Sept. 20, 1960 E. A. WACHSMUTH 2,953,294

SYNCHRONIZING MECHANISM FOR FREE-PISTON ENGINE COMPRESSOR

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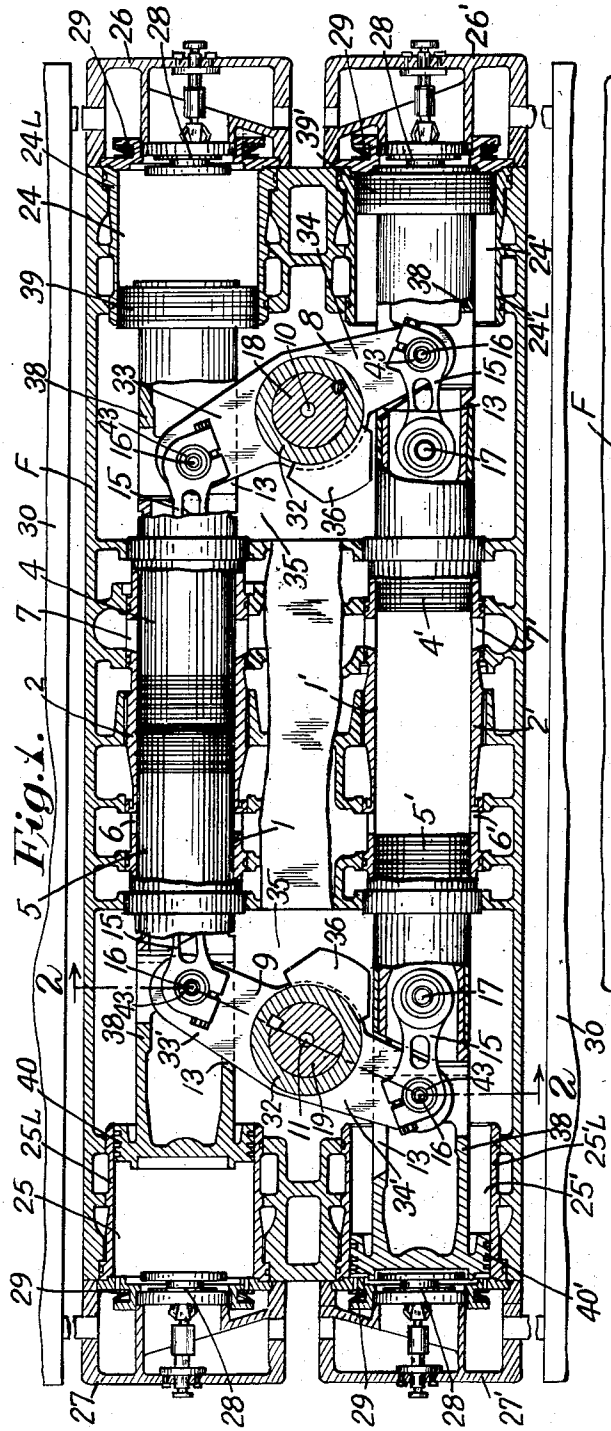

Fig. 1.

