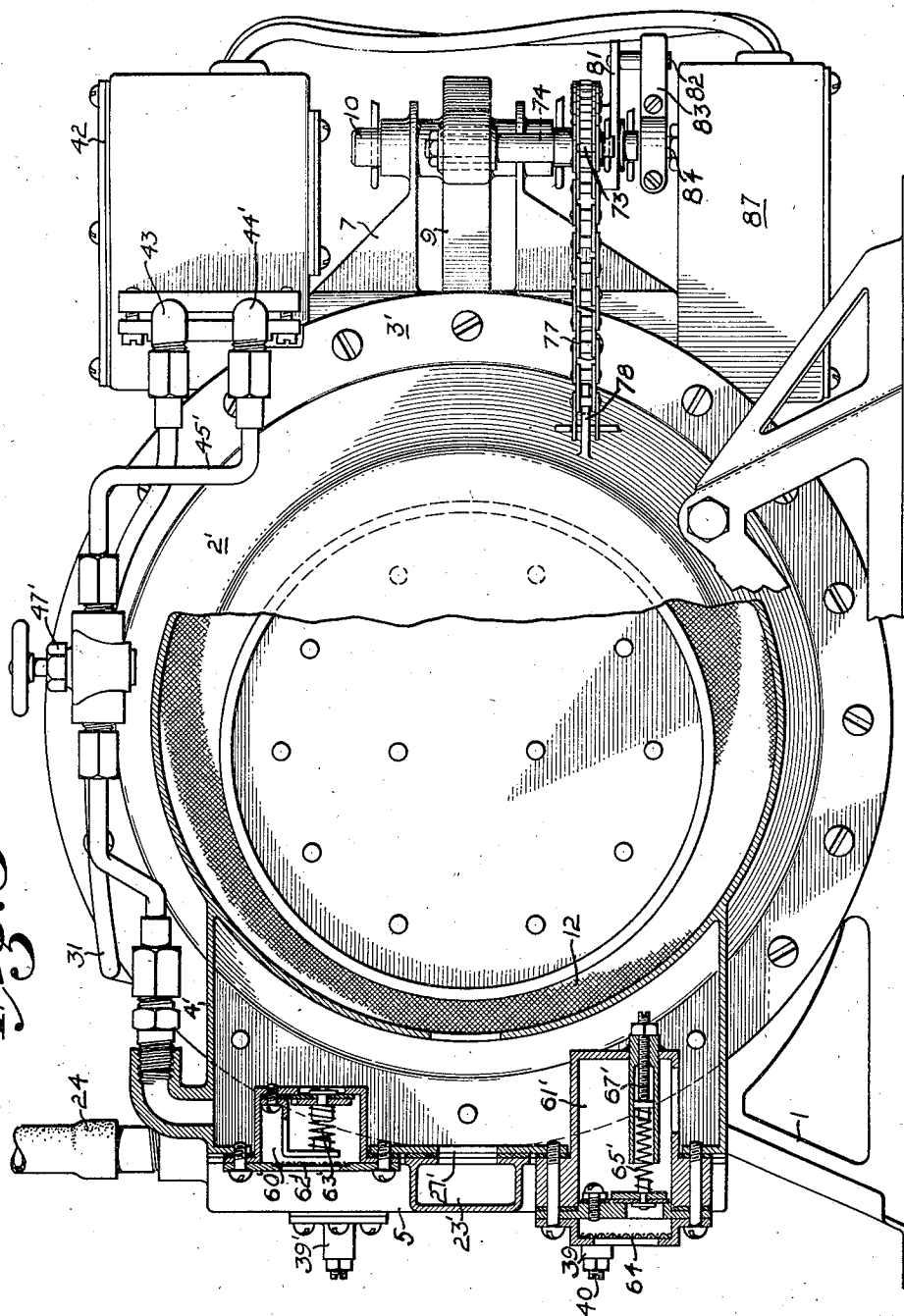
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Filed Dec. 31, 1940

