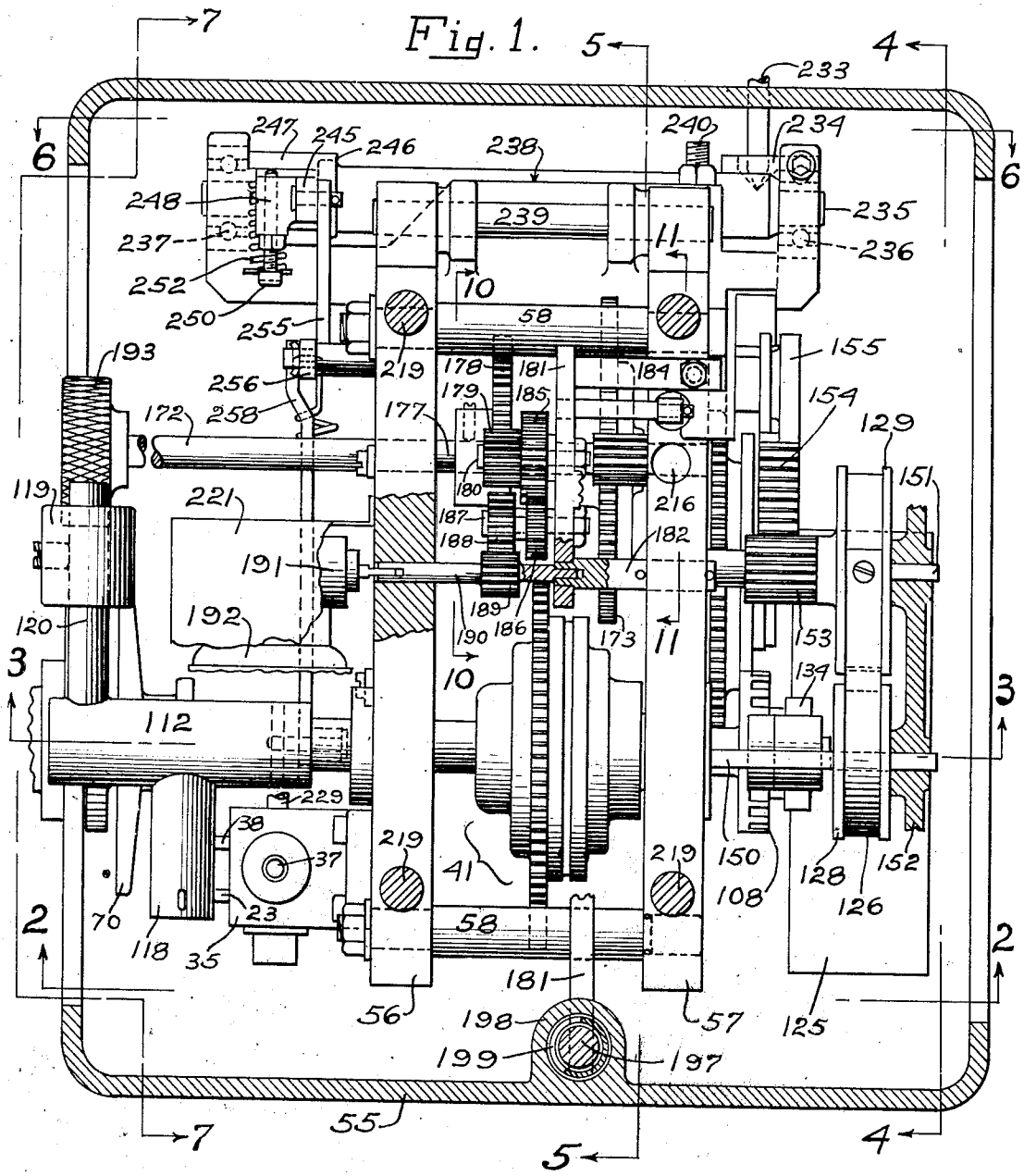
Aug. 20, 1940. W. FERRIS 2,212,140

CHRONOMETRIC MECHANISM

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Fig. 1.



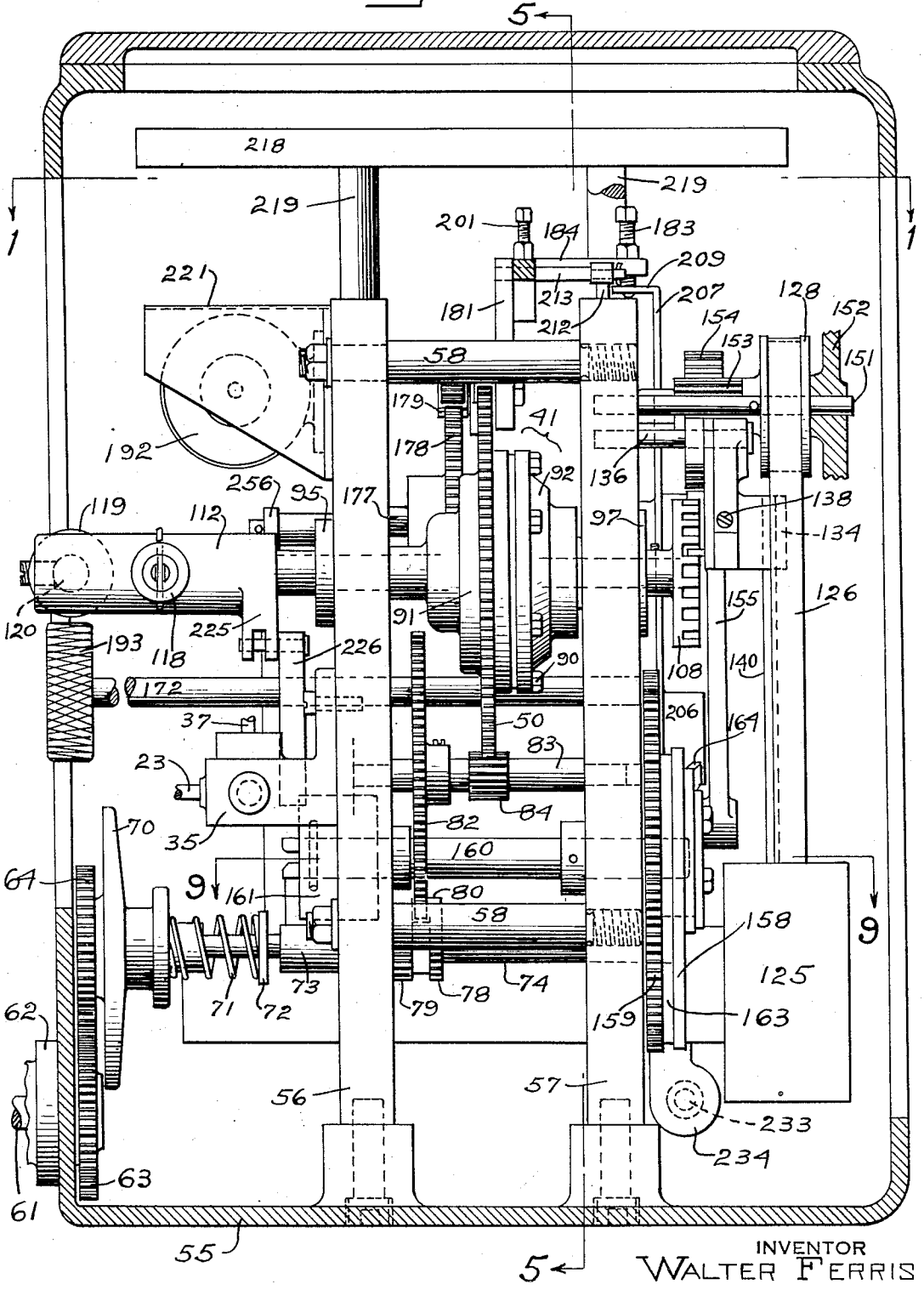
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CHRONOMETRIC MECHANISM

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Fig. 2.



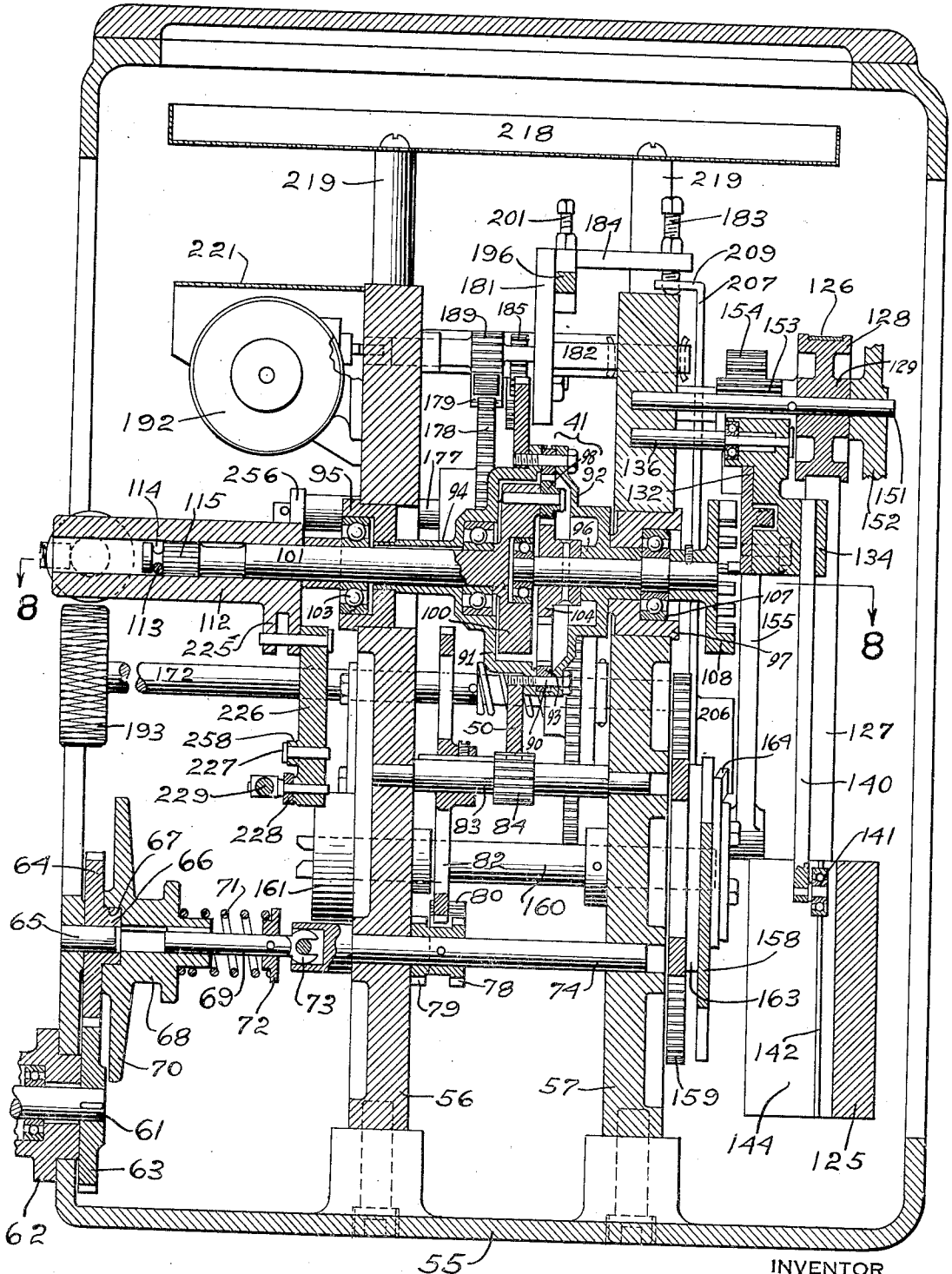
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Fig. 3.



