Sept. 15, 1925. 1,553,941

A. T. KASLEY

BALANCING MACHINE

Filed May 31, 1922 7 Sheets-Sheet 1

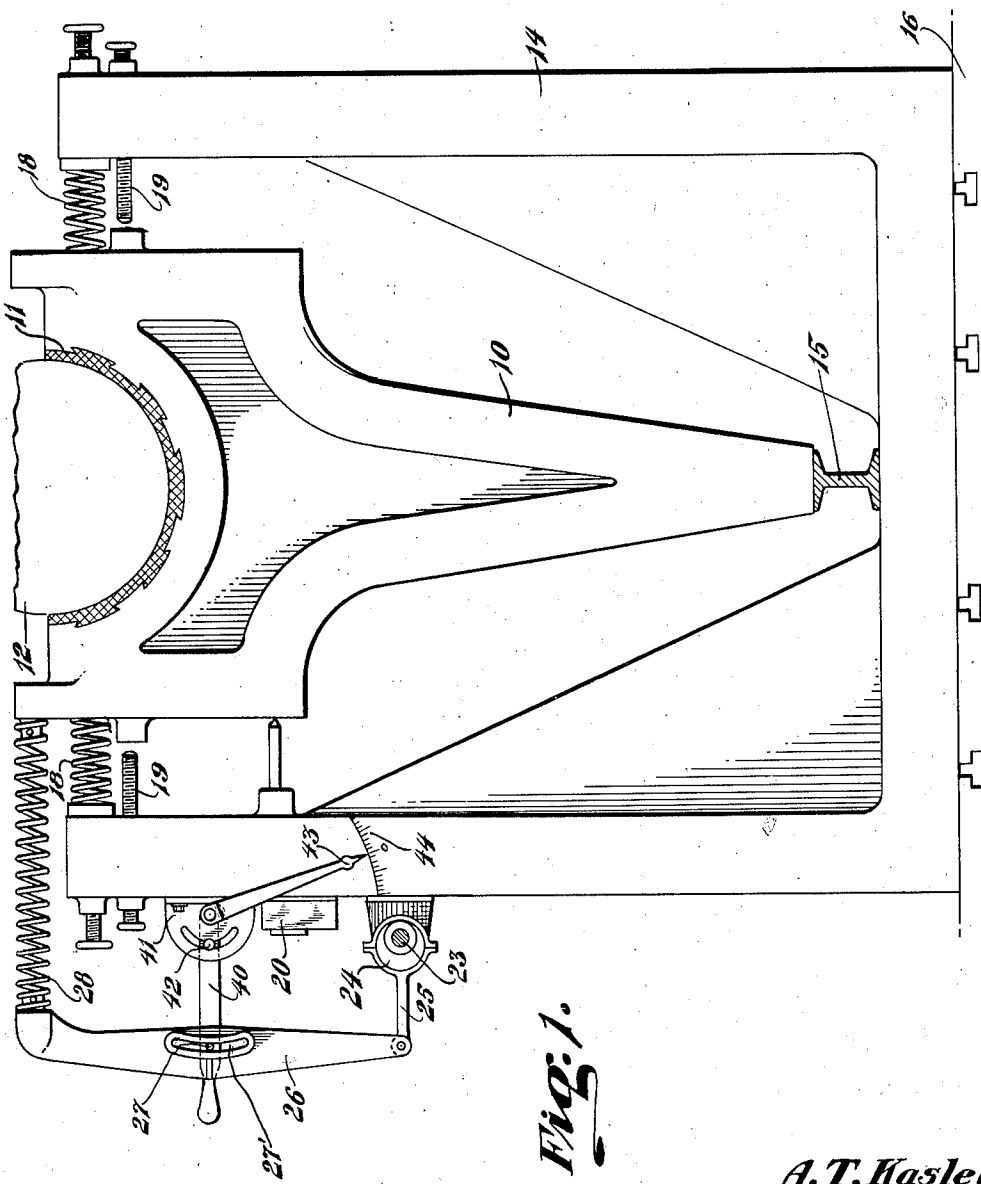


Fig. 1.

WITNESSES:

E. B. Wakefield

A. T. Kasley
INVENTOR

BY D. C. Davis
ATTORNEY

Sept. 15, 1925. 1,553,941

A. T. KASLEY

BALANCING MACHINE

Filed May 31, 1922 7 Sheets-Sheet 2

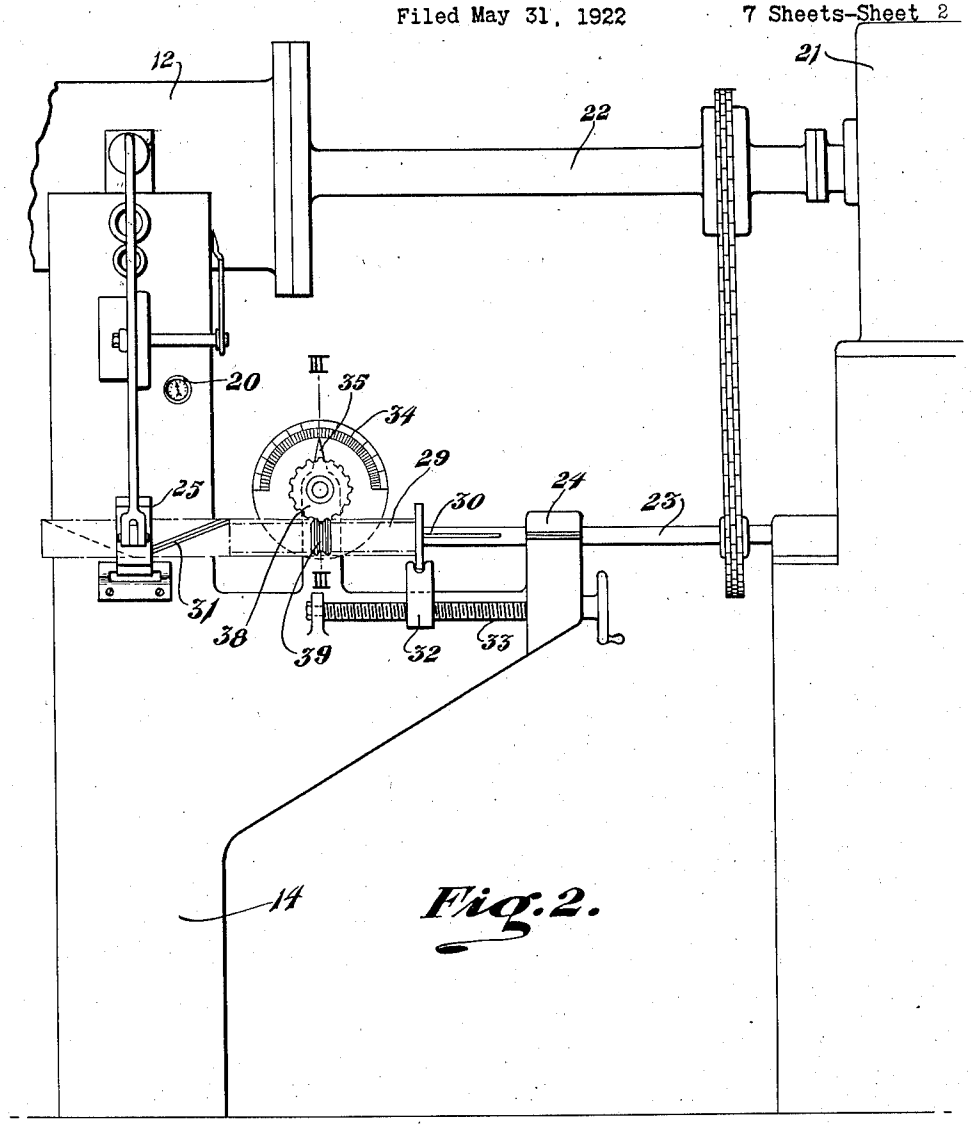


Fig. 2.

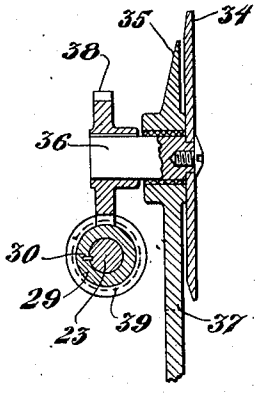


Fig. 3.