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Fig. 3



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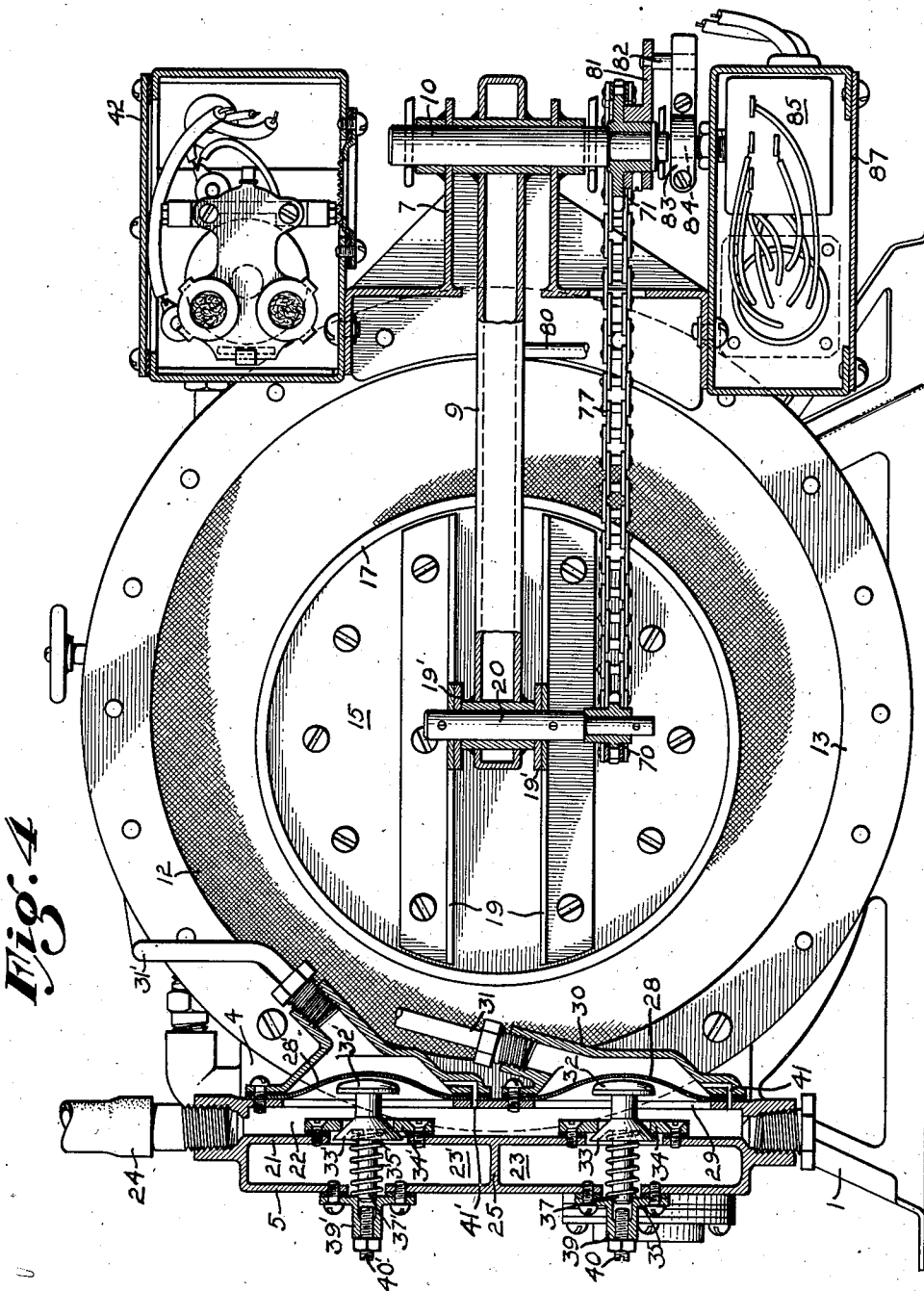
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6 Sheets-Sheet 4