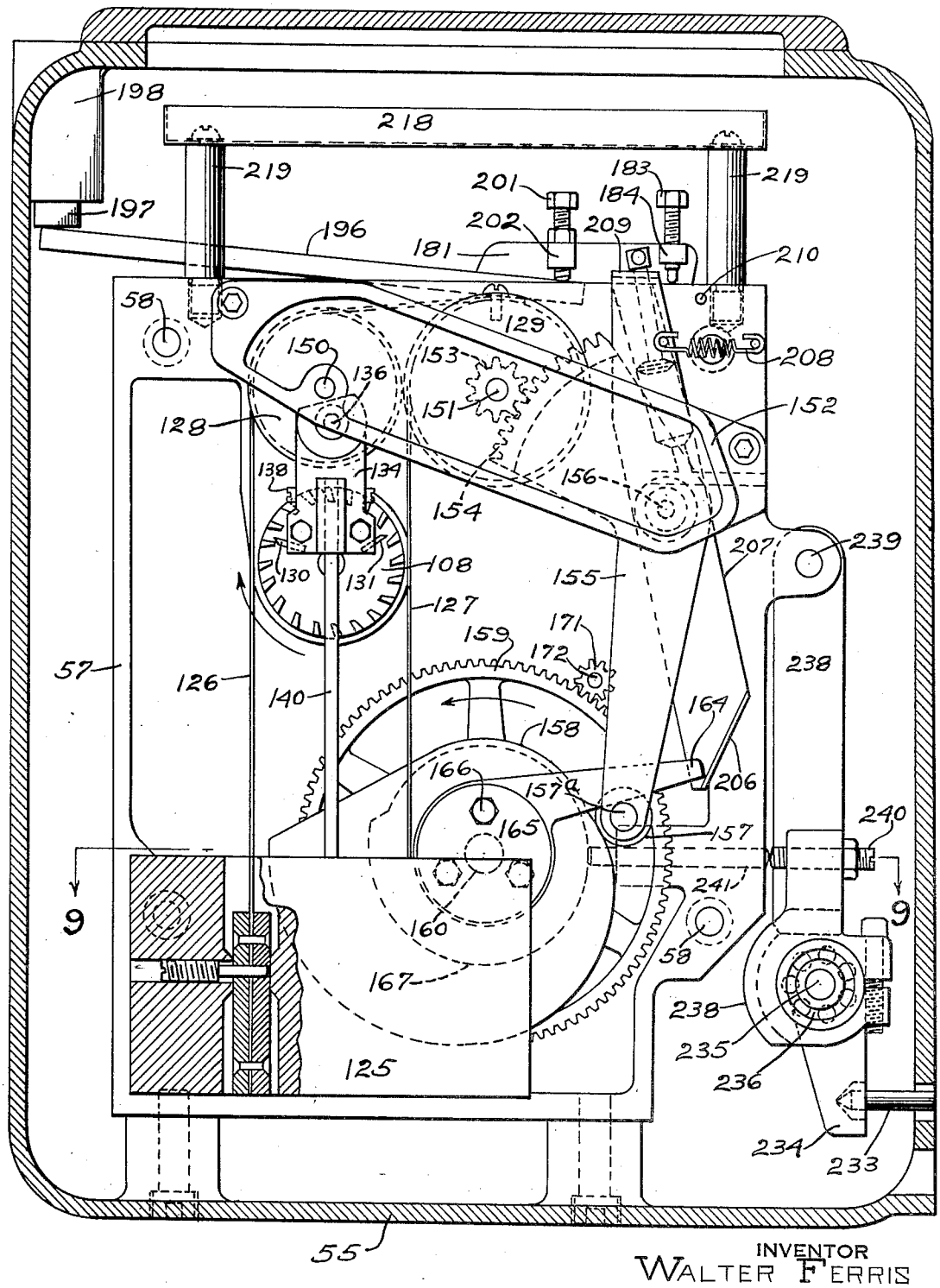
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Fig. 4.



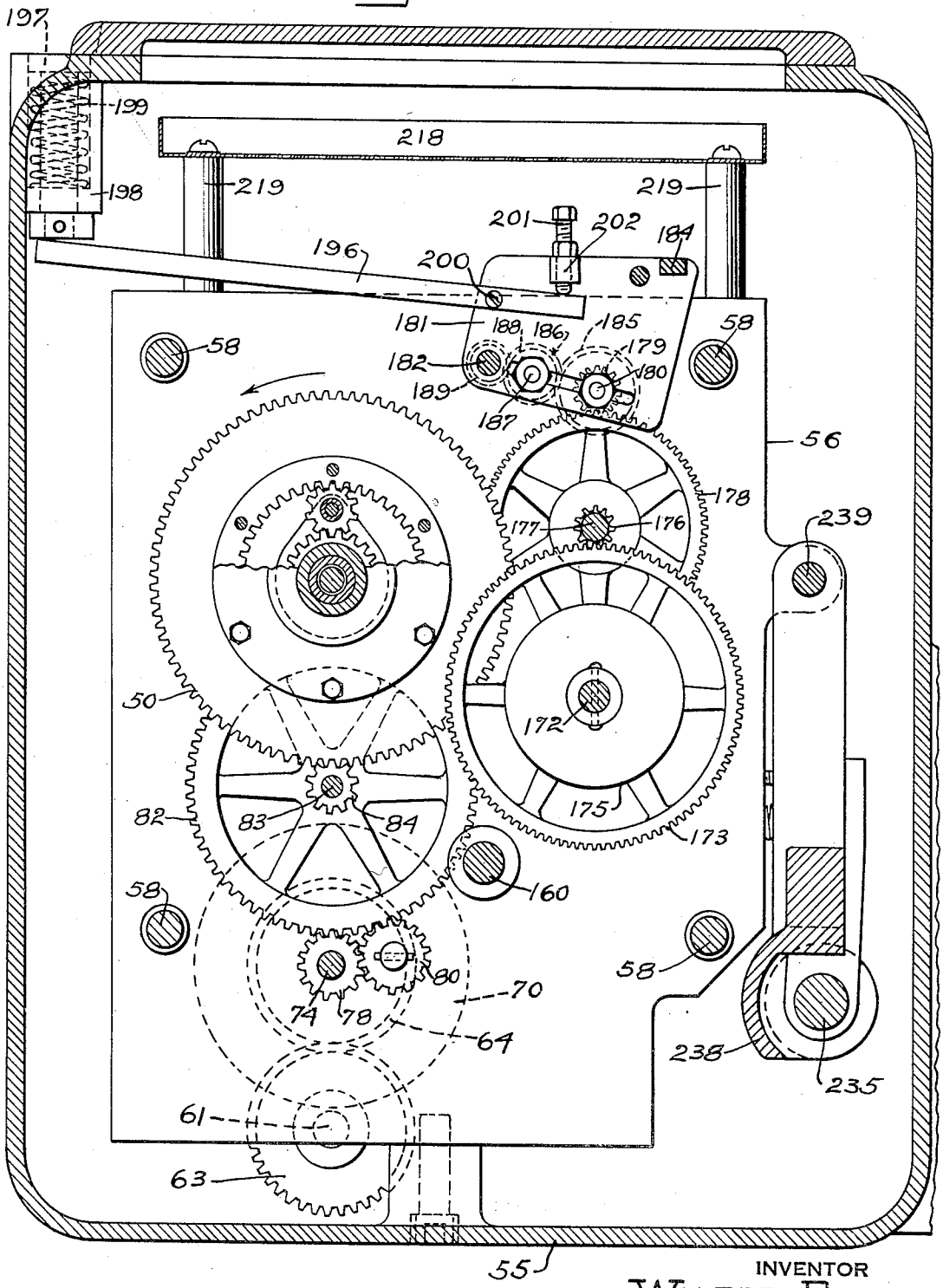
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Fig. 5.



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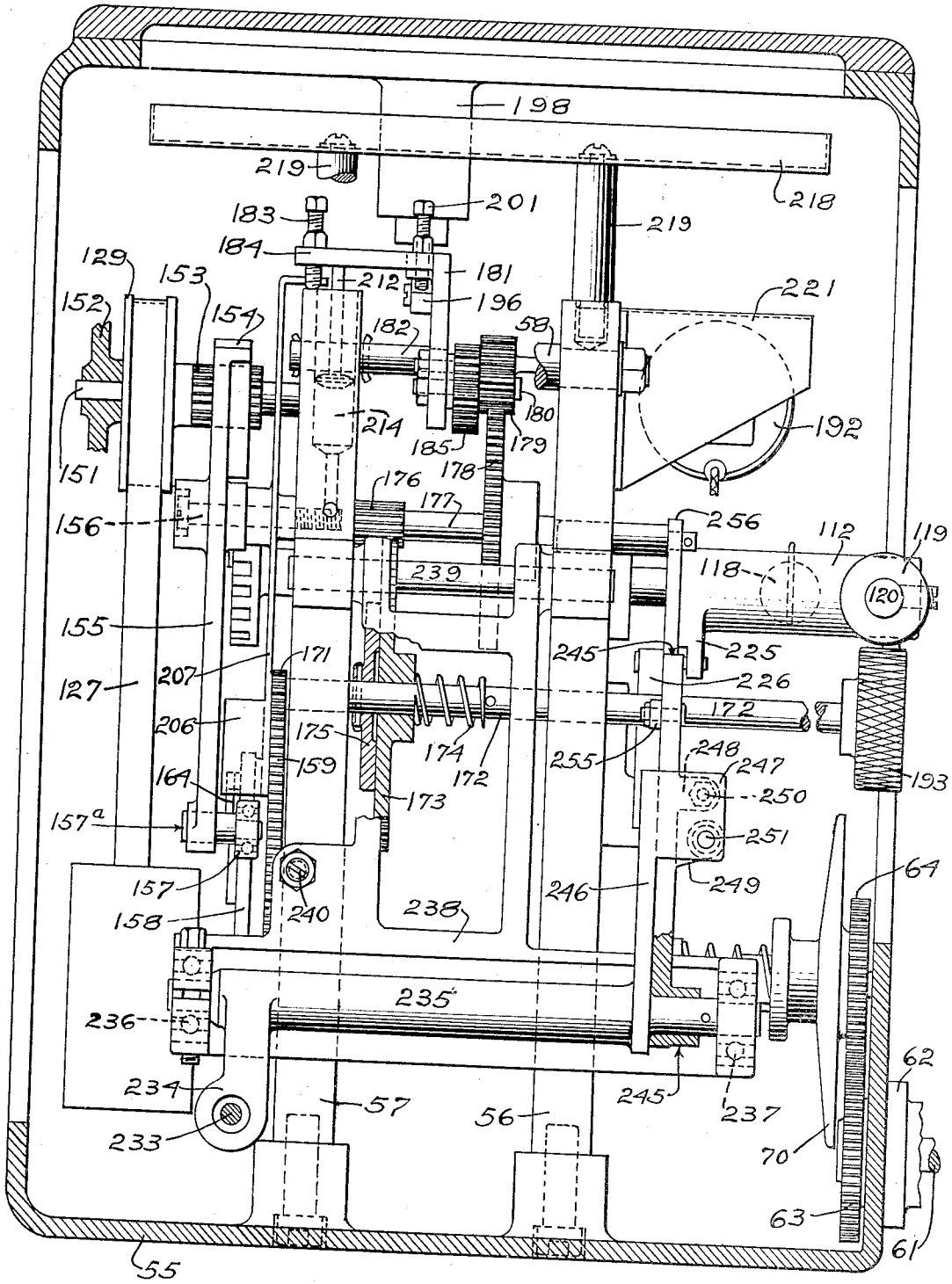
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Fig. 6.



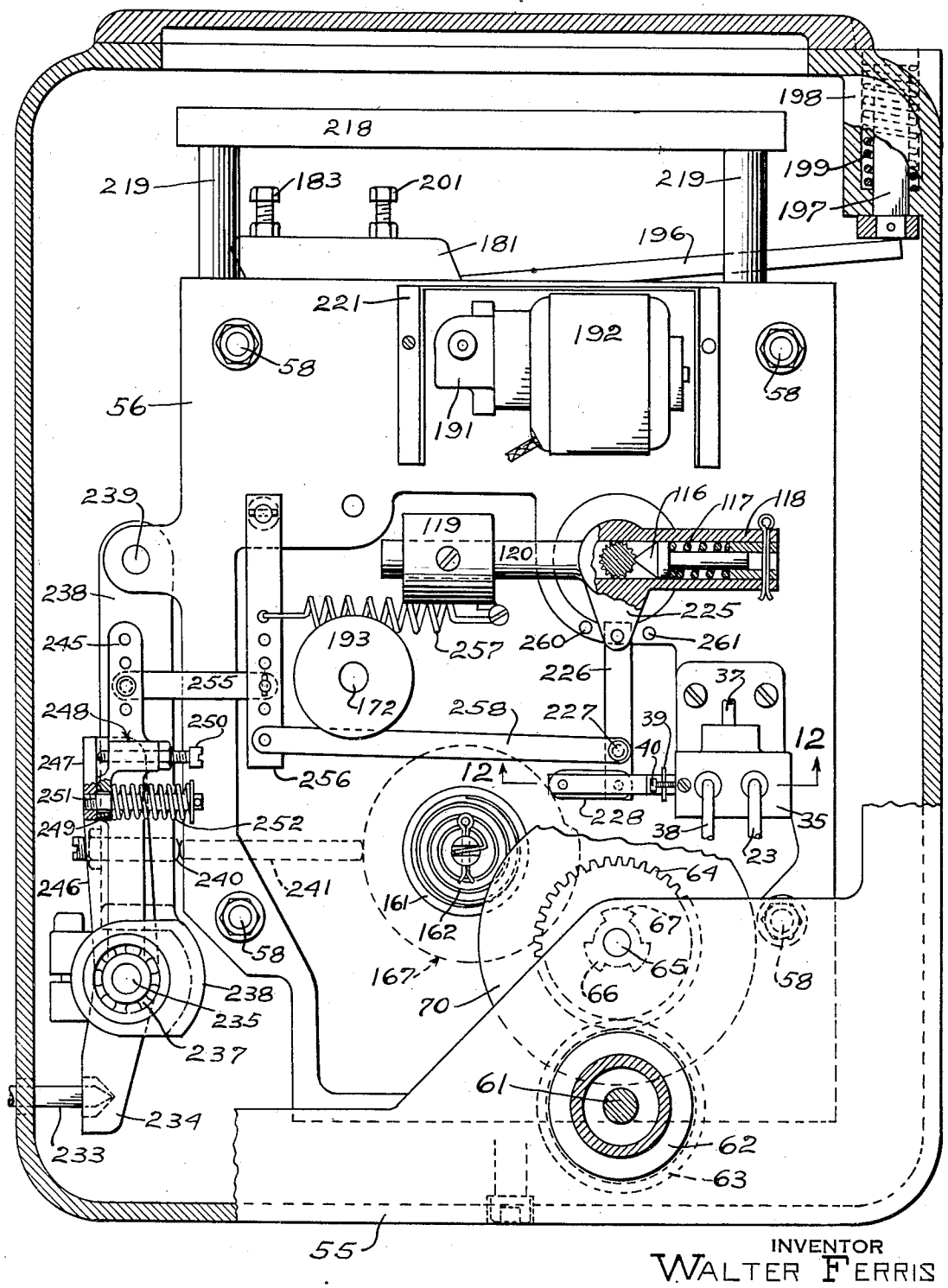
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Fig. 7.