WITNESSES:

A. T. Kasley
INVENTOR

BY

ATTORNEY

Sept. 15, 1925. 1,553,941

A. T. KASLEY

BALANCING MACHINE

Filed May 31, 1922 7 Sheets-Sheet 3

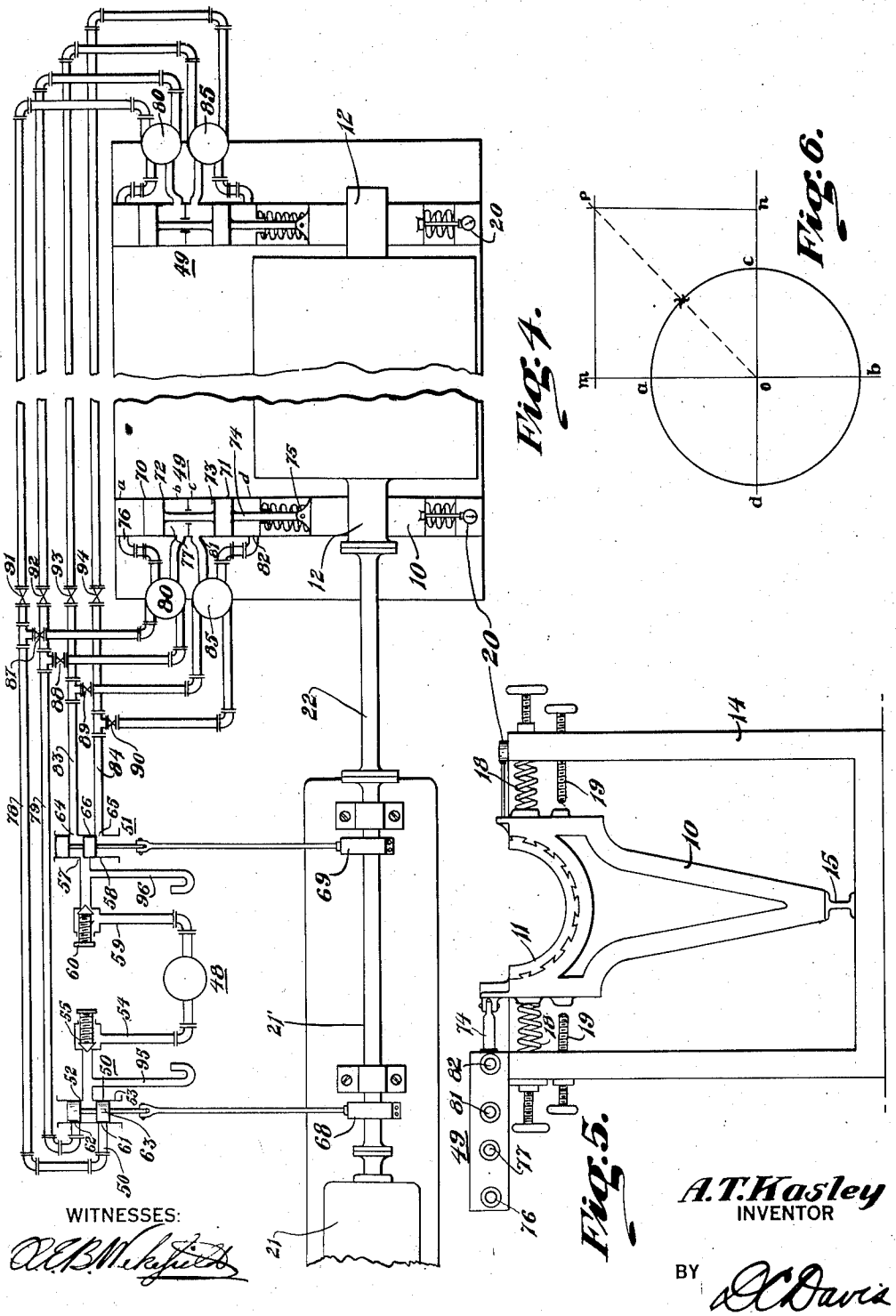


Fig. 4.

Fig. 6.

Fig. 5.

WITNESSES:

A. T. Kasley
INVENTOR

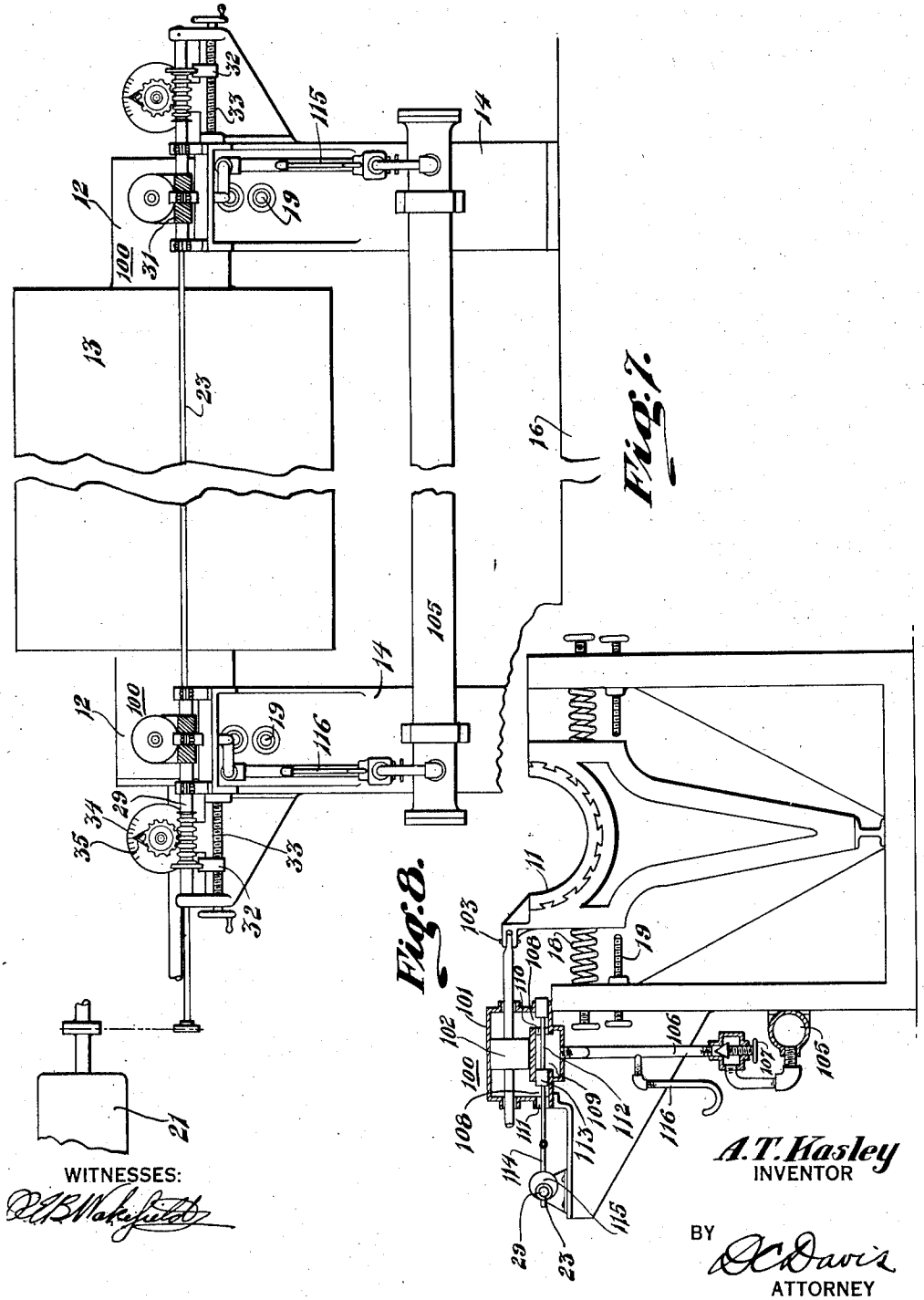
BY D. C. Davis
ATTORNEY

Sept. 15, 1925. 1,553,941

A. T. KASLEY

BALANCING MACHINE

Filed May 31, 1922 7 Sheets-Sheet 4



Sept. 15, 1925.

1,553,941

A. T. KASLEY

BALANCING MACHINE

Filed May 31, 1922

7 Sheets-Sheet 5

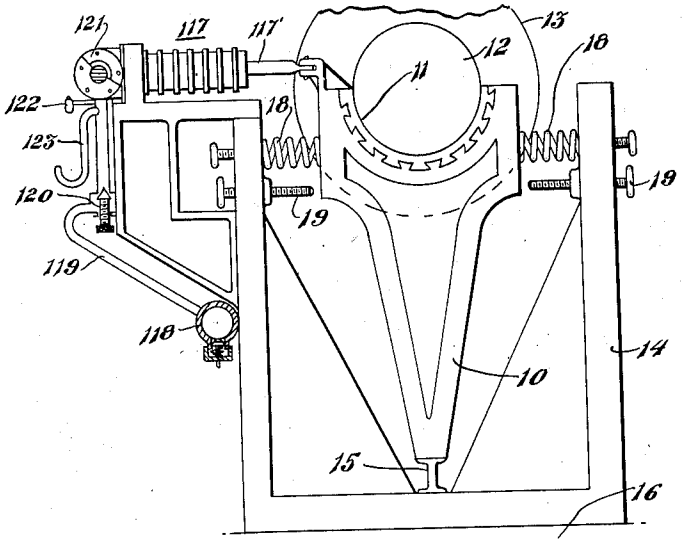


Fig. 9.

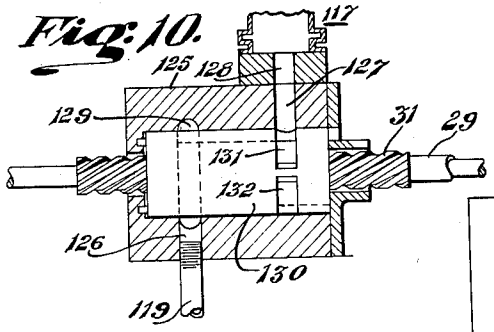


Fig. 10.

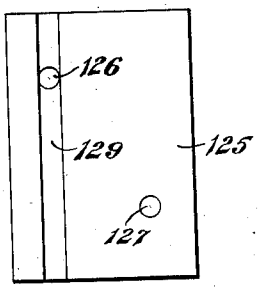


Fig. 12.