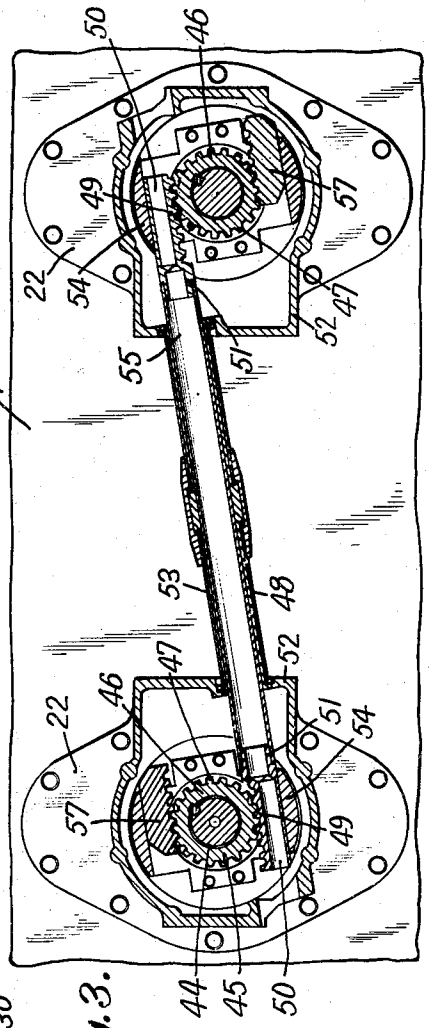

Fig. 3.

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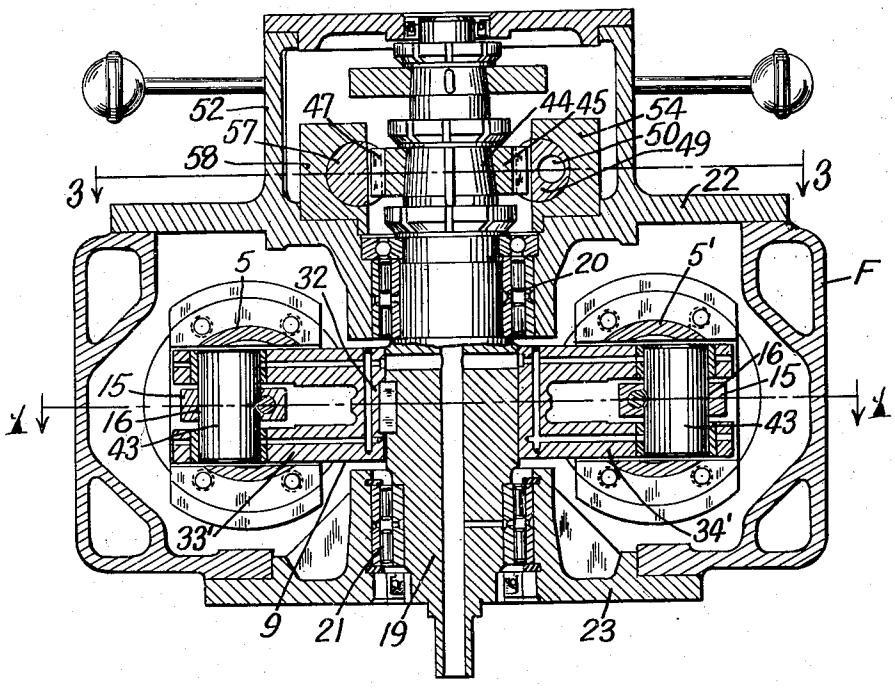
Fig. 2.



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SYNCHRONIZING MECHANISM FOR FREE-PISTON ENGINE COMPRESSOR

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23 Claims. (Cl. 230—56)

This invention relates to free-piston motor-compressors, and more particularly to synchronizing mechanism for such devices of the character in which there are two power cylinders arranged parallel with each other and with their central portions cut by a common plane perpendicular to their axes; there are two pairs of opposed motor pistons adapted to reciprocate in said cylinders respectively, each motor piston having fixed to its outer end a compressor piston; there are two pairs of compressor cylinders each pair having between its cylinders one of the first mentioned cylinders and adapted to receive compressor pistons fixed to the outer ends of the pistons of the first mentioned cylinders respectively; there is means for connecting one motor piston of one pair to the corresponding motor piston of the other pair to cause them to move simultaneously in mutually opposite directions, and means for connecting the other motor piston of said one pair with the corresponding motor piston of said other pair to cause them to move simultaneously in mutually opposite directions, and means is provided for causing the pistons of both pairs to move in synchronism with each other.

A free-piston motor-compressor of the type mentioned is disclosed in my application Serial No. 272,019, filed February 18, 1952, now Patent No. 2,775,398, for Free-Piston Compressor; but the mechanism of said application is much wider than that of this application and the synchronizing mechanism is not arranged outside the machine frame and so is less accessible. The new mechanism of the present invention is small, compact and simple, yet avoids interferences between the synchronizing mechanisms and parts associated with the cylinders, and possesses the kinematic virtue that two synchronized piston systems obey exactly the same law of speed.