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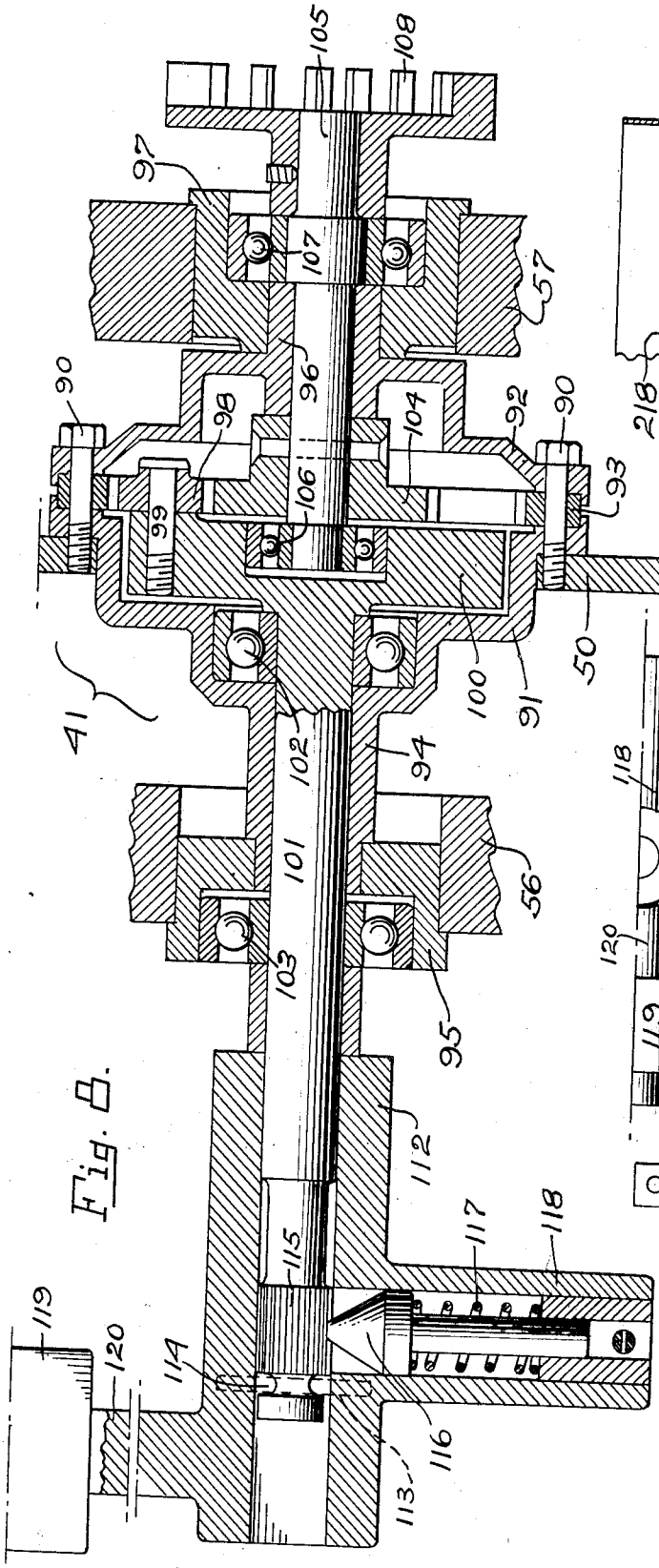


Fig. 8.

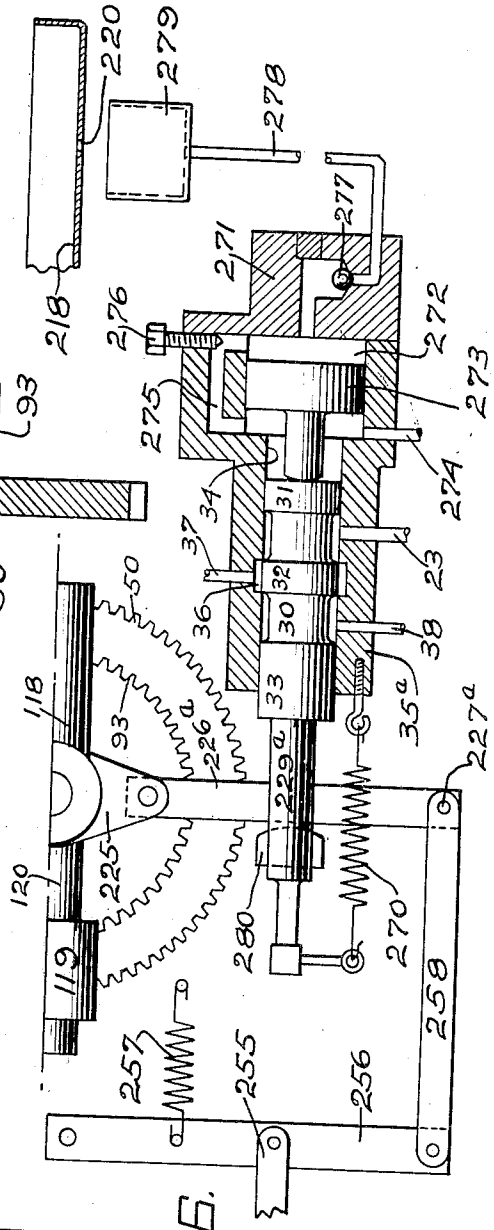


Fig. 16.

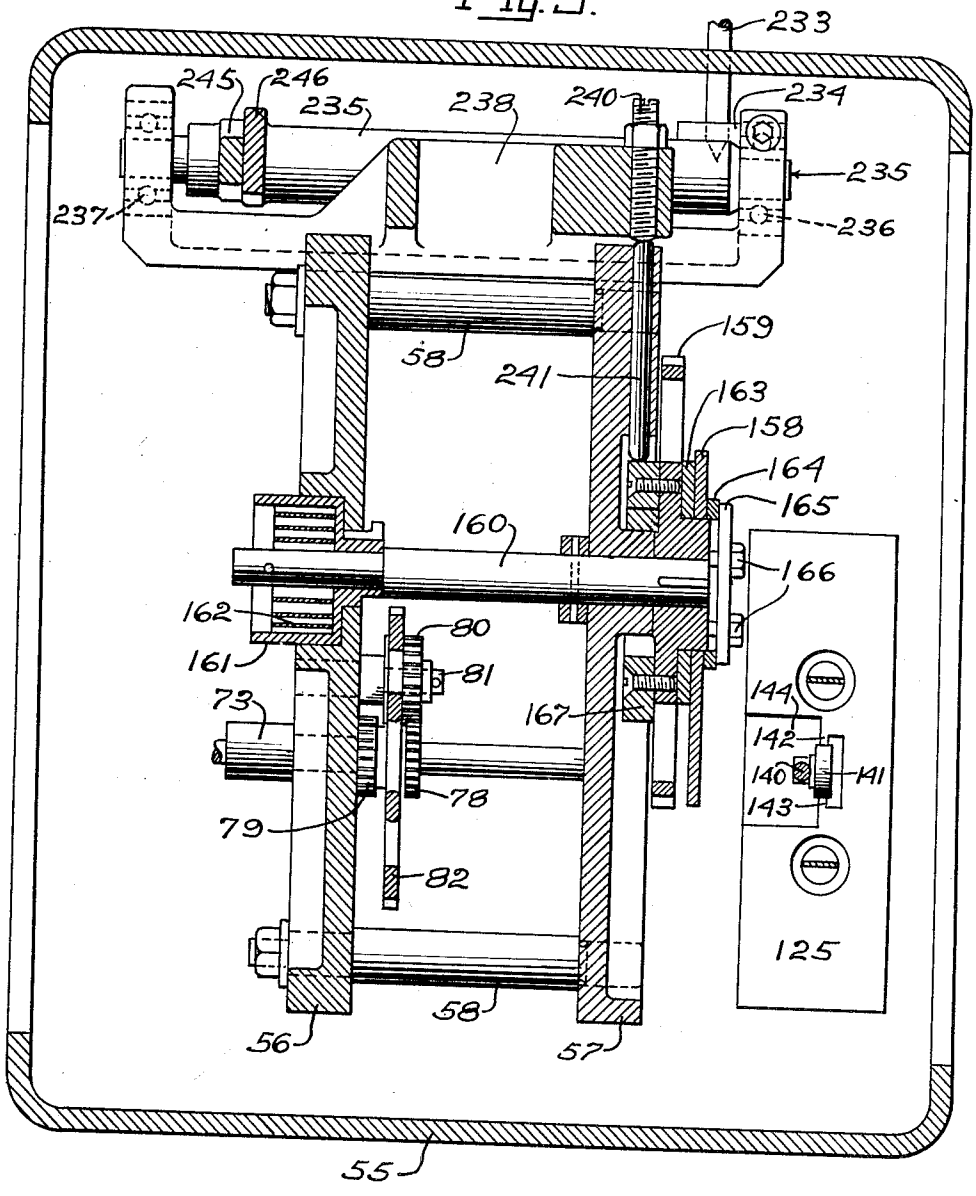
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Fig. 9.



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Fig. 10.

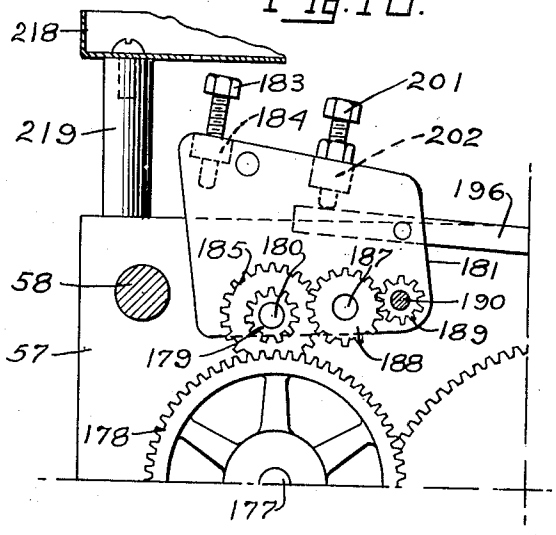


Fig. 11.

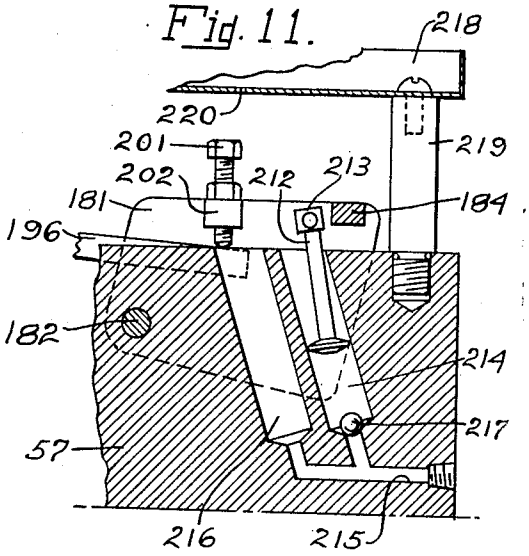


Fig. 14.

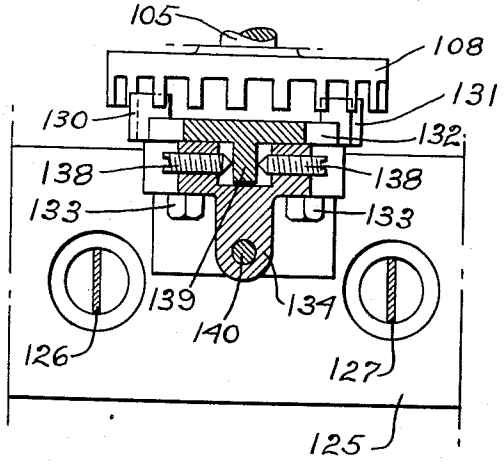


Fig. 13.

