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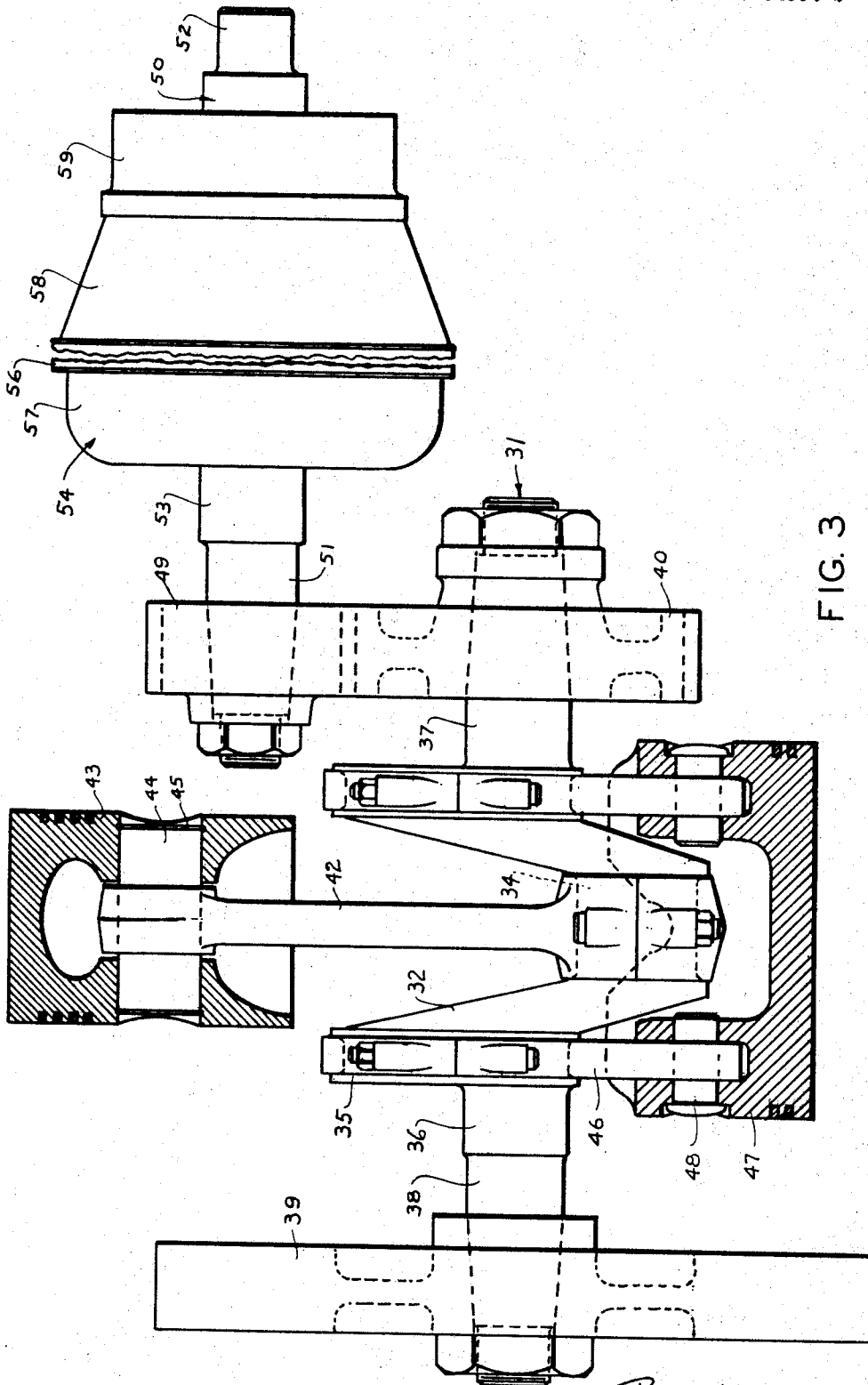
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VIBRATIONLESS ENGINES