From certain of its aspects the invention is also adapted to opposed piston engines, per se, as distinguished from motor-compressors, and from other aspects relates to improved arrangements for maintaining desired relative movements in devices—either motors or motor-compressors—constituting basically one longitudinal half of a motor, or of a motor-compressor of the character above mentioned.

In a desirable embodiment of the invention as applied to a motor-compressor or opposed piston engine the synchronizing mechanism may consist of two equal gear pinions each connected with one of two rocking shafts that cause piston structures traveling in parallel paths between corresponding limits to move oppositely to each other, and a floating diagonally arranged gear rack which mates with the two pinions, and the inertia forces of the floating gear rack may be balanced by two separately floating counterweights—also gear racks, each one mating with one of the pinions, however on diametrically opposed sides from the synchronizing rack but parallel with the latter, whereby the counterweights move opposite to but always with the same instantaneous angular speed as the synchronizing rack and effect perfect balancing of the latter.

It is an object of the present invention to provide an improved apparatus for synchronizing the movements of an apparatus of the opposed piston type. It is a further object of the invention to provide an improved apparatus for synchronizing a motor-compressor of the double, opposed piston type. It is a further object of the invention to provide improved, synchronizing apparatus for machines such as opposed piston motors and motor-compressors having improved counterbalancing means. It is still another object of the invention to provide an improved double opposed piston engine. Still another object is to provide an improved double opposed piston motor-compressor. Another object is to provide an improved counterbalanced synchronizing mechanism. Still a further object is to provide an improved connecting arrangement between parallel, oppositely moving pistons and a connecting rocker. Other objects and advantages of the invention will hereinafter appear.

In the accompanying drawings, in which, for purposes of illustration, one illustrative embodiment of the invention is shown:

Fig. 1 is a diagrammatic view in central longitudinal horizontal section, with parts in elevation, through a motor-compressor in which the invention is incorporated, the section being taken on the plane of the line 1—1 of Fig. 2, and having shown with it certain parts not illustrated in Fig. 2.

Fig. 2 is a vertical transverse section on an enlarged scale on the broken line 2—2 of Fig. 1, showing details of construction.

Fig. 3 is a horizontal section, on the same scale as Fig. 1, on the plane of the line 3—3 of Fig. 2 illustrating details of the synchronizing mechanism and its associated counterbalancing mechanism.

Before proceeding to the specification, it is to be noted that a free-piston motor-compressor includes as a part thereof a free-piston engine or motor and, accordingly, although there are presented claims to a free-piston motor per se, there is no necessity for illustrating an entirely independent free-piston motor to support the claims.

Referring first to Fig. 1, it will be noted that motor cylinders 1, 1' are provided. The axes of these cylinders are at least substantially parallel and the cylinders are supported by a frame F. The motor cylinders 1, 1' have liners 2—2' in which there are reciprocable in counter-stroke (opposed) relation to each other two pistons 4, 5 and 4', 5', which control the scavenging slots 6, 6' and exhaust slots 7, 7'. The four pistons are formed as differential pistons and are coupled in pairs (4 coupled with 4' and 5 coupled with 5'), each pair by a double-armed rocker, or centrally pivoted lever, 8, 9, the first pair by the rocker 8 and the second by the rocker 9, so that the outward travel (working stroke) of the pistons associated with the cylinder 1 corresponds with the inward (compression) stroke of the corresponding pistons of the cylinder 1', and vice versa. The two double-armed rockers 8 and 9 are pivoted respectively at 10 and 11. The piston structures 4, 5 and 4' and 5' are hollow and have slots 13 through their peripheral walls through which slots the rockers 8 and 9 extend. The rockers are built of the necessary strength, but have their weight distributed in such a manner as to allow the necessary range of swing on their axes without having the slots 13 unnecessarily enlarged. There is a connection between each of the several piston structures 4, 5 and 4', 5' with an end of a rocker, and these connections are in the form of connecting rods 15 pivotally connected at 16 to the adjacent end of a rocker arm and pivotally connected at 17 to a piston construction. The rockers are rigidly mounted on (keyed to) oscillating shafts 18 and 19, and these shafts are journaled in appropriate bearings, herein shown as roller bearings 20,

21 respectively, in end plates 22 and 23, closing openings in the top and bottom of the frame F.