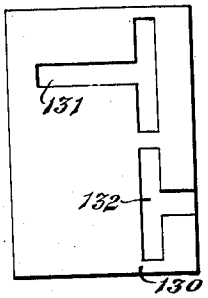


Fig. 11.

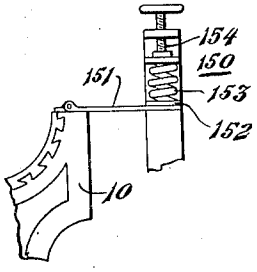


Fig. 22.

WITNESSES:

A. T. Kasley
INVENTOR

BY D C Davis
ATTORNEY

Sept. 15, 1925. 1,553,941

A. T. KASLEY

BALANCING MACHINE

Filed May 31, 1922 7 Sheets-Sheet 6

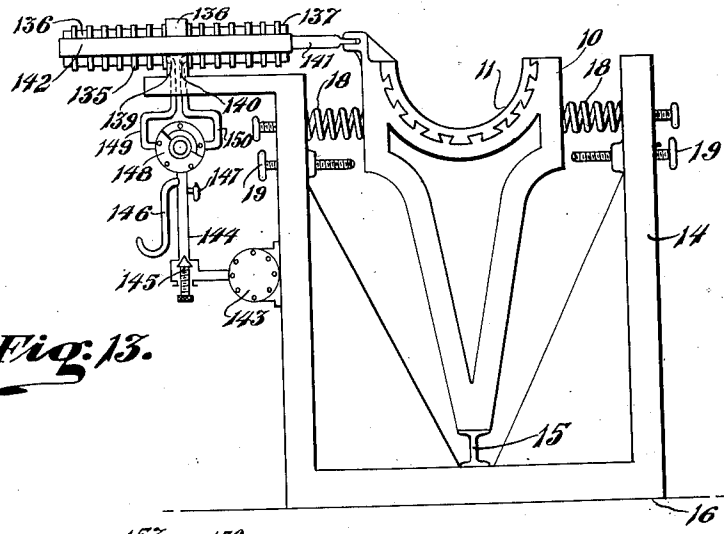


Fig. 13.

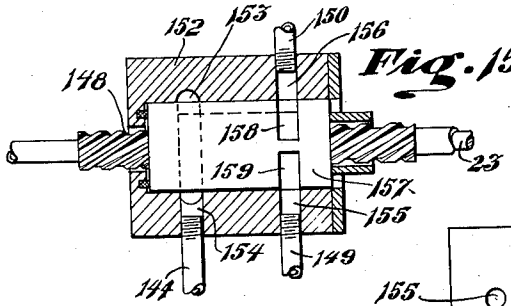


Fig. 15.

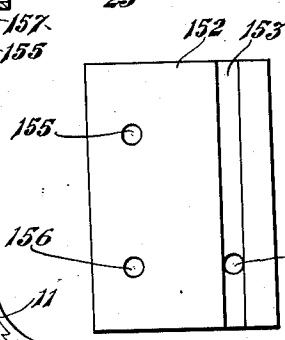


Fig. 16.

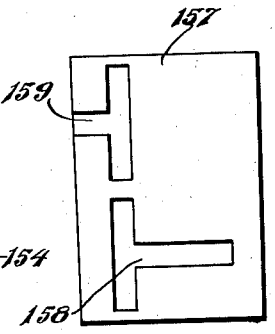


Fig. 17.

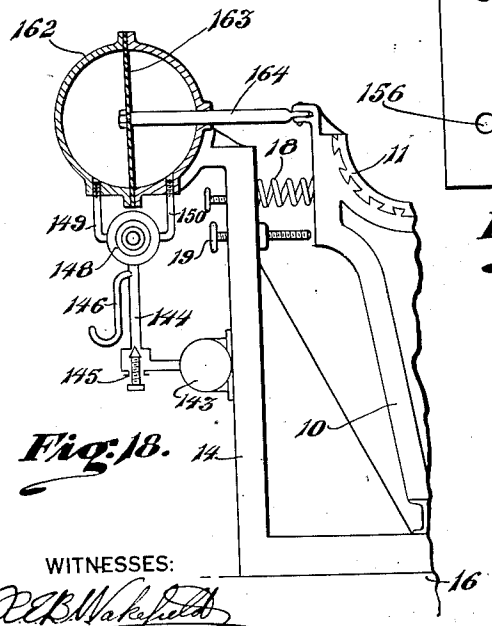


Fig. 18.

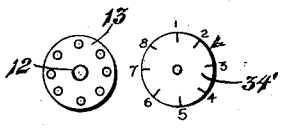


Fig. 19.

WITNESSES:

R. B. Wakefield

A. T. Kasley
INVENTOR

BY D. C. Davis
ATTORNEY

Sept. 15, 1925. 1,553,941

A. T. KASLEY

BALANCING MACHINE

Filed May 31, 1922 7 Sheets-Sheet 7

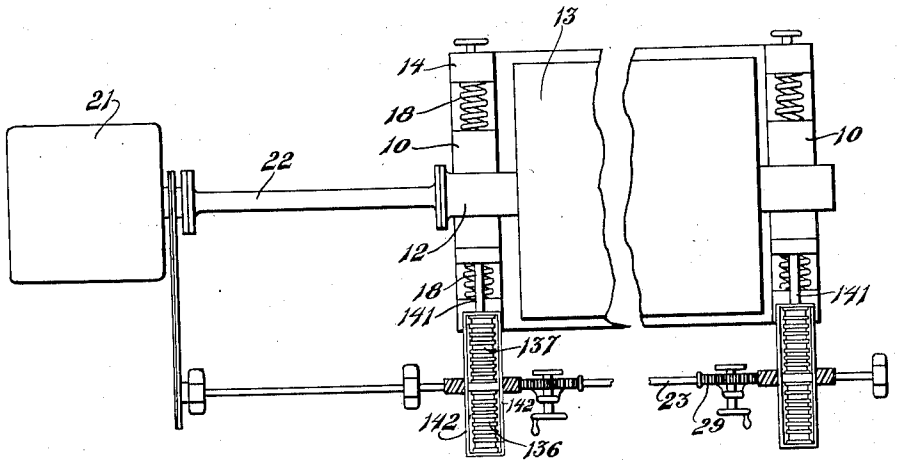


Fig: 14.

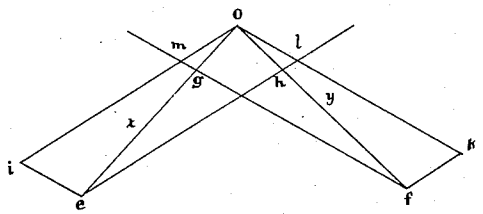


Fig: 21.

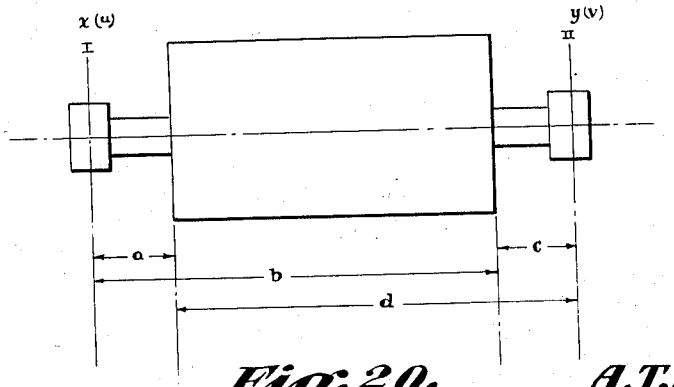


Fig: 20.

A. T. Kasley
INVENTOR

WITNESSES:

BY

ATTORNEY

Patented Sept. 15, 1925. 1,553,941

UNITED STATES PATENT OFFICE.

ALEXANDER T. KASLEY, OF ESSINGTON, PENNSYLVANIA, ASSIGNOR TO WESTINGHOUSE ELECTRIC AND MANUFACTURING COMPANY, A CORPORATION OF PENNSYLVANIA.

BALANCING MACHINE.

Application filed May 31, 1922. Serial No. 564,731.

To all whom it may concern:

Be it known that I, ALEXANDER T. KASLEY, a citizen of the United States, and a resident of Essington, in the county of Delaware and State of Pennsylvania, have invented a new and useful Improvement in Balancing Machines, of which the following is a specification.

My invention relates to balancing machines of the static and dynamic type, and it has for its object to provide apparatus of the character designated which shall be capable of operating to place an unbalanced body both in static and running balance quickly and with a high degree of accuracy.

Apparatus embodying features of my invention is illustrated in the accompanying drawings, forming a part of this application, in which: Fig. 1 is an end elevation of one of the balancing mechanisms for one form of my improved machine; Fig. 2 is a side elevation of the pedestal shown in Fig. 1; Fig. 3 is a sectional view taken along the line III—III of Fig. 2; Fig. 4 is a diagrammatic plan view of a modified form of my improved balancing machine; Fig. 5 is an end elevation of one of the pendulum and pedestal structures shown in Fig. 4; Fig. 6 is a diagrammatic view explanatory of the operation of the apparatus shown in Figs. 4 and 5; Fig. 7 is a fragmentary elevational view of a further modified form of my improved balancing machine; Fig. 8 is an end elevation of the apparatus shown in Fig. 7 with certain parts shown in section; Fig. 9 is an end elevation of a further modified form of my invention; Fig. 10 is a detail view of a rotary valve mechanism employed with the apparatus shown in Fig. 9; Figs. 11 and 12 are developed views of the valve members shown in Fig. 10; Fig. 13 is an end elevation of a further modified form of my invention; Fig. 14 is a plan view of the apparatus shown in Fig. 13; Fig. 15 is a detail view of a rotary valve mechanism employed with the apparatus shown in Figs. 13 and 14; Figs. 16 and 17 are developed views of the valve members shown in Fig. 15; Fig. 18 is an end elevation of a further modified form of my invention; Fig. 19 is a detail view showing a modified form of dial for use with the phase-changing mechanisms employed with all forms except that shown in Figs. 4 and 5; Figs. 20 and 21 are diagrammatic views illustrative of a method for determining the exact degree and position of unbalance at each end of a rotor; and Fig. 22 is a detail view showing frictional braking apparatus for a pendulum.