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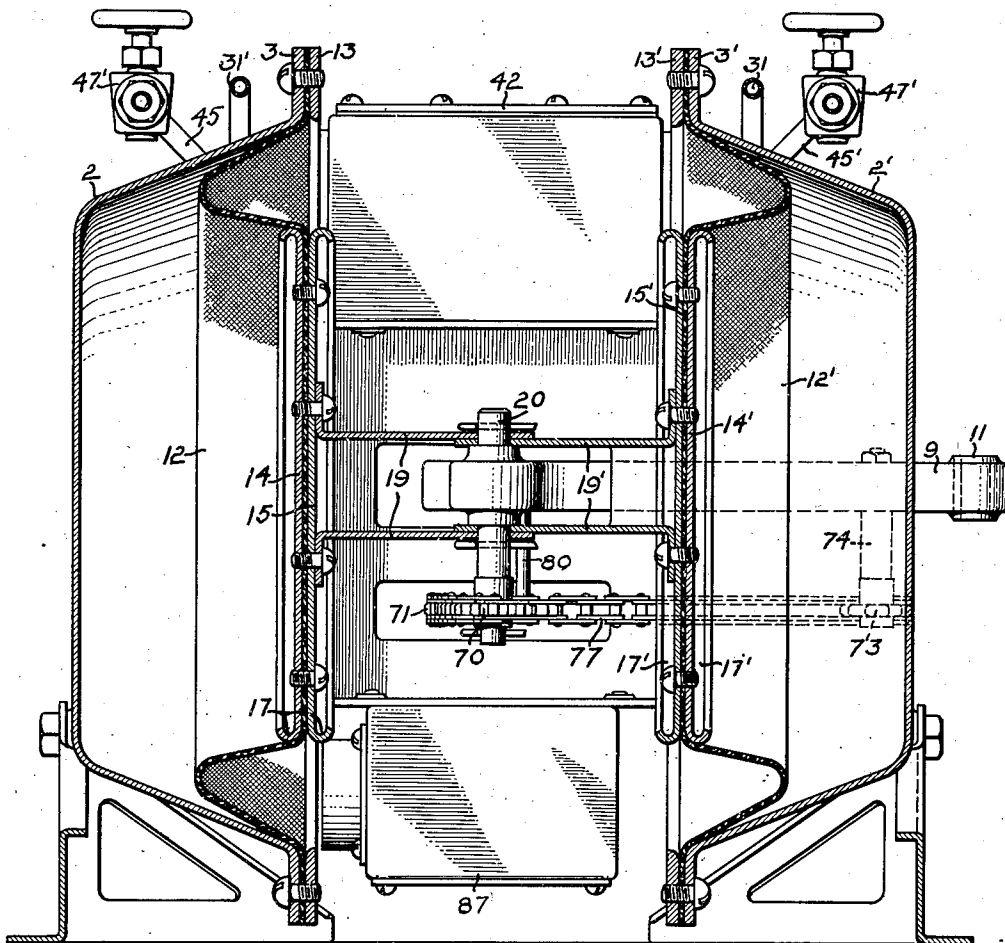
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Fig. 5