Compressor cylinders 24, 25 and 24', 25' are disposed coaxial with the motor cylinders 1, 1', and are open at their ends toward the motor cylinders, but closed at their outer ends by cylindrical heads 26, 27 and 26', 27', which carry the suction and discharge valves 28, 29. There are two receivers 30 respectively receiving compressed fluid from the discharge valves 29 associated with cylinders 24, 25 and from those associated with the cylinders 24', 25'. The compressor cylinders are provided with liners which are distinguished from the cylinders proper in each case by the addition of L to the individual cylinder members.

It will be noted that the rockers 8, 9 are comprised of a central hub portion 32 and at diametrically opposite sides of the hub portion spaced arms 33, 34 and 33', 34'. In the space 35 between the arms there is secured to the hub portion a counterweight 36 which is provided to make the weight at opposite sides of a plane which includes the axes of the pivot connections 16 and the axis 10 (or 11) equal, whereby the rockers per se are balanced statically and dynamically with respect to the pivot axes 10 and 11. It may also be noted that the trunklike portions 38 connecting the motor pistons (4, 4', 5, 5') with the compressor pistons which are numbered 39, 39', 40, 40' are slabbed off at their sides so that there are parallel vertical surfaces at such opposite sides (see Fig. 2).

The connecting rods 15 engage, as shown in Fig. 2, with pins 43 which are suitably journaled in the parallel arms 33' and 34'.

To maintain the proper synchronized relation between the motor pistons in the cylinder 1 and those in the cylinder 1', mechanism as follows is provided.

The shafts 19 each have reduced portions 44, herein shown as tapered, and upon these reduced portions there are mounted elements 45 which have arcuate toothed portions at diametrically opposite sides thereof, these elements having, as herein illustrated, the form of circular pinions 46 with appropriate teeth 47 extending completely around their peripheries, although this is not strictly necessary. The pinions 46 have extending between one side of one of them and the diametrically opposite side of the other a rodlike structure 48 having at each of its opposite ends a rack portion 49 meshing with one of said pinions 46. The rodlike structure 48 extends obliquely to the plane which includes the axes 10, 11, and extends from below such plane at one end, through such plane, and above it at the other end. The rodlike structure 48 is hollow, and the straight rack portions 49 at its opposite ends are formed hollow as at 50 to reduce the overall weight of the rodlike structure 48. The rodlike structure receives shank portions 51 of the rack portions 49 in its opposite ends, and is carefully balanced so that in the mid-position of the rockers half of the rodlike structure is at one side and half at the other of a vertical plane midway between the axes 10 and 11 and perpendicular to the cylinder axes. The pinions and the rodlike structure are suitably housed, the pinions and the reciprocating rack portions being housed in gear boxes 52, and the portion of the rodlike structure between the gear boxes being enclosed in a suitable tubular housing or sheath structure 53.

The structure described in the preceding paragraph is effective to provide a synchronous but counter directed movement of the rocker arms under exactly similar angular speed arrangements. The rack portions 49 are borne by two rack guides 54. The inertia force of the straight reciprocating rack portions 49 and connecting rod portion 55 of the rodlike structure 48 is balanced by two separate floating counterweights 57, also gear racks, each one meshing with one of the pinions 46, but on diametrically opposite sides of the synchronizing rack structure and arranged parallel to it. This makes them move opposite to, but always with the same instantaneous angular speed as the synchronizing rack structure, and allows balancing the latter perfectly. The balancing counterweights also have guides, 58, in the gear housings and each is of the same mass as the adjacent synchronizing rack and that half of the reciprocating rodlike structure which is nearer to the particular counterweight.