Balancing machines, as heretofore constructed and known to me, have employed secondary rotary bodies carried by or connected to the vibratory supporting structure for the purpose of imposing impulses or forces upon the latter which are opposed to the impulses or forces imposed thereupon due to the unbalanced condition of the body being balanced, and means are provided for determining the value of the artificially-developed impulse, and therefore the value of the impulse of unbalance, as well as the position of the latter.

In accordance with my invention, I develop properly timed forces or impulses, and of the proper magnitudes, externally of the vibratory supporting structure of the machine, thereby rendering it possible, not only to simplify the vibratory supporting structure, but also to produce a balancing machine which is capable of securing extremely accurate results with rotary bodies of a wide range of sizes. It is characteristic of my improved type of balancing machine that the counter-balancing impulses are developed in a rectilinear manner.

In my improved type of balancing machine, a vibratory pendulum is arranged to support each end of a rotor to be balanced. Each pendulum is carried by a pedestal structure and the latter is provided with screws so that one pendulum may be fixed while the other is free to move in order to effect the operation of balancing at one end at a time. I provide mechanism carried by the pedestal, or other stationary structure, for developing rectilinear forces or impulses which are regulable in time and magnitude and which may be applied to the pendulum to oppose the impulse or force imposed thereupon due to the unbalanced condition of the body or rotor being balanced.

Referring now to the drawings for a more detailed description of my invention, I show a balancing machine comprising vibratory pendulums 10 having bearings 11 for the trunnions 12 of a body 13 to be placed in static and dynamic balance. The pendulums 10 are connected to pedestal or supporting

structures 14, preferably by means of flexible I-beam members 15, and the supporting or pedestal structures 14 are adjustable with respect to a bedplate 16 so as to accommodate rotors of different lengths.

Springs 18 are interposed between the pendulums 10 and the pedestals 14 in order to magnify oscillations or to increase the sensitiveness thereof when a synchronous speed or a condition of resonance is reached, as set forth on pages 174 to 177, inclusive, of the American edition of Steam Turbines, by Stodola, published in 1905 by D. Van Nostrand Company, New York.

Screws 19 are arranged at the upper portions of the pedestals 14 and cooperate with the pendulums 10 so that the latter may be held in fixed positions when required.

Vibration indicators 20 are associated with each of the pedestals 14 and they cooperate with the pendulums for indicating vibrations of the latter.

The rotor 13 is driven by means of a motor 21, which is connected thereto by a suitable shaft connection 22. The motor 21 is also connected to suitable impulse-developing or controlling means to assure the development and application of impulses synchronous with the rotation of the rotor, as will be described.

In Figs. 1 and 2, the shaft 22 is geared to a counter-shaft 23, which is adapted to extend the entire length of the balancing machine and to be supported by bearings 24, carried by the pedestals 14. I show only one pedestal for the reason that the two pedestals of the machine are duplicates, and the relation thereof will be clear from a consideration of Figs. 4 and 7. The counter-shaft 23 is connected to an eccentric 24, adjacent to a pedestal 14, and each eccentric operates a link 25 to oscillate a lever 26 about an adjustable fulcrum 27 so as to alternately place a spring 28, connected between the upper end of the lever 26 and a pendulum 10, in tension and compression.

The rotary body to be balanced applies forces or impulses in opposite directions during each revolution due to its unbalanced condition, and these forces tend to swing or oscillate a pendulum 10. Also, as the shaft 23 operates synchronously with the rotor 13, two spring forces or impulses in opposite directions are applied to a pendulum 10 by a spring 28. Now, if the spring forces or impulses are brought into opposition to the impulses or forces due to the unbalanced condition of the rotor it is possible to diminish vibration of a pendulum due to the unbalanced condition of the rotor. Also, if the spring forces or impulses are adjustable, the spring force or impulse may be caused to counterbalance the impulse or force due to the unbalanced condition of the rotor so as to completely eliminate vibration and therefore to render possible the exact measurement of the impulse of unbalance.

The function of bringing the spring forces or impulses into opposition to the impulses developed due to the unbalanced condition of the rotor is effected by varying the time at which the spring 28 is placed in tension and in compression. This function is accomplished by causing the eccentric 24 to lead or lag with respect to its operating shaft 23, and this effect is produced by having a sleeve 29 splined at 30 with respect to the shaft 23 and having a steep-pitched thread connection 31 with respect to the eccentric 24. If the sleeve 29 is moved longitudinally, obviously the eccentric will be caused to lead or lag with respect to its operating shaft 23.

The sleeve 29 is moved longitudinally, for the purpose of causing the eccentric to lead or lag with respect to its operating shaft 23, by any suitable mechanism, for example, by means of a yoke 32 which is translated by a manually-operated screw 33.

The angle of lead or lag through which an eccentric 24 is shifted is indicated on a suitable dial 34 cooperating with a pointer 35. I show the dial 34 detachably connected to one end of a short shaft 36, journaled in a standard 37, carried by a pedestal 14. A pinion 38 is connected to the other end of a short shaft 36 and it meshes with a circumferential rack 39, carried by a sleeve 29, so that, when the latter is moved, the dial and pointer cooperate to indicate the angle through which the eccentric has been shifted with respect to its operating shaft 23 and therefore with respect to the rotor 13.

The structure just described renders it possible to bring the spring forces or impulses into exact opposition to the forces or impulses developed by the rotor, due to its unbalanced condition. In order to totally damp out the forces or impulses imparted to a pendulum 10 due to the unbalanced condition of a rotor, it is necessary to vary the force of the spring. The latter result is achieved, for example, in Figs. 1 and 2, by having the fulcrum pin 27 carried by a lever 40, which is pivotally connected to a bracket 41 carried by the pedestal 14.

The lever 40 may be swung up and down to change the position of the fulcrum pin 27 with respect to the lever 26, the fulcrum pin 27 being arranged to travel in an arcuate slot 27', which is concentric with the axis of the pivot of the lever 40. Clamping means 42 is associated with the bracket 41 for the purpose of holding the lever 40 in any given position. When the fulcrum pin 27 is shifted, the displacement of the upper end of the lever 26, and therefore compression and tension forces of the spring 28, are varied.

Knowing the scale of the spring 28, it is possible to have means which indicates the tension and compression forces for different settings of the lever 40. I show a pointer 43 which moves with the lever 40 and cooperates with a scale 44 to indicate the intensity of the forces of tension and compression developed by the spring 28.

With the apparatus shown in Figs. 1 and 2, it is, therefore, possible to determine both the angular position of unbalance at an end of the rotor and the magnitude thereof. The angular position of unbalance with respect to the initial setting is determined by observing the extent of the angle of lead or lag as indicated by the dial 33 and the pointer 34. The angle so indicated represents the angular distance on the rotor of the position of unbalance from original or datum positions of the rotor and indicator. The magnitude of the balancing force or impulse is determined from the reading of the pointer 43 with respect to the scale 44.

In operation, one end of a rotor is held in a fixed position by having the screws 19 tightened to hold the corresponding pendulum 10, the other pendulum being free to move. After observing the position and magnitude of unbalance at the free end, the latter end is then fixed, and the other end is freed for the purpose of observing the position and magnitude of unbalance thereat. After the observations are made at each end of a rotor in this manner, the exact extent and position of unbalance at each end are determined in the manner hereinafter set forth.

In Figs. 4 and 5, I show a modified form of my improved balancing machine in which fluid pressure is utilized for the purpose of imposing forces or impulses upon the pendulums to resist the forces or impulses imposed thereupon due to the unbalanced condition of the rotor. The apparatus shown in these views comprises generally an appropriate source of fluid under pressure at 48, for example, compressed air, which is adapted to be placed in communication with either of the motor devices or mechanisms at 49, carried by the pedestals 14, for developing opposing forces or impulses, the admission of motive fluid from the source of supply to the motor devices being under the control of piston valve mechanisms at 50 and 51, the latter operating synchronously with the motor 21 and the rotor 13 directly connected thereto.

Communication is afforded between the fluid pressure supply at 48 and an inlet port 52, arranged at an intermediate point of the casing member 53 of the piston valve mechanism 50, by means of a conduit 54 including a throttle valve 55. In like manner, communication is afforded between the source of fluid under pressure at 48 and an inlet port 57, located at an intermediate point of the valve casing member 58 of the piston valve mechanism 51, by means of a conduit 59 including a throttle valve 60.