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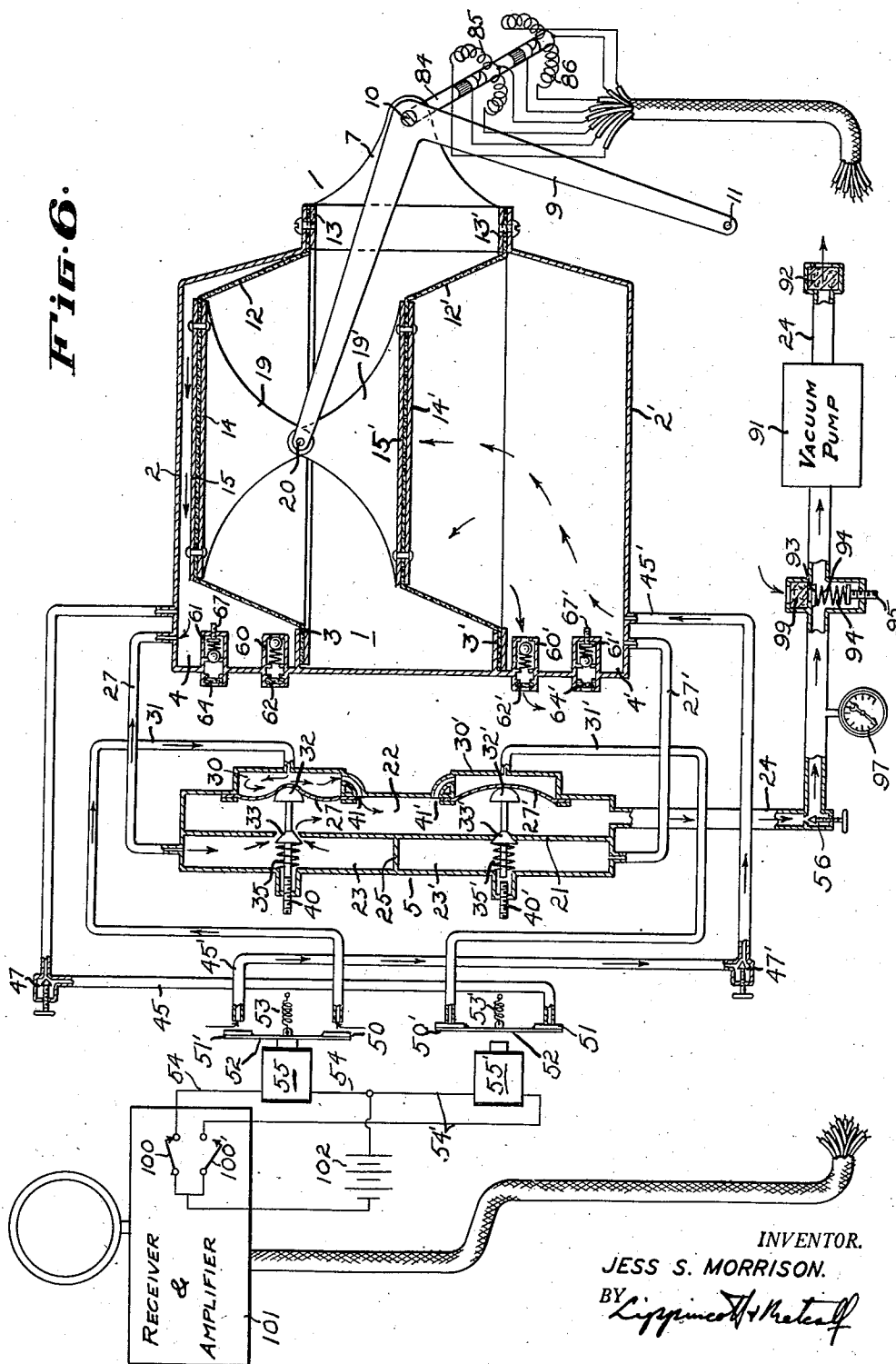
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Fig. 6.



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UNITED STATES PATENT OFFICE

2,347,837

SERVOMOTOR

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Application December 31, 1940, Serial No. 372,447

5 Claims. (Cl. 121-48)

This invention relates to servo-motors, particularly servo-motors adapted for operating the directional controls of vessels, including specifically rudder, aileron, and elevator controls for aircraft.

Among the objects of this invention are: To provide a servo-motor which is positive in action and light in weight; to provide a servo-motor which cannot be jammed by distorting stresses, all of the parts being freely floating; to provide a servo-motor which is sufficiently powerful to actuate any of the controls of an airplane but which may, in case of necessity, be overridden by the pilot upon the application of a predetermined force, and this without the use of mechanical slip-joints, latches, or the like; to provide a servo-motor whose speeds of action in opposite directions may be separately controlled and whose speed of action as a whole may be controlled without interference with the individual adjustments; to provide a servo-motor which will hold the controls of an airplane fixed in any position to which they are moved, regardless of loading conditions until deliberately displaced therefrom by a new actuation of said servo-motor; to provide a servo-motor wherein ultimate force which it is capable of applying is independent of its speed of action; to provide a servo-motor which requires a minimum amount of servicing and lubrication; to provide a servo-motor which can be constructed as a single compact unit which may be mounted or dismounted with minimum time and trouble; and to provide a servo-motor having adjustable means for operating a proportionating potentiometer.

Other objects of my invention will be apparent or will be specifically pointed out in the description forming a part of this specification, but I do not limit myself to the embodiment of the invention herein described, as various forms may be adopted within the scope of the claims.

Considered broadly, the servo-motor of my invention comprises a pair of oppositely disposed bellows each including a bellows plate. The bellows plates are provided with risers both of which are pivotally connected to an operating lever at a point which is substantially perpendicularly above the center of pressure of the plates, which latter are otherwise attached only to the flexible bellows itself. Valve means are provided for optionally connecting either of the bellows to a vacuum line and the other to atmosphere; for sealing both bellows from both atmosphere and vacuum, or for opening both bellows to atmosphere, so that the motor will under these respec-

tive conditions either move in one direction or the other, lock in any position, or release entirely to permit free manual control. There are also preferably provided separate means for regulating the airflow to the two bellows individually and from the device as a whole, so that the speed of operation in the two directions may be individually adjusted to equality or inequality as may be desired, and the overall speed may be adjusted without interfering with the individual adjustment; and there are also preferably provided check valves opening into and out of each of the two bellows, permitting the device to be moved manually to override the motor in case of necessity.