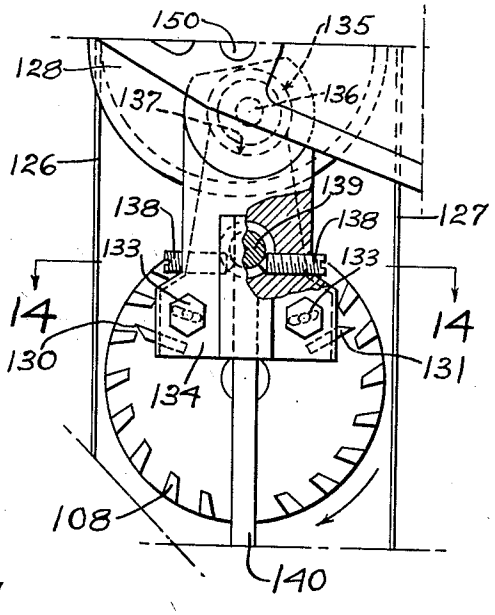
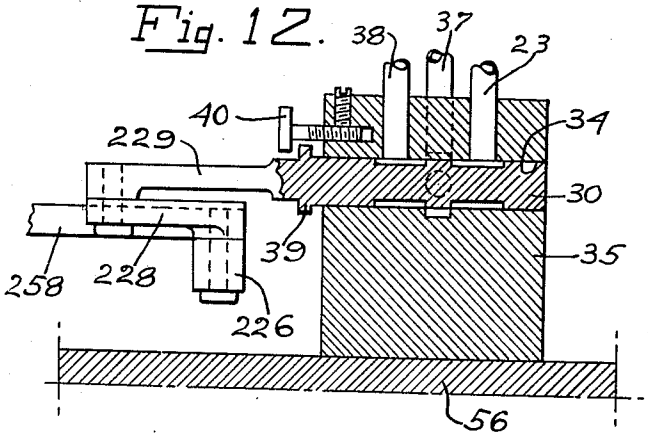


Fig. 12.



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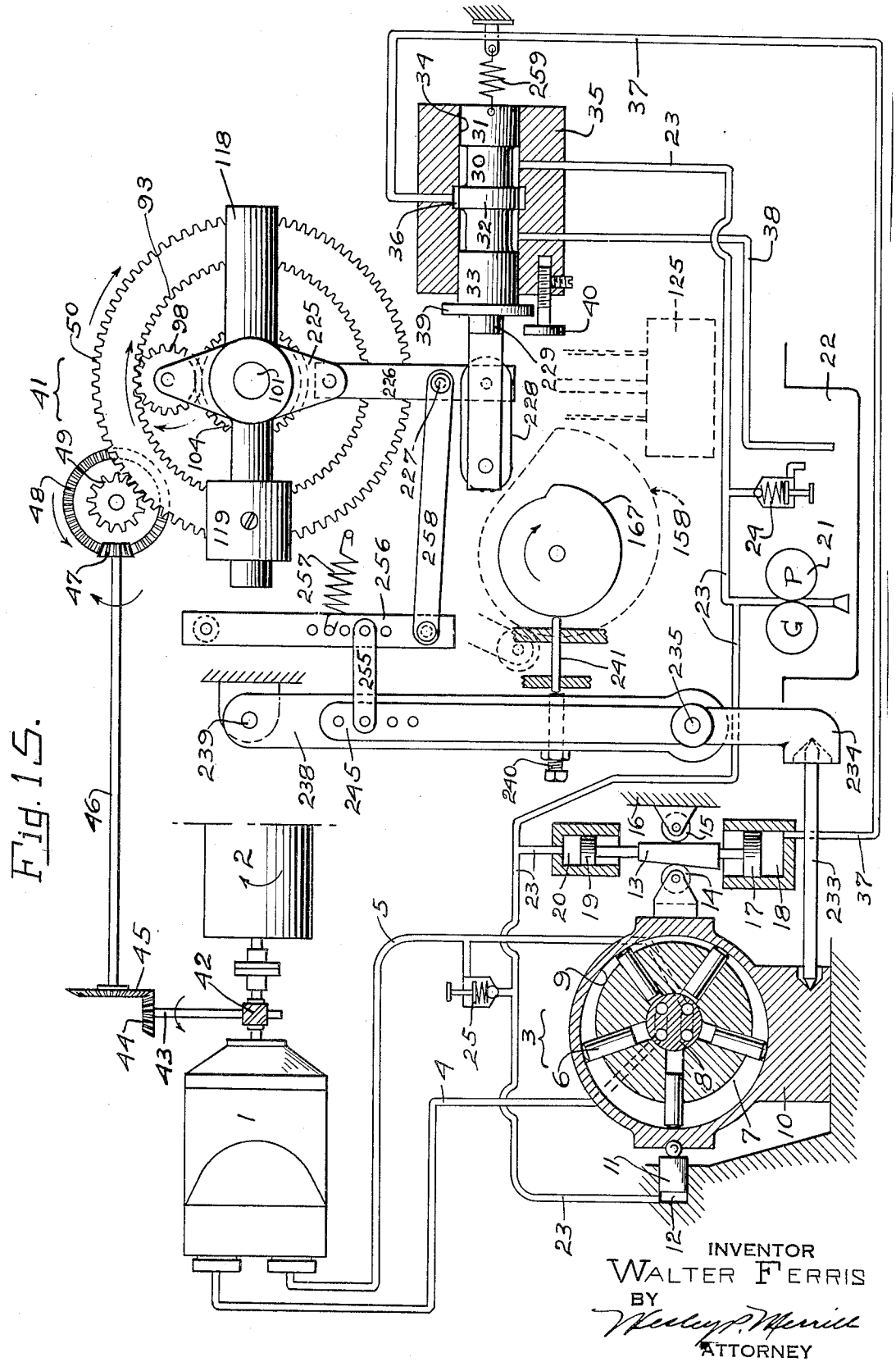


Fig. 15.

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UNITED STATES PATENT OFFICE

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CHRONOMETRIC MECHANISM

Walter Ferris, Milwaukee, Wis.

Application February 18, 1937, Serial No. 126,398

18 Claims. (Cl. 185—46)

This invention relates to apparatus for controlling the speeds of prime movers such as the apparatus disclosed in Patent No. 2,198,035 which issued on application Serial No. 47,008, filed October 28th, 1935, of which this application is a continuation in part.

The function of the apparatus disclosed in the above patent is to maintain the speed of a prime mover proportional to a standard or measuring speed, such as the speed of a chronometric mechanism, a constant speed electric motor or a moving body.

The primary object of the present invention is to provide a chronometric speed controller by means of which the speed of a prime mover may either be maintained constant or be varied according to a predetermined schedule.

More specific objects and particular advantages of the invention will appear hereinafter.

The invention is exemplified by the chronometric controller shown in the accompanying drawings in which the views are as follows:

Fig. 1 is a top plan view of the controller mechanism with certain parts shown in section or partly broken away to expose other parts, the view being taken through the upper part of the controller casing as indicated by the line 1—1 of Fig. 2.

Fig. 2 is a front view of the controller mechanism as indicated by the line 2—2 of Fig. 1.

Fig. 3 is a vertical section taken on the line 3—3 of Fig. 1.

Fig. 4 is an elevation of the right side of the controller mechanism as indicated by the line 4—4 of Fig. 1.

Fig. 5 is a vertical section taken on the line 5—5 of Figs. 1 and 2.

Fig. 6 is a rear view of the controller mechanism as indicated by the line 6—6 of Fig. 1, certain parts being broken away and other parts being shown in section.

Fig. 7 is an elevation of the left side of the controller mechanism as indicated by the irregular line 7—7 of Fig. 1.

Fig. 8 is a sectional plan view of a differential gear and associated parts, the view being taken in the plane of line 8—8 of Fig. 3.

Fig. 9 is a sectional plan view taken on the line 9—9 of Fig. 2.

Fig. 10 is a transverse section taken on the line 10—10 of Fig. 1 but showing certain gears out of mesh with each other.

Fig. 11 is a transverse section taken on the line 11—11 of Fig. 1.

Fig. 12 is a bottom sectional plan view showing the control valve on a larger scale, the view being taken on the line 12—12 of Fig. 7.

Fig. 13 is a view showing a part of the escapement mechanism on a larger scale.

Fig. 14 is a sectional plan view taken on the line 14—14 of Fig. 13.

Fig. 15 is a schematic drawing showing the controller employed to control the speed of a hydraulic motor.

Fig. 16 is a view showing another method of operating the control valve.

For the purpose of illustration, the invention has been shown in Fig. 15 as being employed to control the speed of a hydraulic motor 1 which drives variable load 2, but it is to be understood that the invention may as readily be employed to control the speed of any other type of prime mover as explained in the patent referred to above.

Motor 1 is energized by motive liquid supplied thereto by a pump 3 which is connected to motor 1 by a supply channel 4 and a return channel 5 and which has its displacement varied by the controller in response to any variation in the speed of motor 1 relative to a standard or measuring speed as will be presently explained.

Pump 3 may be of any suitable type. The pump shown schematically in Fig. 15 has not been illustrated nor described in detail as it is fully illustrated and described in Patent No. 2,074,068. It is deemed sufficient to state that it has its pistons 6 fitted in cylinders formed in a rotatable cylinder barrel 7 which is journaled upon a central valve shaft or pintle 8 through which liquid flows to and from the cylinders, that cylinder barrel 7 is rotated at a substantially constant speed by a prime mover not shown, that pistons 6 react against an annular reaction surface 9 which is carried by a slide block 10 and which is eccentric to cylinder barrel 7 when the pump is delivering liquid, and that slide block 10 is shiftable transversely of pintle 8 to vary pump displacement and consequently vary the rate at which pump 3 delivers liquid to motor 1.

As shown, slide block 10 is urged in a direction to decrease pump displacement by a piston 11 fitted in a cylinder 12, and it is adapted to be moved in a direction to increase pump displacement by a wedge or cam 13 having its inclined or cam face in engagement with a roller 14 carried by slide block 10 and its opposite face in engagement with a roller 15 carried by a stationary abutment 16.

Cam 13 has one of its ends connected to a piston 17 which is fitted in a stationary cylinder 18.

The other end of cam 13 is connected to a piston 19 which is fitted in a stationary cylinder 20. Liquid for operating pistons 11, 17 and 19 is supplied by a gear pump 21 which is ordinarily driven in unison with pump 3 and arranged in the casing thereof as shown in the above patent.

Gear pump 21 draws liquid from a reservoir 22 and discharges it into a branched supply channel 23 at a rate in excess of the rate at which gear pump liquid is utilized. The liquid discharged by gear pump 21 in excess of requirements is exhausted through a relief valve 24 which enables gear pump 21 to maintain in channel 23 a constant pressure equal to the resistance of valve 24.

In order that gear pump 21 may also supply liquid to pump 3 to make up for leakage losses according to the usual practice, channel 23 may be connected direct to channel 5 or, if it is desired to supercharge pump 3 at a pressure lower than the pressure employed for operating servomotors 11—12 and 19—20, channel 23 may be connected to channel 5 through a low pressure resistance valve 25 as shown.

Channel 23 has one of its branches connected to cylinder 12 and another branch connected to cylinder 20 so that piston 11 exerts a constant force upon slide block 10 and tends to move it in a direction to decrease pump displacement, and piston 19 exerts a constant force upon cam 13 and tends to move it downward or in a direction to permit piston 11 to move slide block 10 toward zero displacement position.

Liquid for operating piston 17 to move cam 13 upward is supplied by gear pump 21 to cylinder 18 under the control of a valve 30 having three spaced apart heads or pistons 31, 32 and 33 formed thereon and closely fitted in the bore 34 of a valve casing 35 which has an annular groove or port 36 formed in the wall of bore 34 and controlled by piston 32.

A branch of supply channel 23 is connected to valve casing 35 and communicates with that part of bore 34 between pistons 31 and 32. Cylinder 18 is connected to port 36 by a channel 37. That part of bore 34 between pistons 32 and 33 is shown as communicating with a drain channel 38 which is connected to valve casing 35 and discharges into reservoir 22 but, in practice, a duct extends inward from the end of valve 30 into communication with the space between pistons 32 and 33 so that liquid may be discharged therethrough into the casing which encloses the controller mechanism.

The arrangement is such that, when valve 30 is shifted toward the left from its central or neutral position, liquid may flow from gear pump 21 through channel 23, valve casing 35 and channel 37 to cylinder 18 and raise piston 17, thereby raising cam 13 and causing it to shift slide block 10 toward the left to increase the displacement of pump 3 with a resultant increase in the speed of motor 1 and, when valve 30 is shifted toward the right from its central or neutral position, liquid may escape from cylinder 18 through channel 37, valve casing 35 and channel 38 into reservoir 22 and permit piston 19 to move cam 13 downward, thereby permitting piston 11 to move slide block 10 toward the right to decrease the displacement of pump 3 with a resultant decrease in the speed of motor 1.

Valve piston 32 has been shown as being exactly the same width as port 36 so that the slightest movement of valve 30 toward the left will permit liquid to flow from the gear pump to servomotor 17—18 and cause it to increase pump displacement, and the slightest movement of valve 30 toward the right will open channel 37 to the drain channel and permit liquid to escape from cylinder 18 so that servo-motor 11—12 may decrease pump displacement.