It will be observed that the synchronizing mechanism is outside (above) the machine frame F, and above the top bearings 20 of the rocker shafts 18, 19, whereby it is easily accessible. The arrangement described permits locating the cylinders 1 and 1' as close together as is mechanically possible without sacrifice of exhaust duct area or interference between the exhaust ducts and synchronizing rack. The main advantage of the new synchronizing mechanism, in addition to its simplicity and the small space it requires, is the kinematic virtue that the two synchronized piston systems obey exactly the same law of speed.

While there is in this application specifically described one form which the invention may assume in practice, it will be understood that this form of the same is shown for purposes of illustration and that the invention may be modified and embodied in various other forms without departing from its spirit or the scope of the appended claims.

What I claim is:

1. An apparatus of the type described comprising, in combination, at least two power cylinders, at least two pairs of opposed pistons adapted to reciprocate in said cylinders respectively, and connecting means between the pistons of said two pairs for synchronizing the outward strokes of one pair with the inward strokes of the other pair, said connecting means including rockers swingable on fixed axes in planes perpendicular to the axes of said cylinders, toothed circular elements fixed to said rockers for oscillation on the axes of said rockers, and means including an intermediate element having engagement with said toothed circular elements for connecting said toothed circular elements for oscillation equiangularly but in opposite directions, and counterweights engaging with said toothed circular elements at the opposite sides of the latter from the engagements of said intermediate element with said toothed circular elements.

2. An apparatus as set forth in claim 1 in which the intermediate element has its engagements with said toothed circular elements at the opposite sides of its opposite ends.

3. An apparatus as defined in claim 2 in which each counterweight is of a mass equal to one-half the mass of said intermediate element.

4. An apparatus as defined in claim 1 in which each counterweight is equal in mass to the adjacent half of said intermediate element.

5. An apparatus as defined in claim 1 in which the mesh lines of said intermediate element and of said counterweights with said toothed circular elements are equally spaced from the axes of said rockers.

6. An apparatus of the type described comprising, in combination, at least two power cylinders arranged with their axes parallel, at least two pairs of opposed pistons one pair reciprocable in one of said power cylinders and the other pair in the other of said power cylinders, and connecting means between the pistons of said two pairs for synchronizing the outward strokes of one pair with the inward strokes of the other pair, said connecting means including rockers swingable on fixed axes in planes perpendicular to the axes of said cylinders, elements fixed with respect to said rockers for oscillation on the axes of said rockers and each having arcuately arranged toothed portions of like pitch radius and at opposite sides of its center, and means for connecting said elements for oscillation equiangularly but in opposite directions.

7. An apparatus of the type defined in claim 6 in which said means for connecting said elements for oscillation equiangularly but in opposite directions includes a con-

necting element extending obliquely to a plane including the axes of said rockers.

8. In an internal combustion, free-piston motor-compressor, in combination, coaxial motor and compressor cylinders respectively containing motor and compressor pistons which form a pair, other coaxial motor and compressor cylinders containing other motor and compressor pistons which form another pair, said first mentioned motor and compressor cylinders arranged with their axes parallel to the axes of said second mentioned motor and compressor cylinders, and means for connecting the piston pairs contained in said first and second mentioned coaxial motor and compressor cylinders to cause them to move in counterstroke relation to each other including a lever pivotable upon a fixed axis between the cylinders in which said corresponding piston pairs are contained, said axis being disposed between the ends of said cylinders and said lever having its opposite ends connected by connecting rods with said piston pairs at points between the opposite ends of each of the latter.

9. A motor-compressor as defined in claim 8, in which said piston pairs are hollow and having said connecting rods in their interiors.