Where the device is used with a proportioning control, as described in the patent to Ralph S. Thacker, No. 2,257,203, there is also preferably provided adjustable ratio means for actuating one or more potentiometers in proportion to the degree of operation of the motor.

Referring to the drawings:

Fig. 1 is a plan view of the servo-motor of my invention.

Fig. 2 is an end elevation of the servo-motor shown in Fig. 1, the valve chest being shown partly in section.

Fig. 3 is a side elevation of the same servo-motor, a portion of the valve chest again being shown in section.

Fig. 4 is a longitudinal sectional view of the same motor, taken in the vertical plane indicated by the line 4-4 of Fig. 1.

Fig. 5 is a transverse sectional view of the motor taken on the plane indicated by the line 5-5 of the first figure.

Fig. 6 is a purely schematic diagram of the device.

A preferred form of the invention illustrated in the drawings is mounted on a formed base 1 of sheet metal. Since the device is intended for aircraft use the choice of material here is one of the high tensile strength aluminum or magnesium alloys, and throughout the specification it is to be assumed, where metal is specified, that such light weight alloys are used where applicable, although naturally this assumption does not apply to such parts as shafts, pipe fittings, or the like.

Supported on the base or frame 1 are two frusto-conical bellows housings 2, 2' which form the outer side members of the apparatus and are mounted with their axes horizontal and their bases spaced from each other by a distance which is approximately double the axial dimensions of

the housings. Each housing is provided at its base with a peripheral flange 3, 3', and projecting horizontally from one side of each is a valve box 4, 4'. These valve boxes, except where they intersect the conical surfaces of the housings, are substantially rectangular in form, and to them is mounted a main valve chest 5 which also acts as a structural member, bracing the housings and holding them parallel.

A similar structural function is performed at the other end of the device by a bracket 7, on which a bell crank 9 is journaled on a shaft or pin 10. The outer end of the bell crank is provided with an eye or bearing 11, which forms the power takeoff for the device.

An annular bellows 12, of leather, rubberized fabric, or other flexible material is secured to the flange 3 by a mounting ring 13. This bellows is so formed that when collapsed it very nearly contacts the wall of the housing and leaves very little residual space therein. The inner edge of the bellows fabric is clamped between an inner and an outer circular bellows-plate 14 and 15 respectively, each of which is provided with a rolled edge 17 to prevent cutting of the bellows fabric. A hanger or bracket 19 is mounted upon the composite plate thus formed, and in it is journaled a bearing pin 20 which passes through and is journaled in the inner end of the bell crank 9 and serves to drive the latter. The axis of this pin should intersect a perpendicular erected from the center of pressure of the bellows plate, so that when the bellows is under vacuum this plate will tend to position itself stably in a plane parallel to the plane of the flange 3.

A similar bellows arrangement is mounted on the bellows housing 2', and the corresponding parts are identified with the same reference characters as those used to distinguish the ones just described, accents being used throughout to distinguish those parts associated with the right-hand bellows as shown in Fig. 5. The hanger 19' is articulated with the hanger 19 on the pin 20, and since the device is vacuum operated and the hangers 19, 19' are always in tension, the parts thus far described, constituting the driving mechanism of the device, are always in stable equilibrium and the bellows plates 14, 14' maintain themselves parallel whatever their position, and to whatever position they may have moved the bell crank 9. It will be seen that if either of the bellows housings 2, 2' is evacuated, and air is admitted to the other, the external atmospheric pressure will collapse the bellows to which the vacuum is applied and move the bell crank arm in that direction. The pressure tends to equalize on both sides of the bellows which is open to atmosphere, but because of the movement extending the bellows the pressure will be slightly less within it and the stable position of the bellows plate will be maintained.