However, piston 32 may be made slightly wider than port 36 and then shaded. That is, it may have a plurality of fine tapered grooves formed around its periphery at each of its ends as shown in Fig. 12 of the above patent so that, when valve 30 is in its central or neutral position, port 37 will communicate with both the supply channel and the drain channel and there will be a very slight flow or seepage from channel 23 to the drain.

If piston 32 is provided with grooves, a slight movement of valve 30 toward the left will increase the flow of gear pump liquid into port 36 and decrease the flow therefrom so that liquid will flow through channel 37 and operate servomotor 17—18, and a slight movement of valve 30 toward the right will decrease the flow of gear pump liquid into port 36 and increase the flow therefrom so that liquid may escape from servomotor 17—18 and permit servo-motor 11—12 to decrease pump displacement.

In either case, the pressure in channel 37 is lower than the pressure in channel 23 due to the liquid being throttled as it passes between the edge of piston 32 and the edge of port 36. However, the area of piston 17 is so much greater than the area of piston 19 that this low pressure liquid is able to move piston 17 and cam 13 upward when valve 30 is shifted toward the left.

Provision is ordinarily made for limiting the movement of valve 30. As shown, valve 30 has a flange 39 fixed thereon to limit the valve movement in one direction by engaging the end of valve casing 35 and to limit the valve movement in the opposite direction by engaging the head of a stop screw 40 which is threaded into valve casing 35.

Motion is imparted to valve 30 through a differential 41 which has one of its legs driven at a speed exactly proportional to the speed of motor 1 and a second leg driven at a speed exactly proportional to a standard or desired speed as measured by the chronometric mechanism shown in Figs. 1 to 14. The third or output leg of the differential is connected through intervening mechanism to valve 30 so that any deviation of motor 1 from the desired speed results in movement of the third or output leg of the differential and a consequent shifting of valve 30.

Differential 41 has been shown as being of the gear type but it may be any other type, it only being necessary that rotation of one leg causes positive rotation of one or both of the other legs.

For the purpose of illustration, one leg of differential 41 has been shown in Fig. 15 as being driven by motor 1 through a drive which includes a pair of spiral gears 42 one of which is fixed upon the shaft of motor 1 and the other of which is fixed upon one end of a shaft 43 having a bevel gear 44 fixed upon the other end thereof, a bevel gear 45 which meshes with gear 44 and is fixed upon one end of a shaft 46, a bevel gear 47 which is fixed upon the other end of shaft 46 and meshes with a bevel gear 48, and a spur gear 49 which is fixed for rotation with gear 48 and meshes with an external ring gear 50 which forms a part of one leg of differential 41. In practice, however, one leg of differential 41 is ordinarily driven from motor 1 through a drive of the type illustrated in Figs. 1 to 14 which show the de-

tails of the controller mechanism and to which attention is now directed.

The controller has its mechanism arranged within a casing 55 and primarily supported by two frame members 56 and 57 which are arranged in fixed positions within casing 55 as by being bolted to suitable bosses formed upon the bottom wall thereof. Frame members 56 and 57 are connected to each other by a plurality of shouldered bolts 58 which hold them in fixed positions in respect to each other and form therewith a rigid frame for supporting the control mechanism.

A shaft 61 (Figs. 2, 3 and 6), which is adapted to be driven by motor 1 in any suitable manner, is journaled in a bearing 62 carried by one side wall of casing 55. Shaft 61 has a gear 63 splined thereon and in mesh with a gear 64 which is journaled upon a stub shaft 65 fixed in the side wall of casing 55.

Gear 64 has clutch jaws 66 formed thereon and arranged in complementary sockets 67 formed in a clutch member 68 which is splined upon a shaft 69. Clutch member 68 has a flange 70 formed thereon and overlapping gear 63 to retain it in position upon shaft 61.

A spring 71, which is arranged around shaft 69 between a collar 72 fixed thereon and the end of clutch member 68, urges clutch member 68 against gear 64 to retain it upon shaft 65 and to retain jaws 66 in sockets 67.

Shaft 69 is connected by a universal joint 73 to a shaft 74 which is journaled in frame members 56 and 57. When shaft 61 is driven, shaft 74 will be driven through gears 63 and 64, clutch member 68, shaft 69 and universal joint 73.

If it is desired to change the speed of shaft 74 relative to the speed of shaft 61, clutch member 68 may be moved along shaft 69 against the resistance of spring 71 until jaws 66 clear sockets 67 and then swung laterally clear of gears 63 and 64 which may then be removed and replaced by gears having a different ratio, and then clutch member 68 may be returned to its initial position.

Shaft 74 has fixed thereon two gears 78 and 79 which have the same pitch diameter. Gear 78 meshes with a gear 80 (Fig. 9) which is journaled upon a stub shaft 81 fixed in frame member 56. Gear 80 is shown as meshing with a gear 82 which is splined upon a shaft 83 (Fig. 3) and restrained from movement along shaft 83 by means of a set screw. Shaft 83 is journaled in frame members 56 and 57 and has fixed thereon a gear 84 which meshes with the ring gear 50 of differential 41.

The arrangement is such that, when input shaft 61 is rotated in one direction, gear 82 may be meshed with gear 80 as shown and, when input shaft 61 is rotated in the opposite direction, gear 82 may be shifted along shaft 83 out of mesh with gear 80 and into mesh with gear 79 so that ring gear 50 will be driven in the same direction regardless of the direction in which the input shaft 61 rotates. That is, with the controller mechanism constructed as shown, ring gear 50 will always be driven counterclockwise as viewed in Fig. 5 and clockwise as viewed in Fig. 15.

Ring gear 50 is fastened by a plurality of bolts 90 to the outside of a differential case consisting of two parts 91 and 92 as best shown in Figs. 3 and 8. Bolts 90 fasten the two parts of the differential case to each other and clamp an internal ring gear 93 therebetween. Case part 91 is provided with a hub 94 which is journaled in a bearing bushing 95 arranged in frame member 56, and case part 92 is provided with a hub 96 which is journaled in a bearing bushing 97 arranged in frame member 57 so that differential 41 is rotatably supported by frame members 56 and 57.

Ring gear 93 meshes with a planet pinion 98 journaled upon a shaft 99 which is fixed in a flange or head 100 arranged within differential case part 91. Flange 100 is fixed upon or formed integral with a shaft 101 which extends through hub 94 and is rotatably supported by two bearings 102 and 103 fitted, respectively, in case part 91 and in bearing bushing 95.

Pinion 98 also meshes with a sun gear 104 fixed upon a shaft 105 which extends through hub 96 and is rotatably supported by two bearings 106 and 107 fitted, respectively, in flange 100 and bearing bushing 97. Shaft 105 has fixed on the outer end thereof an escape wheel 108 which forms a part of a chronometric mechanism to be presently described.

When shaft 105 and sun gear 104 are rotating in one direction at a measured speed under the control of the chronometric mechanism and gear case 91—92 is rotating in the opposite direction at a speed which has the same ratio to the speed of shaft 105 that the pitch diameter of ring gear 93 has to the pitch diameter of sun gear 104, the axis of planet pinion 98 will remain stationary and no movement will be imparted to shaft 101.

If the speed of gear case 91—92 should increase or if the speed of sun gear 104 should decrease, planet pinion 98 would be carried around by ring gear 93 and thereby rotate shaft 101 in the direction of rotation of ring gear 93. Conversely, if the speed of differential case 91—92 should decrease or if the speed of sun gear 104 should increase, planet pinion 98 would be carried around by sun gear 104 and thereby rotate shaft 101 in the direction of rotation of sun gear 104.

Motion is transmitted from shaft 101 to control valve 30 through a sleeve 112 which is journaled upon the outer part of shaft 101 and restrained from axial movement thereon by a pin 113 which extends through sleeve 112 and is arranged within an annular groove 114 formed in the end of shaft 101.

Sleeve 112 is caused to rotate with shaft 101 by a safety clutch mechanism consisting primarily of a notched wheel 115 fixed to or formed upon shaft 101 near the outer end thereof, and a detent 116 which is urged by a spring 117 into engagement with the teeth of wheel 115 and is arranged in a socket 118 fixed to sleeve 112 or formed integral therewith.

When shaft 101 is rotated in one direction or the other, the clutch mechanism will cause sleeve 112 to rotate with it and cause valve 30 to be shifted in one direction or the other through mechanism to be presently described, thereby causing the speed of motor 1 to be corrected or varied. As will be presently explained, rotation of sleeve 112 in either direction is limited by a suitable stop in order to avoid derangement of certain associated mechanism. If shaft 101 should continue to rotate after rotation of sleeve 112 had been arrested by a stop, the safety clutch would yield and thereby prevent damage to the controller.

Rotation of ring gear 50 by motor 1 will cause ring gear 93, through planet pinion 98 and sun gear 104 to tend to rotate both of shafts 101 and 105. However, shaft 101 is yieldingly restrained from rotation as by means of a weight 119 fixed in adjusted position upon an arm 120 which is fastened to sleeve 112 and extends radially outward therefrom so that, when ring gear 50 is rotated in a counterclockwise direction as viewed

in Fig. 5 and thereby tends to rotate shaft 101 in the same direction, weight 119 will yieldingly restrain shaft 101 from rotation and enable motor 1 to transmit torque through the differential to shaft 105 and rotate it and escape wheel 108 in a clockwise direction as viewed in Fig. 5.

Escape wheel 108 drives a pendulum bob 125 (Figs. 3 and 4) and has its speed controlled thereby. Bob 125 is supported by two thin flexible ribbons 126 and 127 which are arranged parallel to each other and attached to bob 125 at spaced apart points so that bob 125 may oscillate freely but is restrained from movement in any other direction. Ribbon 126 extends downward from the periphery of a deflector sheave 128, ribbon 127 extends downward from the periphery of a winding drum 129, and the ends of both ribbons are fastened to drum 129 which may be rotated to raise and lower bob 125 and thereby vary the effective pendulum length.

By thus supporting bob 125 on parallel ribbons, the power impulses transmitted to the bob impart only translatory movements thereto without the rotation which is imparted to a bob by the rigid pendulum rod ordinarily employed in clocks. This arrangement permits the pendulum to operate accurately at very short lengths even with the large heavy bob employed in the present invention for the reason that this arrangement avoids the rotary acceleration and deceleration of the bob which would require a large part of the available energy and would seriously affect the time of oscillation at short pendulum lengths.

The teeth of escape wheel 108 are engaged successively by two pallets 130 and 131 (Figs. 13 and 14) which are secured to or formed integral with a pallet plate 132 and extend from opposite edges thereof. Pallet plate 132 is fastened by two bolts 133 to a driving arm 134 having a circular hub 135 formed upon its upper end and journaled upon a pin 136 which is fixed in frame member 57 above escape wheel 108 as shown in Fig. 3.

The upper end of pallet plate 132 is shaped to provide a concave contact surface 137 which is complementary to the circular periphery of hub 135 and is held in contact therewith by two adjusting screws 138 which extend inward from opposite edges of arm 134 and into contact with a cylindrical stud or boss 139 fixed to or formed upon pallet plate 132. Screws 138 engage boss 139 below the center thereof and thus urge pallet plate 132 upward and hold contact surface 137 in contact with hub 135.

The holes in arm 134 for bolts 133 are slightly elongated so that, by loosening bolts 133 and then loosening one and tightening the other of adjusting screws 138, the lower end of pallet plate 132 may be swung in one direction or the other to adjust pallets 130 and 131 relative to the teeth of escape wheel 108, contact surface 137 sliding around upon the periphery of hub 135 so that pallet plate 132 in effect swings upon the axis of pin 136 during such adjustment.

A stiff rod 140 is fixed at its upper end to arm 134 and forms therewith and with pallet plate 132 an escape lever through which power impulses are transmitted to cause pendulum bob 125 to oscillate. If the escape lever transmitted power impulses to the same contact spot in all positions of bob 125, the power impulses would vary in intensity as bob 125 was raised or lowered for the reason that the distance between that contact spot and escape wheel 108 would vary.

In order that equal power impulses may be transmitted to bob 125 in all vertical positions thereof, the lower end of rod 140 is provided with a frictionless roller 141 which is arranged at a fixed distance from escape wheel 108 and engages different points on bob 125 as bob 125 is raised or lowered. As shown, roller 141 is arranged between and substantially in contact with two vertical guides 142 and 143 (Figs. 3 and 9) which are formed upon opposite sides of an opening 144 extending vertically through bob 125.

When escape wheel 108 is rotated, the teeth thereof will successively engage pallets 130 and 131 alternately and transmit power impulses through the escape lever to pendulum bob 125, thereby causing bob 125 to oscillate. The power impulses transmitted to bob 125 will be equal at all times for the reason that the distance between escape wheel 108 and the point at which the impulses are applied to bob 125 remains constant regardless of the effective length of the pendulum.

The end or contact face on pallet 130 is inclined inward and downward, and the end or contact face on pallet 131 is inclined outward and downward as shown in Fig. 13. That is, the outer ends of the pallets are beveled or inclined in the same direction in respect to the direction in which the escape wheel rotates as indicated by the arrow in Fig. 13.