10. An apparatus of the type described comprising, in combination, at least two power cylinders arranged with their axes parallel, at least two pairs of opposed pistons one pair reciprocable in one of said cylinders and the other pair in the other of said power cylinders, connecting means between the pistons of said two pairs for synchronizing the outward strokes of one pair with the inward strokes of the other pair, said connecting means including rockers swingable on fixed axes in planes perpendicular to the axes of said cylinders, elements fixed with respect to said rockers for oscillation on the axes of said rockers and each having arcuately arranged toothed portions of like pitch radius at the opposite sides of its center, an element extending obliquely to a plane including the axes of said rockers and contacting one of said first mentioned elements at one side of its center and the other at the other side of its center, and counterweights coacting with the other arcuately arranged toothed portions of each of said first mentioned elements.

11. An apparatus of the type described comprising, in combination, at least two power cylinders arranged with their axes parallel, at least two pairs of opposed pistons one pair reciprocable in one of said power cylinders and the other pair in the other of said power cylinders, connecting means between the pistons of said two pairs for synchronizing the outward strokes of one pair with the inward strokes of the other pair, said connecting means including rockers swingable on fixed axes in planes perpendicular to the axes of said cylinders, elements fixed with respect to said rockers for oscillation on said axes of said rockers and each having arcuately arranged toothed portions of like pitch radius at opposite sides of its center and a bar having teeth on one side of one end thereof and teeth on the other side of the other end thereof, said teeth simultaneously engaging arcuately arranged toothed portions on said elements, and means for counterbalancing the weight of said bar including toothed counterweights engaging the other arcuately arranged toothed portions on said elements.

12. A motor-compressor of the type described comprising, in combination, two power cylinders disposed side by side and each having at each of its opposite ends a compressor cylinder, two pairs of opposed motor pistons, one pair reciprocable in each of said power cylinders, a compressor piston movable with each motor piston and reciprocable in a compressor cylinder, two levers pivoted on fixed axes and each operatively connected at one end with a motor piston and a compressor piston, means arranged wholly between the most widely spaced points in said compressor cylinders for connecting said levers to swing mutually oppositely with respect to each other, in synchronism, said last mentioned means

comprising arcuately disposed teeth associated with each of said levers and arranged in arcs at opposite sides of the pivots of said levers and a bar having rack portions adjacent its opposite ends coacting with the said arcuately disposed teeth at opposite sides of said axes, and counterweights cooperating with the remaining arcuately disposed teeth.

13. A motor-compressor of the type described comprising, in combination, two power cylinders disposed side by side and each having at each of its opposite ends a compressor cylinder, two pairs of opposed motor pistons, one pair reciprocable in each of said power cylinders, a compressor piston movable with each motor piston and reciprocable in a compressor cylinder, two levers pivoted on fixed axes and each operatively connected at one end with a motor piston and a compressor piston, and means arranged wholly between the most widely spaced points in said compressor cylinders for connecting said levers to swing mutually oppositely with respect to each other, in synchronism, said last mentioned means comprising arcuately arranged sets of teeth one at one side of said fixed axes and the other at the other side of said fixed axes and a rod having rack portions cooperating with said arcuately arranged sets of teeth, there being counterweight means at the opposite side of the axis at one side of which one of said arcuately arranged sets of teeth is disposed and also at the opposite side of the axis at the other side of which the other set of arcuately disposed sets of teeth is disposed.

14. A motor-compressor of the type described comprising, in combination, two power cylinders arranged parallel with each other and with their central portions cut by a common plane perpendicular to their axes, two pairs of opposed motor pistons adapted to reciprocate in said cylinders respectively, each motor piston having fixed to its outer end a compressor piston, two pairs of compressor cylinders each pair having between its cylinders one of the first mentioned cylinders and adapted to receive the compressor pistons fixed to the outer ends of the pistons of the first mentioned cylinders respectively, means including an oscillating rocker for connecting one motor piston of one pair to the corresponding motor piston of the other pair to cause them to move simultaneously in mutually opposite directions, means including an oscillating rocker for connecting the other motor piston of said one pair with the corresponding motor piston of said other pair to cause them to move simultaneously in mutually opposite directions, means including a rack bar having rack portions and oscillating toothed segments for maintaining movement of said rockers in synchronism, and means including other rack bars and oscillating toothed segments for counter-balancing said first mentioned rack bar.