The piston valve mechanism 50 comprises an outer casing member 53, having said intermediate inlet port 52 and the outlet ports 61 and 62, and an inner piston valve member 63 which is adapted to place the inlet port 52 in communication either with the outlet port 61 or with the outlet port 62, depending upon the position of the inner valve member 63. In like manner, the piston valve mechanism 51 comprises an outer casing member 58, having said inlet port 57 and the outlet ports 64 and 65, and an inner piston valve member 66 which is adapted to place the inlet port 57 in communication either with the outlet port 64 or with the outlet port 65, depending upon its position. The piston valve member 63 is actuated by an eccentric 68, which rotates with the motor 21 and the rotor 13, so that it places the inlet port 52 in communication with the outlet ports at intervals of 180° of rotation of the rotor 13. The piston valve member 66 is operated by means of an eccentric 69, which is displaced 90° from the eccentric 68, so that the inlet port 57 is placed in communication with the outlet ports 64 and 65 at 180° intervals of rotation of the rotor 13; but, due to the 90° displacement of the eccentrics 68 and 69, the outlet ports 61, 62, 64, and 65 are placed in communication with the source of fluid under pressure at 90° intervals of rotation of the rotor 13. The piston valve casings 53 and 58 are open at the ends to the atmosphere so as to provide for exhaust from one end of a cylinder of the motor devices 49 while the other end is being supplied with fluid under pressure. The eccentrics 68 and 69 are preferably carried by a shaft section 21′ which is coupled directly to the driving motor 21 and to a shaft section 22 which is connected to a trunnion of the rotor 13.

Each of the motor devices 49 comprises axially aligned cylinders 70 and 71 containing pistons 72 and 73, respectively, carried by a piston rod 74, which is connected to a pendulum 10, preferably by a detachable pin connection 75. The cylinder 70 is provided with fluid inlet ports 76 and 77, each of which is adapted to be placed in communication with either of the conduits 78 or 79 connected with the outlet ports 61 and 62, respectively, of the piston valve mechanism 50.

A four-way valve mechanism 80 is employed for connecting either of the conduits 78 or 79 with either of the ports 76 or 77. In like manner, the inlet ports 81 and 82 of the cylinder 71 arranged at opposite sides of the piston 73, are connected to the conduits 83 and 84 which communicate with the outlet ports 64 and 65, respectively, of the piston valve mechanism 51, a four-way

valve mechanism 85 being employed for the purpose of affording communication between either of the ports 81 and 82 and either of the conduits 83 and 84.

The conduits 78, 79, 83, and 84 are provided with valves 87, 88, 89, and 90, whereby communication may be controlled with the left hand motor device 49 and with the valves 91, 92, 93, and 94 whereby communication with the right hand motor device 49 may be controlled.

Pressure gauges or manometric devices 95 and 96 communicate with the conduits 54 and 59, respectively, between the throttle valves 55 and 60 and the inlet ports 52 and 57, respectively, so that the exact pressure of fluid admitted to an inlet port may be ascertained.

Apparatus made in accordance with Figs. 4 and 5 is operated as follows: The rotor 13 to be balanced is placed in the pendulum bearings 11 and the screws 19 for both pendulums 10 are retracted and the pendulums are disconnected from the piston rods 74 so that the rotor may be speeded up to ascertain its state of balance. If the vibration indicators 20 show that the rotor is out of balance, then the operation of balancing is proceeded with. One pendulum is then locked by the screws 19. The throttle valves 55 and 60 are slightly opened, one at a time, and the corresponding four-way valve is moved to its two positions and it is observed whether or not vibrations of the pendulum 10 are minimized due to the introduction of pressure into motor device 49. Then both throttle valves are opened slightly and the effect on vibration is noted. As already pointed out, each piston valve is capable of transmitting two fluid impulses, spaced 180° apart, for each revolution of the rotor; and by manipulating the four-way valve associated with the conduits connected with the piston valve mechanisms, the impulses may be reversed. It is, therefore, possible, by manipulating the throttle valves separately and by shifting the four-way valves associated with the respective sets of conduits, to impose fluid-pressure impulses upon the pendulum for four definitely determined 90° positions. If the position of unbalance on the rotor should be so located as to cause its impulse to be imposed upon the pendulum in exact opposition to any of the definitely determined 90° fluid-pressure impulses, then the position of the unbalancing mass is thereby determined and its magnitude may be readily ascertained by increasing the pressure by opening wider the proper throttle valve. Observation of the corresponding pressure indicating or manometric devices 95 and 96 indicates the magnitude of the unbalancing mass.

Whatever arrangement of throttle valves and four-way valves is accompanied by a minimum amount of vibration of the pendulum 10 is indicative of the fact that the fluid pressure impulses are in opposition to the impulses developed, due to the unbalanced condition of the rotor. The fluid pressure is then increased by opening the throttle valve or valves wider until vibration ceases. From a consideration of the eccentric or eccentrics and the position of the four-way valve or valves, the position of unbalance may be localized. If the opening of one throttle valve is sufficient to create a balanced condition, then the pressure indicated by its associated manometric device gives a measure of the unbalancing mass; however, should it be necessary to open both throttle valves to obtain a balanced condition, then the pressures indicated by the manometric devices 95 and 96 are components of a resultant which represents the magnitude of the unbalancing mass.

While the average air and inertia characteristics or cards may balance each other, yet there are times when these forces do not balance which may result in high period vibration. However, friction is sufficient to damp out these vibrations, or frictional braking apparatus may be used for this purpose. See Fig. 22 in which a pendulum has a braking connection at 150 with respect to the corresponding pedestal. Any suitable braking connection may be employed, for example I show a movable plate member 151 connected to the pendulum and engaged by a stationary plate 152 engaging the plate member 151 with a pressure which depends upon the tension of the spring 153 and the tension of the latter may be varied by appropriate adjustment of the follower 154. Not only is the frictional apparatus at 150 useful in this relation, but it may be used with any of the modifications described for the purpose of limiting or dampening vibrations in order that observations of the vibration indicators may be more readily made.

The operation may be more readily understood by a consideration of the Fig. 6, in which the circle represents one end of a rotor. The positions *a* and *b*, arranged 180° from each other, indicate fluid pressure impulses which are developed by the introduction of fluid under pressure into correspondingly indicated ends of the cylinder 70, and the positions *c* and *d*, arranged 180° apart and 90° from the positions *a* and *b*, indicate fluid pressure impulses corresponding to those developed by the introduction of fluid under pressure to correspondingly indicated ends of the cylinder 71. If the unbalance of the rotor should be in exact opposition to the pair of impulses *a* and *b* or to the

pair of impulses *c* and *d*, then neutralization of the impulse of unbalance may be readily accomplished by properly controlling the direction and magnitude of the pairs of impulses *a* and *b* or *c* and *d*.

In practice, however, it seldom occurs that the condition of coincidence pointed out takes place. In other words, it is usually necessary to open both throttle valves and to manipulate the corresponding four-way valves in order to effect neutralization of impulses. As the eccentrics 68 and 69 have a phase difference of 90° and as each eccentric is capable of operating a piston valve mechanism to develop fluid pressure impulses 180° apart for each revolution of the rotor, it will be apparent that the two eccentrics and the two piston valve mechanisms are capable of transmitting fluid-pressure impulses for each 90° of rotation of the rotor. Also, the four-way valves 80 and 85 may be so manipulated as to secure a leading or lagging effect of the impulses with respect to the rotation of the rotor so that the impulses may be brought into opposition to the impulses of unbalance. For example, for any given position X on the rotor, the following sequences of impulses may be obtained:—

a c b d
c b d a
b d a c
d a c b

In other words, by manipulating the four-way valves the quadrant of the rotor containing the position of unbalance may be localized; and, from the magnitude of the pressures indicated by the indicating or manometric devices 95 and 96, the resultant fluid-pressure impulse, which is equal and opposed to the impulse of unbalance, as well as the angular position thereof, may be readily ascertained. For example, if the position of unbalance should be localized in the quadrant *a c*, then the throttle valves 55 and 60 are so manipulated as to secure cessation of vibration of the pendulum 10 and the vectors *o m* and *o n* may be drawn so that the lengths thereof represent the magnitudes of the pressures indicated by the manometers 95 and 96. The resultant *o p* indicates the magnitude of the resultant fluid impulse which is equal and opposed to the impulse of unbalance. The length of the line *o p* is therefore a measure of the unbalanced mass and its angular position in the quadrant indicates its position on the rotor.

As already pointed out, after the position and magnitude of unbalance at one end of the rotor is ascertained, the other end is then operated upon to ascertain the position of magnitude of unbalance at that end.

In Figs. 7 and 8, I show a further modified form of my improved balancing machine. In this modification some of the features shown in Figs. 1 and 2 are combined with some of the features shown in Figs. 4 and 5. That is, fluid pressure is relied upon to impose impulses upon the pendulum 10 in opposition to the impulses of unbalance and a phase-changing mechanism is employed for the purpose of changing the phase relationship between the fluid-pressure impulses and the impulses of unbalance. The combination of these features very materially simplifies the fluid-pressure apparatus and makes it possible to avoid the use of long pipes or conduits.

In Fig. 7, I show a rotor 13 which is driven by a motor 21 coupled thereto as hereinbefore described. The motor drives the rotor 13 as well as the countershaft 23 for operating the valve eccentrics hereinafter referred to.