The arrangement is such that the chronometric mechanism is self-starting for the reason that, when power is applied to shaft 105 to rotate escape wheel 108, the tooth on the left side of escape wheel 108 in respect to Fig. 13 will act upon the beveled end of pallet 130 and force the escape lever toward the right, thereby causing rod 140 to swing bob 125 toward the right. Then, a tooth on the right side of the escape wheel will act upon the beveled end of pallet 131 and force the escape lever toward the left, thereby causing rod 140 to swing bob 125 toward the left where it is again urged toward the right by a tooth of the escape wheel engaging the beveled end of pallet 130. The interference between either pallet and the escape wheel teeth is very small when the bob is in neutral position, so that the small moment imparted by weight 119 will be sufficient to swing the bob slightly and let a tooth of the escape wheel past the pallet.

The cumulative effect of a few of such impulses causes the pendulum bob to swing through its normal arc and then the pendulum is kept swinging by slight impulses imparted to the bob through the escape lever by the teeth of the escape wheel passing over the beveled ends of the pallets.

Deflector sheave 128 and winding drum 129 (Figs. 1, 2, 3 and 4) are arranged, respectively, upon two shafts 150 and 151 which have the inner ends thereof supported by frame member 57 and the outer ends thereof supported by a U-shaped sub-frame 152 bolted or otherwise secured to frame member 57. Sub-frame 152 is shown in full in Fig. 4 but has been broken away in Figs. 1, 2, 3 and 6 in order to expose other parts of the mechanism.

Winding drum 129 has a gear 153 secured thereto or formed upon its hub and in mesh with a segmental gear 154 formed upon the upper end of a bell crank lever 155 which is pivoted upon a stub shaft 156 (Fig. 6) having one of its ends fixed in frame member 57. A roller 157, carried by a pin 157a fixed in the lower end of lever 155, is urged against a cam wheel 158 by the weight of pendulum bob 125 acting through ribbons 126

and 127, drum 129, gears 153 and 154 and lever 155.

Cam wheel 158 (Figs. 4 and 9) is arranged upon the hub of a gear 159 fixed upon one end of a shaft 160 which is journaled in frame member 57 and in a spring container 161 arranged in frame member 56 and restrained from rotation relative thereto.

Spring container 161 (Figs. 7 and 9) has a torsional spring 162 arranged therein with its inner end fastened to shaft 160 and its outer peripheral surface in frictional contact with the inner peripheral surface of container 161. The function of spring 162 is to assist pendulum bob 125, during downward movement thereof, to turn the gears through which cam wheel 158 is driven when raising bob 125.

The reason that the outer end of spring 162 is not fastened in a stationary position is that the operator, in raising pendulum bob 125, might cause cam wheel 158 to turn so far that roller 157 would ride over the high point thereof and permit bob 125 to descend. He might then continue rotation of cam wheel 158 with the result that spring 162 would be wound up beyond its limit and caused to break if its outer end were fastened. With the arrangement shown, spring 162 would simply slip around inside of container 161 and no damage would result. The use of spring 162 is necessary only when pendulum bob 125 is to be raised at so slow a rate that a large number of reduction gears are required between gear 159 and the motor which drives it as otherwise bob 125 would descend under its own weight and turn the gears through which it is raised.

Cam wheel 158 (Figs. 4 and 9) is clamped upon the hub of gear 159 between a spacer ring 163 and a trip arm 164 by a disk 165 which is fastened to the end of the hub by bolts 166. By loosening bolts 166, cam wheel 158 and trip arm 164 may be adjusted relative to each other and to a cam ring 167 which is bolted to the other side of gear 159 and arranged in a recess formed in frame member 57. The function of trip arm 164 and cam ring 167 will be presently explained.

When gear 159 is rotated, cam wheel 158 will rotate with it and cause lever 155, through the engagement of roller 157 with the periphery of cam wheel 158, to be swung upon shaft 156 and cause gear segment 154 to rotate gear 153 and winding drum 129 to raise or lower pendulum bob 125 depending upon the direction in which the cam wheel is rotated. Cam wheel 158 is adapted to be rotated at a very slow speed in the direction of the arrow in Fig. 4, thereby swinging the lower end of lever 155 outward and causing segmental gear 154 to rotate gear 153 and drum 129 in a direction to raise pendulum bob 125 through a given distance during a given period of time, for instance, to raise bob 125 from the position shown in Fig. 4 to the upper limit of its movement during a period of six hours.

After bob 125 has been raised, it may be lowered by disengaging certain gears, as will be presently explained, and then the bob may be moved downward by its own weight, spring 162 assisting the bob to rotate the several gears and shafts.

Gear 159 (Figs. 4 and 6) meshes with a gear 171 fixed to one end of a shaft 172 which extends through and is journaled in frame members 56 and 57. Shaft 172 has a gear 173 journaled thereon (Fig. 6) and urged by a spring 174 against a friction disk 175 which is fixed to shaft 172 and forms with gear 173 and spring 174 a friction clutch which permits the controller to be manually adjusted and also prevents damage to the mechanism should it stall as by bob 125 being raised too high.

Gear 173 meshes with a gear 176 (Figs. 5 and 6) fixed upon a shaft 177 which is journaled in frame members 56 and 57 and has a gear 178 fixed thereon. Gear 178 meshes with a gear 179 journaled upon a stub-shaft 180 carried by a plate 181 (Figs. 1, 5, 6 and 10), which is pivoted near its front end to frame member 57 by means of a trunnion 182 upon which it may be rocked to disengage gear 179 from gear 178 as shown in Fig. 10.

The rear end of plate 181 is supported by an adjusting screw 183 which normally engages the top of frame member 57 and is threaded through an arm 184 which is fixed to the rear part of plate 181 and extends laterally from the upper edge thereof. By turning screw 183, plate 181 may be so adjusted that gear 179 meshes properly with gear 178.

Gear 179 has a gear 185 fixed for rotation therewith and in mesh with a gear 186 which is journaled upon a stub-shaft 187 fixed in plate 181. Gear 186 has a gear 188 fixed for rotation therewith and in mesh with a gear 189 fixed upon a shaft 190 which is journaled in frame member 56 and in the end of trunnion 182 as shown in Fig. 1 so that plate 181, when swung upon trunnion 182, turns about the axis of gear 189 which remains stationary.

Shaft 190 has been shown in Fig. 1 as being connected by a tongue and slot connection to the output shaft of a reduction gear 191 which is connected to and driven by a synchronous electric motor 192 carried by frame member 56. Reduction gear 191 and motor 192 are ordinarily combined in a single unit which may be obtained in the open market from manufacturers of electric clocks.

The arrangement is such that, when motor 192 is energized, cam wheel 158 may be rotated at a very slow speed so that the speed of motor 1 may be varied throughout a given period of time at either a uniform or a non-uniform rate according to a predetermined schedule as determined by the contour of cam wheel 158. That is, electric motor 192 and the mechanism associated therewith constitute a secondary chronometric mechanism for controlling the speed of the primary chronometric mechanism.

If the speed of motor 1 is to be kept constant, the mechanism for changing the pendulum length is unnecessary. If the speed of motor 1 is to be adjusted at the will of the operator and then kept constant by the controller, shaft 190 may be connected directly to the output shaft of an ordinary electric motor which is manually controlled as by means of a push button switch. If the speed of motor 1 is to be kept proportional to the speed of an external moving body, shaft 190 may be driven from that body through intervening mechanism as shown in the application referred to above.

In order that the operator may adjust the controller manually, shaft 172 (Fig. 6) has fixed thereon an adjusting knob 193 by means of which shaft 172 and the gear 171 fixed thereon may be rotated manually, friction clutch 173—175 permitting shaft 172 to be rotated while gear 173 is held stationary due to it meshing with gear 176. Gear 171 will rotate gear 159 and thereby rotate cam wheel 158 to adjust the controller.

When motor 192 is energized, it will rotate gear

159 through the above described intervening mechanism in a counterclockwise direction as viewed in Fig. 4, thereby causing cam wheel 158 to rotate in the same direction and move roller 157 and the lower end of bell crank lever 155 toward the right so that segmental gear 154 on the upper end of lever 155 will rotate gear 153 and thereby rotate drum 129 which will wind ribbons 126 and 127 thereon and gradually raise pendulum bob 125.

After pendulum bob 125 has been raised, it may be permitted to descend by moving gear 179 out of mesh with gear 178. For this purpose, a release lever 196 has one of its ends connected to plate 181 and its other end in contact with a release button 197 which is arranged in a socket 198 formed in casing 55 as shown in Figs. 4, 5 and 7. Button 197 is normally retained in its inoperative position by a spring 199 arranged around it within socket 198.

In order that lever 196 may be adjusted so that its front end will remain substantially in contact with the lower end of release button 197, it is adjustably connected near its rear end to plate 181. As shown, lever 196 is connected to plate 181 by a pivot 200 and its upper edge is engaged at a point beyond pivot 200 by an adjusting screw 201 which is threaded through a flange 202 formed upon the upper edge of plate 181. By turning screw 201, lever 196 may be so adjusted that its front end will be substantially in contact with the lower end of release button 197 when gear 179 is meshing properly with gear 178.

When release button 197 is depressed, lever 196 will swing plate 181 upon trunnion 182 and thereby raise gear 179 out of mesh with gear 178. Then, the weight of pendulum bob 125 and the force exerted by spring 162 will be able to rotate the several shafts and gears so that pendulum bob 125 may descend. In order to stop the pendulum bob at a predetermined point in its downward travel, trip arm 164 is adapted to engage a suitable stop, such as the pin 157a (Figs. 4 and 6) which carries roller 157 and is fixed to the lower end of lever 155.

Just before trip arm 164 engages pin 157a, the outer end thereof engages a cam 206 arranged upon the lower end of a trip lever 207 which is pivoted intermediate its ends upon shaft 156 between lever 155 and frame member 57. The upper end of trip lever 207 is urged rearward by a spring 208 but it is normally restrained from rearward movement by a flange 209 formed upon its upper end and normally engaging adjusting screw 183.

When plate 181 is swung upon trunnion 182 to raise gear 179 out of mesh with gear 178, it will raise screw 183 above flange 209 so that spring 208 may move the upper end of trip lever 207 rearward until flange 209 is beneath screw 183 at which time rearward movement of flange 209 ceases due to lever 207 engaging a suitable stop, such as a pin 210 inserted into frame member 57. Button 197 may then be released and permit the rear part of plate 181 to fall but screw 183 will engage flange 209 and hold gear 179 out of mesh with gear 178, thereby permitting pendulum bob 125 to descend.

As pendulum bob 125 moves downward, it and spring 162 will rotate the several shafts and gears and thereby cause trip arm 164 to revolve about the axis of shaft 160. When pendulum bob 125 approaches the limit of its downward movement, trip arm 164 will engage cam 206 and swing trip lever 207 upon shaft 156 to move flange 209 from beneath screw 183, thereby permitting the rear end of plate 181 to fall and gear 179 to mesh with gear 178.

Just as flange 209 moves from under adjusting screw 183, trip arm 164 engages pin 157a and stops further descent of the pendulum bob so that gear 178 ceases to rotate before gear 179 meshes therewith. In order to provide ample time for gear 178 to cease rotating before gear 179 meshes therewith and to cushion the fall of plate 181, a dashpot is ordinarily provided.

As shown in Fig. 11, a dashpot plunger 212 is pivoted at its upper end to an arm 213 which is fixed to plate 181. The lower end of plunger 212 has a head formed thereon and loosely fitted in a dashpot 214 which is formed in frame member 57 and connected by a channel 215 to a reservoir 216 also formed in frame member 57. The lower end of dashpot 214 is closed by a check valve 217 which permits liquid to flow freely from reservoir 216 into dashpot 214 but prevents it from flowing in the opposite direction.

When plate 181 falls, plunger 213 tends to eject liquid from the lower part of dashpot 214 but check valve 217 prevents it from passing into channel 215 so that liquid must be squeezed out of the lower part of dashpot 214 into the upper part thereof between the wall of the dashpot and the periphery of the plunger head, thereby retarding the downward movement of plate 181. When plate 181 is raised, plunger 212 will move upward with it and check valve 217 will permit liquid to flow freely from reservoir 216 through channel 215 into the lower part of dashpot 214 to keep it filled.

Reservoir 216 is supplied with liquid from an oil pan 218 which is arranged above the controller mechanism and supported from frame members 56 and 57 by four posts 219. Pan 218 is supplied with oil from a suitable source, such as gear pump 21, through a channel not shown. The bottom of pan 218 has a plurality of small perforations 220 formed therein through which oil may flow to lubricate all parts of the controller mechanism and keep reservoir 216 filled. In order to prevent motor 192 from being bathed by the lubricating oil, it is ordinarily arranged beneath a shield 221 which is fastened to frame member 56.

It has been previously explained that, if the prime mover being controlled drives ring gear 50 (Fig. 8) of differential 41 at a speed which varies relative to the speed of escape wheel 108, shaft 101 will be rotated in one direction or the other depending upon whether the speed of gear 50 increases or decreases relative to the speed of escape wheel 108. In order to maintain the speed of the prime mover proportional to the speed of escape wheel 108, the rotary movements of shaft 101 are utilized for operating valve 30 (Figs. 12 and 15) to thereby vary the speed of the prime mover.