The connection to the vacuum or to atmosphere is accomplished through the mechanism within the valve chest 5, and can best be seen in Figs. 2 and 4, or in the schematic diagram of Fig. 6. The chest is divided by a vertical partition 21 into inner and outer chambers 22 and 23, 23' respectively. The inner chamber 22 connects to a main vacuum line 24 leading to a pump or other source of negative pressure. The two outer chambers 23, 23' are separated by a diagonal septum 25, the chamber 23 connecting directly through a port 27 into the bellows hous-

ing 2, while the chamber 23' connects through a port 27' into the bellows housing 2'. Within each chamber is a pneumatic relay valve for connecting the respective chambers into the main vacuum line chamber 22.

The two relay valves are identical in construction, and the description of one may be taken as applying to both. The one opening from chamber 22 is actuated by a flexible diaphragm 28 clamped over an aperture 29 in the outer wall of chamber 22 by means of a fitting 30, into which connects a relay pipe 31. The valve is of the tulip type, having a rounded head 32 which is formed integrally with the mushroom skirt 33. This skirt engages a separate valve seat 34 screwed to the inner partition 21, and the valve is normally held closed by a spring 35 which surrounds the stem 37 of the valve. The end of the stem enters and is centered by a guide bushing 38 mounted on the outer wall of the chamber, and the motion of the valve is limited by an adjusting set-screw 40.

If the control pipe 31 is closed, air within the housing 30 will leak through a small vent 41 which connects the interior of this housing with the main vacuum chamber 22, and the pressure on both sides of the diaphragm 28 equalizing, the spring 35 closes the valve. If, however, the pipe 31 be opened to atmosphere, the external pressure will operate the diaphragm against the force of the spring 35 and lift the skirt 33 to open a connection between the chamber 22 and the chamber 23, thereby exhausting the bellows housing 2 through the port 27, collapse the corresponding bellows, and move the bell crank lever to the left, as seen from the aspect shown in Fig. 1 or 5.

In order that any such motion may take place, however, it is necessary that the opposite bellows be open to atmosphere. This is accomplished simultaneously with the opening of the pipe 31 to operate the exhaust valve by means of an electro-pneumatic relay mechanism mounted in a housing or relay box 42 on the bell crank bracket 7. The pipe 31 is carried up and over the housing 2' and enters the side of the relay box through an L-fitting 43. Immediately below it a similar fitting 44' is mounted which connects through a pipe 45' through an adjusting needle valve 47' with the valve box 4'. The pipes 31' and 45' are similarly arranged to enter the other side of the relay box. Within the box are two symmetrically arranged and similar relays. The ends of pipes 31 and 45' are normally closed by valve flaps 50 and 51' both mounted on an armature 52 and held against the orifices of the pipes by a tension spring 53. Closing the circuit indicated by the leads 54 excites a magnet 55 and attracts the armature 52 to actuate the two valves simultaneously. The pipe 31 opens fully instantly, so that the action of the exhaust valve tending to collapse its associated bellows is very rapid. The speed of operation of the device can, however, be adjusted by means of the valve 47', controlling the speed of admission of air into the opposite bellows.

The needle valves 47, 47' are used to regulate the relative rates of action of the bellows; to regulate the overall speed of operation there is used a needle valve 56 in the main vacuum line 24, preferably mounted on the control panel 58 of the plane within easy reach of the pilot.

In order to permit a pilot to override the motor when necessary, two check valves, indicated by the general reference characters 60 and 61

respectively, are mounted in the valve box 4, and a similar pair of valves 60', 61' in the valve box 4'. Valve 60' is an outwardly opening check valve which permits the bellows housing to exhaust to atmosphere through a filter 62', the valve opening when the pressure within the bellows exceeds a value determined by a spring 63'. The valve 61' is an oppositely disposed check valve which admits air through a filter 64' when the pressure differential within and without the bellows becomes sufficient to actuate the spring 65'. It is not ordinarily necessary to provide means for adjusting the exhaust valves 60 and 60', since the pressure to actuate them may be sufficiently accurately determined by the choice of the spring, and as in normal operation no positive pressure ever exists within the bellows chambers, the springs may be very light. Because, however, the bellows ordinarily operate under vacuum it is desirable to have the inlet checks 61, 61' adjustable in order that they may not operate under differential pressures normally existing, and an adjusting screw 67' is provided in the valve 61' for this purpose and a similar screw 27 in the valve 61.

In the service for which this motor was primarily developed there is employed a potentiometer whose setting is dependent upon the position of the controls operated by the servo-motor, and it is highly desirable, in order to obtain the results wanted, that the ratio between the potentiometer setting and the movement of the controls should be made adjustable. Means are accordingly incorporated within this device to the ends mentioned.