Each pedestal 14 is provided with a fluid-pressure motor device at 100, including a cylinder 101 and a piston 102, the piston being connected to the pendulum 10 by any suitable means, for example, by a detachable pin connection 103. Fluid under pressure is supplied to the cylinder 101 from any suitable source 105 by means of a suitable conduit connection 106, which includes a throttle valve 107. The cylinder is provided with inlet and exhaust passages 108 adapted to communicate with the chest 109 by means of ports 110 and with the atmosphere by means of ports 111. The chest 109 is supplied with fluid under pressure from the conduit 106. A piston valve 112 having piston portions 113 operates in the ports to place opposite ends of the cylinder 106 alternately in communication with the chest 108 and with the atmosphere.

The piston valve 112 is actuated by a suitable connecting rod 114 associated with an eccentric 115, which has a suitably threaded connection 31 with respect to a longitudinally movable sleeve 29, which is moved with respect to the counter-shaft 23 by means of a suitable yoke 32 and operating screw 33.

A manometer 116 is associated with the conduit 106 between the throttle valve 107 and the fluid-pressure motor at 100 in order to indicate the degree of pressure of the fluid supplied to the latter.

In operation, the throttle valve 107 is opened slightly and the sleeve 29 is reciprocated longitudinally in order to cause the eccentric 115 to lead or lag with respect to the shaft 23, which is operated synchronously with the rotor 13. In this way, it is possible to so vary the time of operation of the fluid-pressure motor at 100 with respect to the rotation of the rotor 13 as to bring the impulses developed by said motor into opposition to the impulses of unbalance. Therefore, the sleeve 29 is reciprocated until

a point is reached where the minimum vibration of the pendulum 10 takes place; and, thereafter, the pressure of fluid supplied to the motor device at 100 is increased by opening the throttle valve 107 wider and wider until vibration of the pendulum ceases.

The angle through which the eccentric 115 has been shifted with respect to the counter-shaft 23, and therefore with respect to the rotor 13, is indicated by the position of the pointer 35 relatively to the dial 34, as pointed out in connection with Figs. 1 and 2. The indication on the dial, therefore, gives the angular position of the unbalanced mass of the rotor, and the pressure indicated by the manometric device 116 is a measure of the magnitude of the unbalanced mass.

In Fig. 9, I show a further modified form of my improved balancing machine in which a fluid-pressure motor device 117 of the sylphon type is employed for developing impulses for imposition upon the pendulum 10 to resist vibration thereof due to the impulse of unbalance of the rotor 13. The sylphon is connected to a pendulum by a detachable link connection 117', similar to the link connections described in connection with Figs. 4, 5, 7, and 8. It has been found that a single-acting sylphon is sufficient to damp out vibrations due to the impulse of unbalance for the reason that the pressure applied by the sylphon may cooperate with the opposing reactive pressure of one of the springs 18, so that the sylphon pressure and the spring pressure cooperate to damp out the two impulses in opposite directions for each revolution of the rotor 13.

Fluid under pressure is supplied to the sylphon mechanism 117 from any suitable source 118 by means of a conduit 119, including a throttle valve 120 for varying the pressure of fluid admitted to the admission valve 121. The portion of the conduit between the throttle valve 120 and the admission valve preferably includes a pressure relief valve 122 for limiting the pressure so that the sylphon mechanism will not be supplied with fluid under excessive pressure. A pressure-indicating device 123, for example, of the manometric type, is arranged in the conduit between the throttle valve 120 and the admission valve 121 for the purpose of indicating the pressure of fluid supplied to the sylphon mechanism.

The admission valve 121 is preferably of the rotary type. It is normally operated in synchronism with the body being balanced, and it is provided with means whereby the time of its operation may be varied with respect to the rotation of the rotor so that fluid-pressure impulses developed by the sylphon mechanism 117 may be varied in order that opposition of impulses may be brought about. For example, in Figs. 10, 11 and 12, I show one form of rotary valve which may be used for this purpose.

In Fig. 10, I show a valve casing 125 which is provided with a fluid inlet port 126 adapted to communicate with the fluid-pressure supply conduit 119 and with a port 127 adapted to communicate with a passageway 128 which communicates with the sylphon mechanism 117. The valve casing is provided with an annular interior channel 129 which communicates with the inlet port 126. See Fig. 12.

The interior or rotary valve member 130 is provided with T-shaped recesses 131 and 132, as may be more clearly seen from the developed view, Fig. 11. The T-shaped recess 131 is adapted to afford communication between the channel 129 and the port 127 through nearly 180° of rotation of the valve member 130. In like manner, the T-shaped recess 132 is adapted to afford communication between the port 127 and the atmosphere for nearly 180° of rotation of the interior valve member 130, in order that the pressure in the sylphon mechanism 117 may be relieved. It is to be understood that any suitable valve mechanism may be used to admit and exhaust fluid from the sylphon 117, and that the valve 121 particularly described is to be considered by way of example only.

The interior valve member 130 fits steep threads 31 on a reciprocating sleeve 29 splined to a shaft 23 driven in synchronism with the rotor as in Fig. 2. The sleeve 29 is provided with a circumferential rack portion for operating an angle indicating device as hereinbefore described, in connection with Figs. 1, 2, 7, and 8.

While I show only one pedestal 14 in Fig. 9, it is to be understood that the two pedestals are alike and that separate impulse-developing means is carried by each pedestal as may be seen from other views in this application, for example, see Fig. 14.

The apparatus shown in Fig. 9 operates as follows: The unbalanced body 13 is placed on the pendulums 10 and brought up to balancing speed. One pendulum is freed for vibration while the other is held fixed by the holding screws. The sleeve 31, associated with the free pendulum, is reciprocated in order to vary the timing of the valve 121 in order to vary the time at which fluid-pressure impulses are applied by the sylphon 117. When the fluid-pressure impulses are brought into opposition to the impulses of unbalance of the rotor, the vibratory supporting member or pendulum 10 vibrates at a minimum. Thereafter, the pressure of fluid admitted to the sylphon mechanism 117 may be increased by opening the throttle valve 120 until a point is reached where vibration of the pendulum ceases. It has been found that a single

sylphon mechanism is sufficient to perform the operation of balancing for the reason that a sylphon and an opposed spring constitute a pair of impulse-developing means which are capable of applying impulses to the pendulum in opposite directions in order to oppose the impulses imposed upon the latter due to the unbalance of the rotor. For example, in Fig. 9, I show only one sylphon mechanism 117, which is capable of developing a fluid-pressure impulse toward the right. In operation, the latter impulse is opposed by the force of the right-hand spring 18; and, as the fluid-pressure is built up, the right-hand spring is compressed, and these two forces, namely, the fluid-pressure and the force of the right-hand spring 18, cooperate to resist the impulses of unbalance of the rotor.

The pressure of fluid admitted to the sylphon 117 may be varied by operating the throttle valve 120 and the conduit arranged between the throttle valve and the sylphon is provided with a pressure relief valve 122 so as to limit the pressure which may be applied to the sylphon mechanism. The latter portion of the conduit is also provided with any suitable pressure-indicating device 123 so that the exact degree of pressure of fluid supplied to the sylphon may be ascertained. The timing of the valve 121 is accomplished by shifting the sleeve 31. When starting, only a slight amount of pressure is admitted to the sylphon 117 so that the position where maximum vibration occurs may be determined by varying the timing of the valve 121. When this position is found, the pressure of fluid admitted is increased by opening wider the throttle valve 120 until vibrations cease.

After one end of the rotor is balanced in this way, the pendulum at that end is fixed and the other pendulum is freed for balancing of the other end of the rotor.

In Figs. 13 to 17, inclusive, I show a further modified form of balancing machine in which a double-acting sylphon mechanism 135 is employed for imposing impulses upon a pendulum 10 to resist the impulses imposed upon the latter due to the unbalance of the rotor. The double-acting sylphon mechanism 135 comprises a sylphon 136 active toward the left and a sylphon 137 active toward the right. The sylphons are secured to an intermediate abutment 138 which is provided with inlet supply ports 139 and 140 communicating with the sylphons 136 and 137, respectively. The sylphons 136 and 137 are connected to a pendulum 10 by common mechanism, including a rod 141, which is connected in any suitable manner to the outer end of the sylphon 137 and detachably connected to a pendulum 10 so as to transmit the impulse developed by the latter to the pendulum, such impulse being transmitted by compression of the rod 141. The other sylphon 136 is connected to the rod 141 by means of side links 142 so that, when the sylphon 136 moves outward, a pull is transmitted by the side links 142 and the rod 141 to the pendulum 10.

Fluid under pressure is supplied to the passages 139 and 140 from any suitable source 143 by means of a conduit 144, which includes a suitable throttle valve 145, a pressure-indicating device 146, pressure relief valve 147, and a rotary valve mechanism 148 for affording communication between the conduit 144 and the conduits 149 and 150 communicating with the sylphons 136 and 137, respectively.

The rotary valve 148 will be more clearly understood upon reference to Figs. 15, 16, and 17. The rotary valve comprises an outer casing member 152 which has an interior annular channel 153 communicating with a supply port 154, which communicates with the conduit 144. The casing member is also provided with ports 155 and 156 arranged 180° apart which communicate, respectively, with the conduits 149 and 150. The inner rotary valve member 157 is provided with T-shaped recesses 158 and 159, the T-shaped recess 158 being adapted to afford communication between the annular channel 153 and the supply ports 155 and 156 for nearly 180° of rotation of the inner valve member 157 and the T-shaped recess 159 being adapted to afford communication between the ports 155 and 156 and the exhaust, alternatively during nearly 180° of rotation of the inner valve member. When the recess 158 affords communication between the channel 153 and one of the ports 155 or 156, the other recess 159 affords communication between the other of the ports 155 or 156 and the atmosphere. In this way, when fluid under pressure is being admitted to one of the sylphons, the other sylphon is in communication with the atmosphere.