Movements are transmitted from shaft 101 through an arm 225 which is fixed to sleeve 112 or formed integral therewith as shown in Figs. 2, 3, 7, 8 and 15. Arm 225 is pivoted at its free end to the upper end of a lever 226 which is pivoted intermediate its ends upon a pin 227 and has its lower end connected by a link 228 to the stem 229 of valve 30.

From an inspection of Fig. 15 it will be obvious that, if pin 227 is stationary and if the speed of motor 1 decreases or the speed of escape wheel 108 increases so that shaft 101 is rotated in a counterclockwise direction, arm 225 will swing

the upper end of lever 226 toward the right and cause the lower end thereof to shift valve 30 toward the left to permit liquid from gear pump 21 to flow to cylinder 18 and increase the displacement of pump 3 with a resultant increase in the speed of motor 1; and that, if the speed of motor 1 increases or the speed of escape wheel 108 decreases so that shaft 101 is rotated in a clockwise direction, arm 225 will swing the upper end of lever 226 toward the left and cause the lower end thereof to shift valve 30 toward the right to permit liquid to escape from cylinder 18 and thereby permit servo-motor 11—12 to decrease the displacement of pump 3 with a resultant decrease in the speed of motor 1.

When valve 30 is shifted in one direction or the other to effect movement of slide block 10 and thereby correct a variation in the speed of motor 1 relative to the speed of escape wheel 108, it is necessary to transmit motion from slide block 10 back to valve 30 in order to prevent pump 3 from hunting.

For this purpose, a push pin 233 extends through the wall of casing 55 and has one of its ends in contact with slide block 10, as shown in Fig. 15, and its other end in contact with a lever arm 234 as shown in Figs. 1, 4, 6, 7, 9 and 15.

Lever arm 234 is fixed upon a shaft 235 which is supported at its ends in bearings 236 and 237 carried by the substantially U-shaped lower part of a hanger 238 at opposite ends thereof. Hanger 238 is pivoted at its upper end to frame members 56 and 57 by means of a shaft 239 so that shaft 235 may be moved toward and from slide block 10 as will be presently explained.

The vertical part of hanger 238 has a stop screw 240 threaded therethrough and in contact with one end of a push pin 241 which is slidably fitted in a suitable bore formed in frame member 57 and has its other end in contact with cam ring 167 as best shown in Fig. 9. The arrangement is such that the lower part of hanger 238 and shaft 235 will be swung toward or from slide block 10 when cam ring 167 is rotated.

Shaft 235 has a lever 245 (Figs. 6 and 7) journaled thereon and a vertical lever arm 246 fixed thereon alongside lever 245 and provided at its upper end with a flange 247 which overlaps a boss 248 and a flange 249 formed upon lever 245. An adjusting screw 250 is threaded through boss 248 into contact with flange 247. A bolt 251 is threaded into flange 247, extends through flange 249 and has a helical spring 252 arranged thereon between flange 249 and a suitable collar which is retained in position upon bolt 251. Spring 252 urges flange 249 toward flange 247 and holds adjusting screw 250 in contact with flange 247, thereby causing lever 245 to normally operate as an integral part of lever arm 246 and shaft 235. By turning screw 250, the angle between lever arm 234 and lever 245 may be varied to thereby adjust the controller in respect to slide block 10.

Lever 245 is connected near its upper end by a link 255 to a lever 256 intermediate the ends thereof. Levers 245 and 256 have a plurality of holes formed therein for connecting link 255 thereto in various positions to thereby adjust the controller. Lever 256 is pivoted at its upper end to frame member 56 and urged toward the right in respect to Fig. 7 by a spring 257 which holds lever arm 234 in contact with push pin 233 and holds stop screw 250 (Fig. 9) against push pin 241.

The lower end of lever 256 is pivoted to one end of a link 258 which has its other end connected to lever 226 by the pin 227 upon which lever 226 is swung to operate valve 30.

In order that the accuracy of the controller may not be impaired by slack or lost motion in the mechanism through which motion is transmitted from arm 225 and slide block 10 to valve 30, and to avoid the necessity of closely and accurately fitting the pins which connect the several parts of that mechanism, spring means are provided for taking up all slack or lost motion in that mechanism.

Spring 257, by causing lever arm 234 to press push pin 233 firmly against slide block 10, takes up all slack in the joints between link 255 and levers 245 and 256 so that there is no lost motion in that part of the mechanism.

In practice, all slack in the other parts of the mechanism is taken up by other springs and auxiliary levers which have been omitted from the drawings to avoid complicating the views. In lieu thereof, the controller has been shown in Fig. 15 as being provided with a light flexible spring 259 which urges valve 30 toward the right and thereby takes up all slack in the joints between valve stem 229, link 228, lever 226, link 258 and lever 256 so that there is no lost motion between arm 225 and valve 30 or between slide block 10 and valve 30. Spring 259 or its equivalent, while strong enough to take up the slack in the joints mentioned, is so light and flexible that it does not add appreciably to the power required to swing arm 225.

Operation

When motor 1 is operating at the desired speed and driving ring gears 50 and 93 of differential 51 in a clockwise direction as viewed in Fig. 15, ring gear 93 will tend to carry planet pinion 96 around with it and thereby tend to rotate shaft 101 in a clockwise direction. However, weight 119 will oppose a definite turning moment to rotation of shaft 101 and thereby cause sun gear 104 to rotate in a counterclockwise direction and drive the chronometric mechanism.

Each time a pallet 130 or 131 (Fig. 13) engages a tooth of escape wheel 108, it will momentarily arrest rotation of sun gear 104 (Fig. 8), and thereby cause shaft 101 to rotate through a small angle in a clockwise direction as viewed in Fig. 15 and raise weight 119. Each time a pallet 130 or 131 releases a tooth of escape wheel 108, weight 119 will fall and rotate shaft 101 through a small angle in a counterclockwise direction, and then a pallet will engage another tooth of escape wheel 108 and again momentarily arrest rotation of sun gear 104. Weight 119 in falling will impart a turning moment to sun gear 104 through pinion 98. The effect is that weight 119 is raised intermittently by power derived from motor 1 and falls intermittently, but continuously transmits a definite turning moment to sun gear 104 to enable it to drive the chronometric mechanism. Sun gear 104 will thus be rotated intermittently but, since the oscillation period of a constant length pendulum remains constant, the overall or net speed of sun gear 104 will be constant as long as cam wheel 158 (Fig. 4) remains stationary.

If motor 1 is rotating at exactly the desired speed as determined by the adjustment of the chronometric mechanism, shaft 101 will be rotated through the same limited angular distance in each direction of rotation and cause arm 225 to oscillate through a very limited range which has a fixed angular position as long as motor 1

continues to rotate at exactly the desired speed. Oscillation of arm 225 through this limited range causes valve 30 to be oscillated through a range which is so small that the adjustment of pump 3 is not materially affected. In practice, it is found that such limited oscillation of valve 30 causes the speed of motor 1 to vary momentarily much less than one-tenth of one percent above and below the desired speed. Since such slight momentary variations are immaterial in actual practice, they have been disregarded in the foregoing description and will be disregarded hereinafter.

If motor 1 deviates from the desired speed and thereby drives the differential gears 50 and 93 at a different speed, or if pendulum bob 125 is raised or lowered and thereby causes sun gear 104 to rotate at a different speed, the variation in the relative speeds of gears 93 and 104 will cause planet pinion 98 to be carried around sun gear 104 in one direction or the other and thereby rotate shaft 101 in one direction or the other.

If the speed of motor 1 decreases so that the speed of gears 50 and 93 is decreased or if pendulum bob 125 is raised so that the speed of sun gear 104 is increased, shaft 101 will be rotated in a counterclockwise direction as viewed in Fig. 15 and cause arm 225 to swing the upper end of lever 226 toward the right. Lever 226 will pivot upon pin 227 and shift valve 30 toward the left and permit liquid to flow from gear 21 to cylinder 18 and shift slide block 10 toward the left, thereby increasing the displacement of pump 3 and consequently increasing the speed of motor 1 as previously explained.

Since push pin 233 is held in contact with slide block 10 by the action of spring 257 (Figs. 7 and 15), movement of slide block 10 toward the left permits push pin 233 and the lower end of lever arm 234 to move toward the left, shaft 235 to rotate in bearings 236 and 237 and the upper end of lever 245 and link 255 to move toward the right, thus permitting spring 257 to move the lower end of lever 256 and link 258 toward the right so that pivot pin 227 is moved toward the right substantially simultaneously with the movement of slide block 10 toward the left with the result that valve 30 is returned to its neutral position and further adjustment of pump 3 ceases as soon as arm 226 ceases to swing toward the right. Until another variation occurs, lever 226 will remain in this new position, its upper end having been shifted toward the right to open valve 30 and its lower end having been shifted toward the left to close valve 30 during the above described adjustment of pump 3.

If the speed of motor 1 increases so that the speed of gears 50 and 93 is increased or if pendulum bob 125 is lowered so that the speed of sun gear 104 is decreased, shaft 101 will be rotated in a clockwise direction as viewed in Fig. 15 and cause arm 225 to swing the upper end of lever 226 toward the left. Lever 226 will pivot upon pin 227 and shift valve 30 toward the right to permit liquid to escape from cylinder 18 and thereby permit servo-motor 11—12 to shift slide block 10 toward the right to decrease the displacement of pump 3 with the resultant decrease in the speed of motor 1 as previously explained.

As slide block 10 moves toward the right, push pin 233 will swing the lower end of lever 234 toward the right and thereby rotate shaft 235 in bearings 236 and 237 and swing the upper end of lever 245 and link 255 toward the left. Link 255 will swing the lower end of lever 256 and move link 258 toward the left and thereby move pin 227 toward the left substantially simultaneously with the movement of slide block 10 toward the right so that valve 30 is returned to its neutral position and further adjustment of pump 3 ceases as soon as arm 225 ceases to swing toward the left. Until another speed variation occurs, lever 226 will remain in this new position, its upper end having been shifted toward the left to open valve 30 and its lower end having been shifted toward the right to close valve 30 during the time the displacement of pump 3 was being reduced to correct the variation in the speed of motor 1.

The control mechanism is thus capable of maintaining the speed of motor 1 proportional to a standard or measuring speed as determined by the adjustment of the chronometric mechanism. That is, it will keep the motor speed substantially constant as long as the pendulum length remains constant and it will keep the motor speed at a predetermined ratio to the speed of sun gear 104 when the pendulum length is varied slowly. If pendulum bob 125 should be raised or lowered at high speed, the adjustment of motor speed would lag behind the adjustment of the measuring speed.

If the axis of shaft 235 remained stationary during extensive adjustment of the controller to vary the speed of the prime mover through a wide range or if the speed of the prime mover should tend to vary so much from the desired speed that arm 225 would tend to swing lever 226 beyond the range it can accurately adjust valve 30, arm 225 would engage one or the other of two stops 260 and 261 which are fixed in frame member 56 upon opposite sides of arm 225. Then, continued rotation of shaft 101 would cause detent 116 to ride over a tooth of ratchet wheel 115, thereby keeping lever 226 within its useful range and preventing damage to the controller.

In order that continued adjustment of the controller to vary the speed of motor 1 through a wide range may not cause lever 226 to be shifted beyond the range in which it can accurately adjust valve 30, cam ring 167 (Figs. 4 and 9), push pin 241 and hanger 238 (Figs. 4, 6 and 9) are provided. When motor 192 (Figs. 1 and 7) is energized and gear 179 (Figs. 5, 6 and 10) is in mesh with gear 178, motor 192 will rotate cam wheel 158 (Figs. 4 and 9) which will swing lever 155 upon shaft 156 to gradually raise pendulum bob 125 and thereby cause slide block 10 (Fig. 15) to be gradually moved toward the left in respect to Fig. 15 to increase the speed of motor 1 as previously explained. Since cam ring 167 is fixed for rotation with cam wheel 158, it will be rotated in unison therewith and cause push pin 241 to swing hanger 238 upon shaft 239 and thereby move shaft 235 in the same direction that slide block 10 is moved, that is, toward the left in respect to Fig. 15. The contour of cam ring 167 is such that shaft 235 is moved at a rate proportional to the rate at which slide block 10 is moved so that lever 226 is displaced but little from its initial position during the time that the speed of motor 1 is being increased by raising pendulum bob 125.

With the controller constructed and adjusted as shown, the speed of the prime mover controlled by the controller will be gradually increased when motor 192 is energized to raise pendulum bob 125 as previously explained. If it is desired to employ the controller to gradually decrease the speed of a prime mover, pendulum bob 125 would be raised manually by turning knob 193 and the controller would be adjusted to gradually lower

bob 125 either by reversing cam wheel 158 and cam ring 167 or by reversing the direction of rotation thereof.

In one case, it is simply necessary to turn cam wheel 158 and cam ring 167 over in respect to gear 159. In the other case, it is simply necessary to reverse the direction of rotation of gear 159 either by changing a part of the gearing or reversing the direction of rotation of the motor which drives the gearing. In both cases trip arm 164 would be shifted to a position in which it would not interfere with trip lever 207.