15. A motor-compressor of the type described comprising, in combination, first aligned motor and compressor cylinders, second aligned motor and compressor cylinders arranged parallel to the first cylinders, a piston structure including motor and compressor pistons reciprocable in said first motor and compressor cylinders, a piston structure including motor and compressor pistons reciprocable in said second motor and compressor cylinders, a double-armed rocker pivoted on a stationary axis midway between said first and said second motor and compressor cylinders, and connections between each arm of said rocker and one of said piston structures including connecting rods connected pivotally to said pistons and to said arms respectively.

16. A motor-compressor of the type described comprising, in combination, first aligned motor and compressor cylinders, second aligned motor and compressor cylinders arranged parallel to the first cylinders, a piston structure including motor and compressor pistons reciprocable in said first motor and compressor cylinders, a piston structure including motor and compressor pistons reciprocable in said second motor and compressor

cylinders, a double-armed rocker pivoted on an axis between said first and said second motor and compressor cylinders, and connections between each arm of said rocker and one of said piston structures including connecting rods one housed in each piston structure and each pivotally connected to a piston structure and to a rocker.

17. In combination, a pair of parallel cylinders, a pair of pistons movable in opposition in each of said cylinders, separate means for connecting a piston in one cylinder for movement in alternation with a piston in the other cylinder, means for synchronizing the movements of said separate means whereby the pistons in each cylinder move in opposition, said latter means during its operation assuming positions of unbalance, and counterweight means operatively associated with said synchronizing means automatically for offsetting such condition of unbalance thereby to assure smooth relatively vibrationless operation of said pistons.

18. A combination as set forth in claim 17 wherein said synchronizing means includes gear elements rotatable with each pair of alternatively moving pistons, and rack means engaging both gear elements, said rack means engaging the relatively opposite sides of said gear elements.

19. A combination as set forth in claim 18 wherein said counterweight means includes oppositely moving weight elements also engaging relatively opposite sides of said gear elements.

20. In combination, at least two spaced elongated power cylinders each of which has a pair of opposed reciprocable pistons therein, spaced connecting means connecting each one of said pistons of one of said pairs of pistons to separate pistons of the other of said pairs of pistons to obtain movement away from one another of one pair of said pistons upon movement toward one another of the other pair of said pistons whereby each of said connecting means has an oscillatory movement and a linear reciprocable member engaging said connecting means on opposite sides of the plane in which the axes lie about which such oscillations occur, respectively, to synchronize such oscillation in opposed equiangular relationship.

21. In combination, at least two spaced elongated power cylinders each of which has a pair of opposed reciprocable pistons therein, spaced connecting means connecting each one of said pistons of one of said pairs of pistons to separate pistons of the other of sad pairs of pistons to obtain movement away from one another of one pair of said pistons upon movement toward one another of the other pair of said pistons whereby each of said connecting means has an oscillatory movement, means secured to said oscillating connecting means, respectively, so as to oscillate therewith, and a linearly reciprocable link engaging each of said last mentioned means on opposite sides of the plane in which the axes lie about which said oscillation occurs, respectively, to synchronize such oscillation in opposed equiangular relationship.

22. In combination, a pair of parallel cylinders, a pair of pistons movable in opposition in each of said cylinders, separate means for connecting a piston in one cylinder for movement in alternation with a piston in the other cylinder, and interconnecting means for synchronizing the movements of said separate means whereby the pistons in each cylinder move in opposition, said interconnecting means comprising elements connected to each of said separate means and bodily shiftable means interconnecting and moving relative to said elements.

23. A combination as set forth in claim 22 wherein said bodily shiftable means creates conditions of unbalance and cooperating bodily shiftable means acting in opposition to said first mentioned shiftable means counteracting said conditions of unbalance.

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