The inner valve member 157 is rotated by means of a shaft 23 through the intermediary of timing mechanism, including a shiftable sleeve having a steep-threaded connection with respect to the rotary valve member 157 and a splined connection with respect to the shaft 23. The timing or phase-shifting mechanism has been hereinbefore described at length, and it will not be necessary to refer to it further.

Apparatus made in accordance with Figs. 13 to 17, inclusive, operates as follows: The unbalanced body is placed in the bearings of the pendulums 10, and air at a slight pressure is admitted into the conduit 144 after the rotor has been brought up to balancing speed. The inner rotary valve member 157 is then shifted until a point is

reached where minimum vibration occurs. Thereafter, pressure fluid at increasing pressures is admitted to the rotary valve by opening the throttle valve 145 wider until such a point is reached that vibration of the pendulum 10 ceases. From a reading of the dial and pointer mechanism associated with the phase-shifting device of the rotary valve, the exact position of unbalance on the rotor may be determined; and, from consideration of the pressure shown by the pressure-indicating device 146, the magnitude of the fluid-pressure impulses developed by the sylphons 136 and 137 may be ascertained.

The pressure relief device 147, like the relief device 122 of Fig. 9, serves to limit the maximum pressure which may be imposed upon the sylphons.

In Fig. 18, I show a further modified form of my improved balancing machine in which the fluid-pressure controlling apparatus is the same as that shown in Figs. 13 to 17, inclusive, but the motor device is different. That is, instead of sylphons, a chamber 162 is employed which has a diaphragm 163 connected by means of a rod 164 to a pendulum 10. Instead of having the conduits 149 and 150 supplying fluid under pressure to two sylphons 136 and 137, as in Fig. 13, in Fig. 18, I show similar conduits for supplying fluid under pressure to opposite sides of the diaphragm 163. As the diaphragm is not subject to distortion due to excessive pressures, as is the case with sylphon mechanism, it is unnecessary to supply the diaphragm type with pressure relief mechanism. In Fig. 18, I have, therefore, omitted the pressure relief device 147 associated with the conduit 144 in Fig. 13.

Apparatus made in accordance with Fig. 18 operates substantially the same as that shown in Figs. 13 to 17, inclusive, except that the diaphragm transmits impulses oppositely to the sylphon 135 for given fluid admissions, and further description thereof is deemed to be unnecessary.

With the modifications utilizing elastic fluid, such as air, (Figs. 4 to 18 inclusive) allowance must be made for the fluid necessary to fill the clearance spaces in compression. A variable lag is, therefore, introduced which must be taken care of by properly calibrating the machine.

As hereinbefore pointed out in connection with Fig. 4, the inertia impulses of the body being balanced may not at all times be truly balanced by the artificially-developed counter impulses, although their average values may be equal. This condition may be productive of a high-frequency vibration at such times as the counter forces do not balance and friction may be relied upon to damp out these vibrations. The friction, or resistance of the apparatus to movement, may serve to damp out these vibration; or, if necessary, the frictional or braking apparatus shown in Fig. 22 may be employed.

The frictional or braking apparatus shown in Fig. 22 is also useful in limiting or damping vibrations so that balancing may be more expeditiously performed.

In the operation of apparatus made in accordance with any of the aforesaid modified forms, it may be advantageous to observe the position of maximum vibration in order to determine the position of minimum vibration, the latter being 180° from the former.

The dial construction used with all modifications with the exception of Figs. 4 and 5, may be simplified as shown in Fig. 19; and, for this reason, I have shown the dial 34 as being detachably connected to its operating shaft 36 in Fig. 3. Rotors to be balanced ordinarily have a circumferential series of balance openings at each end; and, in Fig. 19, I show one end of a rotor 13 having eight balance openings. I propose to have dials having thereon the same number and spacing of indications as the balance openings in the end of the rotor. In Fig. 19, I show such a dial 34′ which has eight balance indications corresponding to the eight balance openings in the end of the rotor. With this dial in position, it is not necessary to read the phase angle in degrees, but the pointer will either coincide with one of the indications or be located between two adjacent indications. For example, if the pointer should register with indication 5, this indicates that material should be added to the balance opening 5 of the rotor, the amount of material to be so added being ascertained by magnitude determining means. If the pointer should come to rest between two indications, for example, between indications 2 and 3, as indicated in Fig. 17, it is then necessary to divide the amount of material between adjacent openings inversely as the distances of the pointer therefrom.

After the position and magnitude of unbalance is determined for each end of a rotor by any of the machines hereinbefore described, it is necessary to resort to further computation in order to obtain, with precision, the exact mass to be added to each end of a rotor as well as the exact position at which the additions are to take place. The reason for this is that the planes of the balance openings in the ends of a rotor do not coincide with the median planes of the supporting bearings 11 and therefore the indicated impulse of unbalance at a rotor end represents not only the actual unbalance at the end under observation, but also the effect of unbalance of the other end at the end under observation. For example, in

Fig. 20, if the bearing at I is fixed and the bearing at II vibrates, as a result of unbalance of the rotor, then the impulse of unbalance is due, not only to the unbalance of the end adjacent to the bearing II, but also to the effect of unbalance of the end adjacent to the fixed bearing at I at the end designated II. The indicated balance on any of the measuring devices hereinbefore described, therefore, does not represent the exact mass to be added to each end of the rotor nor is the indicated angular position correct. It is, therefore, necessary to analyze the indicated impulse so as to obtain the true amount of material to be added to each end of the rotor and the true angular position at which each addition is to take place, if extremely accurate results are to be obtained; and, I disclose, for example, the following method for making the computation:

In Fig. 20, assume that the bearing at the end II is fixed and that the bearing at the end I is free to move. If the indicating apparatus indicates that the end of the rotor at I is out of balance x units, it is evident that this indication is a resultant of the true unbalance at the end I and the unbalance at the end II which is effective at the end I. In like manner, if the end I is fixed and the end at II is free to move, the indicating apparatus will indicate that the end at II is out of balance y units; and, likewise, this amount is a resultant of the true unbalance at the end II and the unbalance at the end I which is effective at the end II.

The problem presented for solution, therefore, is to find the components of these resultants so as to ascertain the exact amount of unbalance effective at each end of the rotor. If the true unbalance at the end I is assumed to be u and the true unbalance at the end II is assumed to be v, the distances of the planes of the balance openings of the rotor at the ends II and I from the median plane of the bearing at the end I to be a and b, respectively, and the distances of the planes of the balance openings at the ends I and II from the median plane of the bearing at II to be c and d, respectively, then x is the resultant of u and $\frac{c}{d} x v$ and y is the resultant of v and $\frac{a}{b} x u$.

In Fig. 21, lay off the vectors $o e$ and $o f$ corresponding in angular position and magnitude to the resultants x and y, respectively. Find a point g on the vector $o e$ such that the distance $g o$ is equal to $\frac{a}{b} x o e$ or $\frac{a}{b} x x$. In like manner, find a point h on the vector $o f$ such that the distance $o h$ is equal to $\frac{c}{d} x o f$ or $\frac{c}{d} x y$. Draw lines from e and f passing through the points h and g, respectively. Draw lines from o which are parallel with the lines $e h$ and $f g$, one line intersecting $e h$ prolonged at l and the other line intersecting $f g$ prolonged at m. Complete the parallelograms by drawing the lines $e i$ and $f k$ parallel, respectively, with the intercepts $o l$ and $o m$. From geometry, it is evident that the line $o k$ is divided at l in the same ratio as the line $o f$, that is, $o l$ is equal to $\frac{c}{d} x o k$. In like manner, the portion $o m$ of $o i$ is equal to $\frac{a}{b} x o i$.

The figures $o i e l$ and $o m f k$ are parallelograms of which $o e$ (x) and $o f$ (y) are diagonals. Therefore, the vector $o e$ (x) is the resultant of $e l$ or $o i$ and $o l$ or $\frac{c}{d} x o k$. In like manner, $o f$ (y) is the resultant of $f m$ or $o k$ and $o m$ or $\frac{a}{b} x o i$. It is evident, therefore, that $o i$ or $e l$ is equal to u and $o k$ or $m f$ is equal to v, as set forth in the preceding paragraph; and the values there of may be exactly determined either by direct measurement or by calculation. The angle between the lines $o i$ and $o e$ represents the angle in a clockwise direction beyond the line $o e$ at the end I of the rotor at which a mass corresponding to u must be added. Also, the angle between the lines $o f$ and $o k$ indicates the true angular position at which the mass v must be added at the end II of the rotor beyond the position of the indicated unbalance y.

While I have particularly set forth one method of accurately determining the exact degree of unbalance of each end of a rotor, it is to be understood that, in practice, tables and charts may be provided which are based on the characteristics of a particular machine in order to expedite the work of balancing.

From the foregoing, it will be apparent that I have devised an improved type of balancing machine which is both extremely accurate and capable of handling large-sized rotors. It is characteristic of my invention that the supporting devices for the rotor are made as simple as possible, that is, they are not encumbered with neutralizing-impulse developing devices, and impulses of a rectilinear type are developed by apparatus carried by the supporting structure which are imposed upon the pendulums for the purpose of opposing the impulses imposed thereon due to the unbalance of the rotor. The rectilinear impulses are easily timed with respect to the rotation of the rotor and the magnitude of such impulses may be easily varied in order to secure a state of neutralization. The timing mechanisms and the magnitude-changing devices

are provided with indicating means whereby the phase angle and the impulse magnitude are capable of being directly observed.