Fig. 16

This figure illustrates a different method of operating the control valve. As shown, control valve 30 is urged toward the right by a spring 270 which has one of its ends connected to the stem 229ª of valve 30 and its other end connected to the casing 35ª in which valve 30 is fitted and which is the same as valve casing 35 except that it has a dashpot 271 arranged upon its right end.

Dashpot 271 has a cylinder 272 formed in its casing in communication with the bore of valve casing 35ª and a dashpot plunger 273 fitted in cylinder 272 with its stem extending into the bore of casing 35ª. The left end of cylinder 272 is open to a drain channel 274, and the right end of cylinder 272 has been shown as being connected to drain through a channel 275 which connects the two ends of the cylinder to each other and has a needle valve 276 extending into it to restrict the flow of liquid therethrough.

The right end of cylinder 272 is connected through a check valve 277 and a channel 278 to a reservoir 279 which is kept filled with oil supplied thereto through one or more of the perforations 220 formed in oilpan 218. Check valve 277 permits liquid to flow freely from reservoir 279 into the right end of cylinder 272 but prevents liquid from escaping therefrom except through channel 275 through which it may flow only at a limited rate due to the throttling action of needle valve 276.

When valve 30 is moved toward the left, liquid from reservoir 279 will flow through channel 278 and check valve 277 into the right end of cylinder 272 and move plunger 273 with it, reservoir 279 being arranged high enough to provide sufficient head to enable the liquid to move plunger 273 in cylinder 272 and to keep its stem in contact with the end of valve 30.

When valve 30 is moved toward the right by spring 270, plunger 273 must eject liquid from the right end of cylinder 272 but check valve 277 will be closed so that this liquid must flow through channel 275 past needle valve 276 which will limit the flow of liquid therethrough and thereby retard the movement of valve 30.

Valve casing 35ª is connected in circuit in the same manner that valve casing 35 is connected in circuit and as shown in Fig. 15 so that, when valve 30 is shifted toward the left, liquid may flow to cylinder 18 to increase the displacement of pump 3 with the resultant increase in the speed of motor 1 and, when valve 30 is shifted toward the right, liquid may escape from cylinder 18 and permit the displacement of pump 3 to be decreased with the resultant decrease in the speed of motor 1.

Valve 30 is adapted to be moved toward the left by a lever 226ª which is pivoted at its upper end to arm 225, pivoted at its lower end to link 258 by a pin 227ª and extends alongside an abutment 280 fixed to valve stem 229ª so that, when the lower end of arm 225 swings toward the left, lever 226ª will engage abutment 280 and move valve 30 toward the left.

It has been previously pointed out that, when motor 1 is operating at the desired speed and driving ring gears 50 and 93 of differential 41 in a clockwise direction as viewed in Fig. 15, shaft 101 will be rotated in a clockwise direction and swing the lower end of arm 225 toward the left through a small angle each time a pallet 130 or 131 (Fig. 13) engages a tooth of escape wheel 108, and it will be rotated in a counterclockwise direction and swing the lower end of arm 225 toward the right each time a pallet 130 or 131 releases a tooth of escape wheel 108 and permits weight 119 to fall.

Since shaft 101 is rotated in a clockwise direction due to rotation of gear 93, the lower end of arm 225 will be swung toward the left at a relatively slow speed and, since shaft 101 is rotated in a counterclockwise direction by weight 119 when falling, the lower end of arm 225 will be swung toward the right at a relatively high speed.

The arrangement is such that, when a pallet 130 or 131 engages a tooth of escape wheel 108 and causes shaft 101 to be rotated in a clockwise direction as previously explained, arm 225 will swing lever 226ª upon pin 227ª and lever 226ª will engage abutment 180 and shift valve 30 toward the left and, when the pallet disengages a tooth of the escape wheel and permits weight 119 to fall and rotate shaft 101 in a counterclockwise direction, arm 225 will swing lever 226ª out of contact with abutment 180 and permit spring 270 to move valve 30 toward the right. The movement of valve 30 toward the right under the influence of spring 270 is retarded by dashpot 271 so that, as long as the speed of motor 1 remains constant, valve 30 moves but little toward the right before lever 226ª again engages abutment 180 and moves it toward the left. The result is that, as long as the speed of motor 1 remains constant, valve 30 is oscillated through such a small range that its movement has no material effect upon the displacement of pump 3. If the speed of motor 1 varies from the desired speed as measured by the chronometric mechanism, arm 225 will be oscillated through a different range and thereby cause valve 30 to be shifted to correct that variation in speed as previously explained.

The invention herein set forth is susceptible of various modifications and adaptations without departing from the scope thereof as hereafter claimed.

The invention is hereby claimed as follows:

1. In a chronometric controller, the combination of a three-legged differential having a first leg driven from an external source of power and a second leg provided with a weight which resists rotation thereof and thereby causes rotation of the third leg, and a chronometric mechanism having an escapement connected to said third leg to control the speed thereof and permitting said third leg to rotate intermittently and thereby cause said weight to be alternately raised and permitted to fall, said weight being raised by power derived from said external source and transmitting this power when falling to said chronometric mechanism to drive the same.

2. In a chronometric mechanism, the combination of a pendulum bob, means including an escapement for transmitting power impulses to

said bob to cause it to oscillate, supporting means, and two thin flexible ribbons having the upper ends thereof attached to said supporting means and the lower ends thereof attached to said bob at spaced apart points to support said bob and to cause said power impulses to move it by translation and without rotation in a given vertical plane.

3. In a chronometric mechanism, the combination of a pendulum bob, means for transmitting power impulses of uniform value to said bob to cause it to oscillate, supporting means including a winding drum, two thin flexible ribbons having the upper ends thereof attached to said drum and the lower ends thereof attached to said bob at spaced apart points to support said bob and to cause said power impulses to move it by translation and without rotation in a given vertical plane, and means for rotating said drum to move said bob vertically and thereby vary the effective pendulum length.

4. In a chronometric controller, the combination of a pendulum bob, two thin flexible ribbons connected to said bob to support the same, an escape wheel, an escape lever carried by a stationary pivot and connected to said bob, pallets carried by said escape lever to engage the teeth of said escape wheel, and means for rotating said escape wheel to enable it to transmit power impulses through said lever to said bob and thereby cause said bob to oscillate, said ribbons being attached to said bob at widely separated points to thereby cause said impulses to move said bob by translation and without rotation.

5. In a chronometric controller, the combination of a pendulum bob, rotatable means, flexible means connected to and supported by said rotatable means and connected to said bob to support the same, an escape wheel, an escape lever carried by a stationary pivot and connected to said bob, pallets carried by said escape lever to engage the teeth of said escape wheel, means for rotating said escape wheel to enable it to transmit power impulses through said lever to said bob and thereby cause said bob to oscillate, and means for rotating said rotatable means in one direction or the other to wind said flexible means thereon or unwind the same therefrom and thereby raise or lower said bob.

6. In a chronometric controller, the combination of a winding drum and a deflector sheave rotatable upon stationary axes, a pendulum bob, two flexible ribbons fastened to said drum and connected to said bob at spaced apart points to support the same, one of said ribbons extending downward from the periphery of said drum and the other passing over said sheave and extending downward from the periphery thereof, means for transmitting power impulses to said bob to cause it to oscillate, and means for rotating said drum to thereby vary the effective pendulum length.

7. In a chronometric mechanism, the combination of a pendulum having a bob, means for raising said bob to shorten the effective length of said pendulum, a power source, a drive for transmitting motion from said source to said bob raising means to operate the same, and means for disengaging a part of said drive from an associated part to thereby permit said bob to descend.

8. In a chronometric mechanism, the combination of a pendulum having a bob, means for raising said bob to shorten the effective length of said pendulum, a power source, a drive for transmitting motion from said source to said bob raising means to operate the same, means for disengaging a part of said drive from an associated part to thereby permit said bob to descend, and means for stopping the downward movement of said bob at a predetermined effective pendulum length.

9. In a chronometric mechanism, the combination of a pendulum having a bob, means for raising said bob to shorten the effective length of said pendulum, a power source, a drive including intermeshing gears for transmitting motion from said source to said bob raising means to operate the same, means for moving one of said gears out of mesh with another gear to permit said bob to descend, means responsive to moving said gear out of mesh for latching it in out-of-mesh position, means for stopping downward movement of said bob at a predetermined point, and means operated by the last mentioned means for unlatching said gear to permit it to mesh with its mating gear.

10. In a chronometric mechanism, the combination of a pendulum having a bob, means for raising said bob to shorten the effective length of said pendulum, a power source, a drive including intermeshing gears for transmitting motion from said source to said bob raising means to operate the same, means for moving one of said gears out of mesh with another gear to permit said bob to descend, means responsive to moving said gear out of mesh for latching it in out-of-mesh position, means movable in response to vertical movement of said bob for stopping downward movement of said bob at a predetermined point, means operated by the last mentioned means for unlatching said gear to permit it to mesh with its mating gear, and a dashpot for delaying the meshing of said gears until rotation thereof ceases.

11. In a chronometric mechanism the combination of a pendulum having a bob, means for raising said bob to shorten the effective length of said pendulum, a power source, a train of gears for transmitting motion from said source to said bob raising means to operate the same, means for moving one of said gears out of mesh with its mating gear to permit said bob to descend, and spring means for assisting said bob to descend.

12. In a chronometric mechanism the combination of a pendulum having a bob, means for raising said bob to shorten the effective length of said pendulum, a power source, a train of gears for transmitting motion from said source to said bob raising means to operate the same, and means including a clutch for permitting said bob to be manually adjusted without disengaging any of said gears.

13. In a chronometric mechanism, the combination of an escape wheel, means for driving said wheel, a pendulum bob, a support therefor, means for suspending said bob from said support, means for varying the effective length of said suspending means to thereby move said bob vertically, an escape lever for transmitting power impulses from said escape wheel to said bob to cause it to oscillate, pallets carried by said lever and engaging the teeth of said escape wheel to transmit power impulses from said wheel to said lever, and means for maintaining constant in all vertical positions of said bob the distance between the center of said wheel and the point upon said bob to which said power impulses are delivered.

14. In a chronometric mechanism, the combination of a pendulum bob having a vertical

opening therein, a support, means for suspending said bob from said support, means for varying the effective length of said suspending means to thereby move said bob vertically, an escape wheel, means for driving said wheel, an escape lever extending into said opening, pallets carried by said lever and engaging the teeth of said wheel to enable said lever to transmit power impulses from said wheel to said bob, and a roller arranged upon the lower part of said lever to engage the sides of said opening and deliver said power impulses at various points upon said bob as said bob moves vertically.

15. In a chronometric controller, the combination of a chronometric mechanism having an escape wheel, an intermediate shaft, means for transmitting rotary motion from said shaft to said wheel to drive the same, a support, a drive shaft journaled in said support, a gear keyed upon said shaft, a stub shaft carried by said support, a gear arranged upon said stub shaft and meshing with the gear upon said drive shaft to be driven thereby, a clutch coupling connected to the gear upon said stub shaft, and a drive having a pivotal driving connection with said intermediate shaft and a telescopic driving connection with said coupling whereby said intermediate shaft may be driven by the gear upon said stub shaft and said drive may be contracted to permit said gears to be changed.

16. In a chronometric controller, the combination of a chronometric mechanism having an escape wheel, an intermediate shaft, means for transmitting rotary motion from said shaft to said wheel to drive the same, a support, a drive shaft journaled in said support, a gear splined upon said shaft, a stub shaft carried by said support, a gear arranged upon said stub shaft and meshing with the gear upon said drive shaft to be driven thereby, a clutch coupling connected to the gear upon said stub shaft, a flange carried by said coupling and overlapping the gear on said drive shaft to retain it in position thereon, and a drive having a pivotal driving connection with said intermediate shaft and a telescopic driving connection with said coupling whereby said intermediate shaft may be driven by the gear upon said stub shaft and said drive may be contracted to permit said gear to be changed without the aid of tools.

17. In a chronometric controller, the combination of a three-legged differential gear having a first leg driven from an external source of power and a second leg provided with a weight which resists rotation thereof and thereby causes rotation of the third leg, a chronometric mechanism connected to said third leg to control the speed thereof and causing said second leg to rotate in response to a variation in the speed of said first leg relative to the speed of said chronometric mechanism, a stop for preventing movement of said weight beyond a given point, and a friction clutch connecting said weight to said second leg to permit said second leg to rotate after further movement of said weight has been prevented by said stop.

18. In a chronometric controller, the combination of a three-legged differential gear having a first leg driven from an external source of power and a second leg yieldingly restrained from rotating to thereby cause the third leg to rotate, a chronometric mechanism connected to the third leg of said differential to control the speed thereof whereby any variation in the speed of said first leg relative to the speed of said chronometric mechanism will cause said second leg to rotate, a lever connected to said second leg for transmitting motion to a control element, stops for preventing said lever from moving beyond a predetermined range, and a friction clutch for permitting rotation of said second leg after further movement of said lever has been prevented by a stop.

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