Mounted on the lower end of the bearing pin 20 which connects the bellows plates with the bell crank is a sprocket wheel 70, journaled to rotate freely upon the pin. A somewhat larger sprocket 71 is similarly mounted in the same plane on the lower end of the main bearing pin 10. A third sprocket 73 is mounted upon a stub shaft 74 which is carried by the outer end of the bell crank 9 and may be located in any one of a number of holes 75 provided in the crank arm for the purpose.

A sprocket chain 77 engages each of these sprockets, extending from an anchor 78 on bellows housing 2' around sprockets 73, 71, and 70 in succession, to a tension spring 79 whose other end is fixed to an anchor pin 80 which extends downward from the inner end of the bell crank 9 near its bearing.

A crank arm 81 carrying a crank pin 82 is fixed to the sprocket 71 and turns with it. The crank pin is gripped by a second arm 83, mounted on a common shaft 84 for the potentiometers 85, 86 which shaft is mounted coaxially with the shaft 10 in a housing or box 87 secured to and beneath the bracket 7.

It will be seen that the distance from the anchor pin 80 around the three sprockets to the center line of the two sprockets 71 and 72 does not change with the position of the bell crank, but that the distance from this point to the anchorage 78 does change very nearly in the ratio of the change of angular position of the bell crank. This change can only be accommodated by variation in the length of the tension spring 79, all of the sprockets moving to accommodate such change in length and the sprocket 71 thereby operating the potentiometer. By changing the position of the stub shaft 74 as between the various holes provided for the purpose, with corresponding change of the anchor-

age 78 to the position 78', 78'', the ratio of movement of potentiometer to the movement of the bell crank may be changed in approximately the proportion of 2:1.

Certain features of the device are shown in the schematic diagram of Fig. 6. The vacuum source 91, designated as a pump, may be a venturi or aspirator, although I prefer a positively driven pump. A filter 92 is provided at the outlet of the pump in order to prevent the entry of dust into the system during periods of idleness. The pump preferably has capacity to supply a considerably greater vacuum than that actually employed, and a regulator comprising a flap valve 93, held closed by a spring 94 adjustable by means of a screw 95 regulates the actual pressure used, which may be read upon a vacuum gauge 97. A filter 99 is also preferably provided for use on the regulator.

When the device is in operation, the solenoids 55, 55' are operated by actuating one or the other of contacts 100, 100', closing the circuit from a suitable source 102 through the respective magnets.

The contacts may be operated by any suitable control device, preferably, however, the directional radio receiver 101 whose null axis is varied by the setting of the rudder by means of the potentiometer 85, as disclosed in the patent to Ralph S. Thacker, No. 2,257,203. It will be seen that the operation of this device is such that it will function satisfactorily in either of two ways. If the contacts 100, 100' are normally open, closure of one of them will open the corresponding pneumatic pipes and cause the motor to actuate the controls in one direction. If the contacts be then opened the electro-pneumatic valve will close, and the motors will hold the plane rudder or other control surface of the plane in the position that has then been attained, until it is released or further actuated by again closing one of the contacts 100, 100'. If, however, the contacts 100, 100' be normally closed, air will normally be admitted to both bellows and the motor will exert no force, so that the plane may be controlled manually with a minimum of effort. Under these circumstances opening either of the contacts 100, 100' will put the motor into operation, but it will release and instantly return to neutral as soon as the open contact be again closed. The arrangement therefore permits operation under two quite different systems of control. The motor may, however, at all times be overridden by the pilot if it be necessary that he do so, irrespective of whether normally open or normally closed control contacts be used.

The servo-motor here described has a number of features which render it particularly desirable in use. One of the chief of these is the fact that it is completely self-contained, has only one bearing, and because of this structure it is impossible to warp or strain it so as to cause binding. The frame is small and rigid, and can readily be so mounted as not to be subject to twisting stresses, but even if such stresses do occur the fact that the bellows float freely on the lever arm prevents any effect on the action of the motor.

Furthermore, the motor as specifically described herein weighs but 12 pounds, but will, with a 12½ inch vacuum, pull 146 pounds. Since there is only one bearing to be oiled it is not ordinarily necessary to remove it from the plane for service, except for periodical

check and overhaul after approximately 500 hours duty, but when such removal is required the light weight and accessible mounting of the device make it a simple matter.