While I have shown my invention in several forms, it will be obvious to those skilled in the art that it is not so limited, but is susceptible of various other changes and modifications without departing from the spirit thereof, and I desire, therefore, that only such limitations shall be placed thereupon as are imposed by the prior art or as are specifically set forth in the appended claims.

What I claim is:

1. In a balancing machine, a horizontally movable support for supporting one end of a rotary body to be balanced, a fluid pressure motor for resisting movement of the movable support, and means for energizing the fluid pressure motor in a definite timed relation to the rotation of the body.

2. In a balancing machine, the combination of horizontally movable supports for supporting a body to be balanced, means for holding each support in a fixed position, a fluid pressure motor associated with each support, and means for energizing the fluid pressure motor associated with a freely movable support at the proper time to resist movement of the movable support due to the unbalanced condition of the body.

3. In a balancing machine, a stationary member, a movable member for supporting a rotary body to be balanced, an energy source, and means carried by the stationary member to control the application of energy to said movable member to neutralize the running unbalanced condition of the rotary body, said means being operative in a definite timed relation to the rotation of the body.

4. In a balancing machine, a movable member for supporting a rotating body to be balanced, a motor device for developing impulses, means operative synchronously with the body for supplying energy to said motor device, means for determining the intensity of the impulses, means for controlling the motor so that the latter may develop impulses in opposition to the impulses developed due to the unbalanced condition of the rotary body, and means for indicating the phase relation of the developed impulses.

5. In a balancing machine, a movable member for supporting a rotary body to be balanced, a fluid-pressure motor for resisting movement of the body due to its unbalanced condition, means for indicating the pressure of fluid supplied to said motor, and controlling means for the motor, whereby the latter may be rendered effective to prevent movement of the rotating body due to its unbalanced condition.

6. In a balancing machine for balancing a rotary body, means for restricting movement of the body due to its unbalanced condition to a predetermined path, fluid-pressure means for resisting movement of the body in said path, means for indicating the pressure of fluid supplied to said fluid-pressure means, and controlling means associated with said fluid-pressure means, whereby the latter may be rendered effective to prevent movement of said body in said path due to its unbalanced condition.

7. In a balancing machine, the combination of a horizontally movable support for a body to be balanced, a motor device for developing impulses in opposite directions during each rotation of the body being balanced, means for energizing the motor device which is operative normally in synchronism with the body being balanced, means for causing the impulses to lead or lag with respect to rotation of the body, means associated with the energizing means to vary the intensity of the impulses, whereby, when the impulses developed by the motor device are opposite and equal in intensity to the impulses developed by the rotary body, vibrations of the latter will cease, means for indicating the extent of lead or lag, and means associated with the energizing means to indicate the intensity of impulses developed thereby.

8. In a balancing machine, the combination of two horizontally movable supports, means for yieldingly restraining the supports, means associated with each support for holding it in a fixed position when desired, a motor device for each movable member for imposing impulses in opposite directions upon the latter in its plane of movement during each revolution of the body being balanced, means operating normally in synchronism with a body for controlling the admission of motive fluid to the motor devices, means for causing the last-named means to lead or lag with respect to said body, means for increasing or decreasing the pressure of motive fluid supplied to the motor devices, means for indicating the angle of lead or lag of said motive fluid admission means, and means for indicating the pressure of motive fluid supplied to said motor devices.

9. A balancing machine comprising a horizontally movable supporting member for a body to be balanced, a double-acting motor device of the reciprocatory type for opposing movement of said member due to the unbalanced body including a valve for controlling the admission of motive fluid thereto, means for operating said valve and normally driven in synchronism with said body, means for causing the operation of the valve to lead or lag with respect to said body, means for indicating the extent of lead or lag, and means for indicating the pressure of fluid admitted by said valve.

10. In a balancing machine for a rotary body having a plurality of circumferentially spaced balanced openings, a vibratory supporting member for a body adapted to be moved due to the unbalanced condition of the latter, means for opposing movement of the vibratory supporting member in response to the unbalanced condition of the body and operating normally in synchronism with said body, means for varying the effectiveness of said means including indicating means, means for causing said opposing means to lead or lag with respect to said device, and an indicator associated with said last-named means having indicia spaced proportionally or similarly to said balanced openings.

11. The process of determining the resultant unbalanced force and the plane thereof of a rotary body carried by a movable supporting member which consists in developing impulses in opposite directions by fluid under pressure during each revolution of the rotary body, in changing the phase relationship of the impulses with respect to the rotation of the body in order to bring the fluid pressure impulses into opposition with the impulses developed by the body due to its unbalanced condition, in observing the angle through which the phase has been changed, in increasing the intensity of the fluid pressure impulses until the latter are equal to the impulses developed by the body due to its unbalanced condition, and in observing the pressure of fluid supplied for developing impulses.

12. In a balancing machine, a pedestal, a pendulum adapted to support one end of a body to be balanced and to be moved in response to the unbalanced condition of the body, a shaft driven in synchronism with the body, impulse-developing means to apply impulses to the pendulum, an eccentric for securing operation of the impulse-developing means, and a connection between the eccentric and the shaft such that the eccentric may be caused to lead or lag with respect to said shaft.

13. In a balancing machine, a pedestal, a pendulum adapted to support one end of a body to be balanced and to be moved in response to the unbalanced condition of the body, a shaft driven in synchronism with the body, impulse-developing means to apply impulses to the pendulum, an eccentric for securing operation of the impulse-developing means, and a connection between the eccentric and the shaft such that the eccentric may be caused to lead or lag with respect to said shaft.

14. In a balancing machine, a pedestal, a pendulum adapted to support one end of a body to be balanced and to be moved in response to the unbalanced condition of the body, a fluid motor carried by the pedestal and operatively connected to the pendulum, a valve for controlling the admission of motive fluid to said motor, means for normally operating the valve synchronously with the body, and means for causing the operation of said valve to lead or lag with respect to said body, and means for varying the power of said motor.

15. In a balancing machine, a pedestal, a pendulum adapted to support one end of a body to be balanced and to be moved in response to the unbalanced condition of the body, a fluid motor carried by the pedestal and operatively connected to the pendulum, a valve for controlling the admission of motive fluid to said motor, means for normally operating the valve synchronously with the body, and means for causing the operation of said valve to lead or lag with respect to said body.

16. In a balancing machine, a pedestal, a pendulum adapted to support one end of a body to be balanced and to be moved in response to the unbalanced condition of the body, a fluid motor carried by the pedestal and operatively connected to the pendulum, a source of motive fluid under pressure, a valve for controlling the admission of motive fluid to said motor, means for normally operating the valve synchronously with the body, means for causing the operation of said valve to lead or lag with respect to said valve, means for controlling the pressure of fluid discharged from said source to said motor, an indicating device for indicating the extent of lead or lag, and a pressure-indicating device for indicating the pressure of fluid supplied to said motor.

17. In a balancing machine, the combination of a vibratory member for supporting a body to be balanced and fluid pressure means for developing impulses rectilinearly for imposition on said vibratory member to oppose vibration thereof due to the impulse of unbalance of the body.

18. In a balancing machine, the combination of a vibratory member for supporting a body to be balanced, springs for normally holding the vibratory member in a given position and resisting vibrational movements thereof, and fluid-pressure means for developing impulses rectilinearly for imposition on said vibratory member.

19. In a balancing machine, the combination of a vibratory member for supporting a body to be balanced, fluid-pressure means for developing impulses for imposition on said vibratory member, and means for varying the pressure of fluid admitted to said fluid-pressure means.

20. In a balancing machine, the combination of a vibratory member for supporting a body to be balanced, fluid-pressure means for developing impulses for imposition on said vibratory member, means for varying

the pressure of fluid admitted to said fluid-pressure means, and means for varying the time of operation of the fluid-pressure means with respect to the rotation of the rotor.

21. In a balancing machine, the combination of a vibratory member for supporting a body to be balanced, springs arranged on each side of the vibratory member for resisting vibrational movement thereof, fluid-pressure means for developing impulses for imposition upon said vibratory member, means for admitting fluid under pressure to said fluid-pressure means including a throttle valve, and means for measuring the pressure of fluid between the throttle valve and the fluid-pressure means.

22. In a balancing machine, the combination of a vibratory member for supporting a body to be balanced, springs arranged at the sides of the vibratory member to resist vibration thereof, fluid-pressure means for developing impulses for imposition upon the vibratory member, means for supplying fluid under pressure to said fluid pressure means, including a throttle valve and an admission valve, and means for varying the time of operation of said admission valve with respect to the rotation of the rotor.

23. In a balancing machine, the combination of a vibratory member for supporting a body to be balanced, springs arranged at the sides of the vibratory member to resist vibration thereof, fluid-pressure means for imposing impulses upon the vibratory member, means for supplying fluid under pressure to said fluid-pressure means including a throttle valve and an admission valve, means for indicating the pressure of fluid between the throttle valve and the admission valve, and means for varying the time of operation of the throttle valve with respect to the rotation of the rotor.

In testimony whereof, I have hereunto subscribed my name this 23rd day of May 1922.

ALEXANDER T. KASLEY.