I claim:

1. In a servo-motor having a pair of opposed bellows, mechanical means interposed between said bellows and movable thereby, and a source of vacuum, a normally closed diaphragm actuated valve associated with each bellows and operative when said diaphragm is opened to atmosphere to connect said source to said bellows, a duct connected to each of said diaphragms, a second duct connected to each bellows, and a pair of electro-pneumatic relays for energizing said servo-motor, each relay comprising an electromagnet, an armature for said magnet, a pair of valves carried by said armature, and means for normally closing said valves to block the ducts connecting respectively to one of said diaphragms and the opposed bellows from the atmosphere, whereby when neither of said relays is excited both of said bellows are completely sealed to lock said mechanical means in whatever position it may have been moved to.

2. In a servo-motor having a pair of opposed bellows, mechanical means interposed between said bellows and movable thereby, and a source of vacuum; walls defining a main chamber connected to said source, a pair of diaphragms each forming a part of the wall of said chamber, means defining separate diaphragm chambers around the outer sides of each of said diaphragms, a pair of auxiliary chambers each connected to one of said bellows, and each having valve openings connecting with said main chamber, a valve normally closing each of said openings and positioned to be operated by one of said diaphragms, a duct connected to each of said bellows, a duct connected to each of said separate chambers, each of said bellows ducts opening to the atmosphere adjacent an opening to the atmosphere of a separate chamber duct, and separate control valves movable to simultaneously seal, or selectively open each pair of adjacent duct openings to the atmosphere.

3. In a servo-motor having a pair of opposed bellows, mechanical means interposed between said bellows and movable thereby, and a source of vacuum; walls defining a main chamber connected to said source, a pair of diaphragms each forming a part of the wall of said chamber, means defining separate diaphragm chambers around the outer sides of each of said diaphragms, a pair of auxiliary chambers each connected to one of said bellows, and each having valve openings connecting with said main chamber, a valve normally closing each of said openings and positioned to be operated by one of said diaphragms, a duct connected to each of said bellows, a duct connected to each of said separate chambers, each of said bellows ducts opening to the atmosphere adjacent an opening to the atmosphere of a separate chamber duct, and

separate control valves movable to seal or open each pair of adjacent openings, means for normally holding said separate control valves closed to seal both of said bellows from the atmosphere in whatever position they may have moved to, and means for selectively moving said valves to open the adjacent valve controlled openings to the atmosphere thereby changing the position of said bellows.

4. In a servo-motor having a pair of opposed bellows, mechanical means interposed between said bellows, and movable thereby, and a source of vacuum; a normally closed diaphragm actuated valve associated with each bellows and operative when said diaphragm is opened to atmosphere to connect said source to said bellows, a duct connected to each of said diaphragms, a second duct connected to each bellows, and a pair of electro-pneumatic relays for energizing said servo-motor, each relay comprising an electromagnet, an armature for said magnet, a pair of valves carried by said armature, means for normally closing said valves to block the ducts connecting respectively to one of said diaphragms and the opposed bellows from the atmosphere, whereby when neither of said relays is excited both of said bellows are completely sealed from the atmosphere to lock said mechanical means in whatever position it may have been moved to, and means for selectively exciting said relays to open the ducts controlled by the connected valve and thereby permit said source to the atmosphere to move said mechanical means to a new position.

5. In a servo-motor having a pair of opposed bellows, mechanical means interposed between said bellows, and movable thereby, and a source of vacuum; a normally closed diaphragm actuated valve associated with each bellows and operative when said diaphragm is opened to atmosphere to connect said source to said bellows, a duct connected to each of said diaphragms, a second duct connected to each bellows, and a pair of electro-pneumatic relays for energizing said servo-motor, each relay comprising an electromagnet, an armature for said magnet, a pair of valves carried by said armature, means for normally closing said valves to block the ducts connecting respectively to one of said diaphragms and the opposed bellows from the atmosphere, whereby when neither of said relays is excited both of said bellows are completely sealed from the atmosphere to lock said mechanical means in whatever position it may have been moved to, means for applying an exterior force to override said servo-motor, and a pair of spring actuated check valves respectively opening into and out of each of said bellows for admitting atmospheric air or releasing air respectively into or from said bellows as required to permit said override upon application of a predetermined exterior force.

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