Filed Sept. 18, 1964

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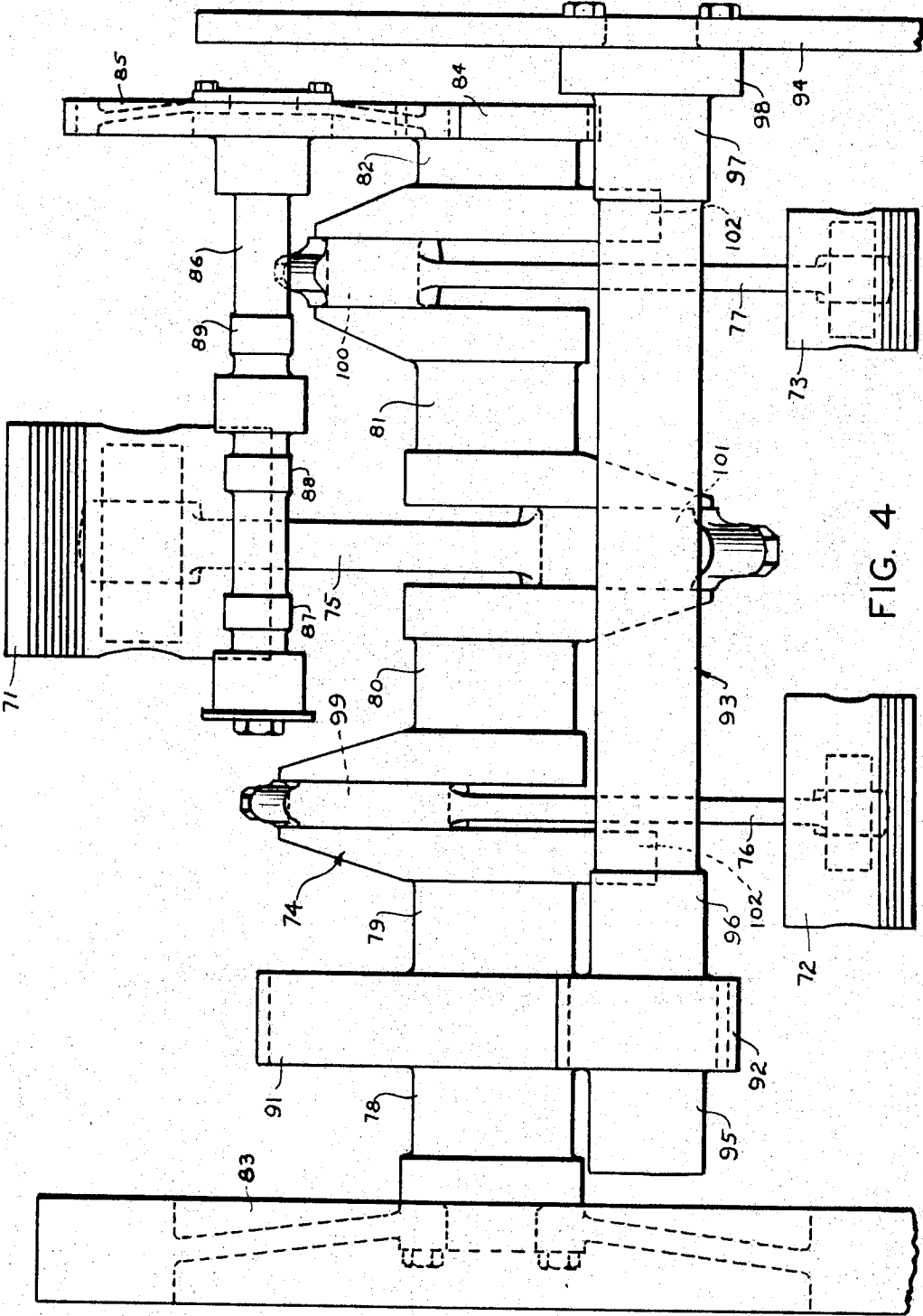
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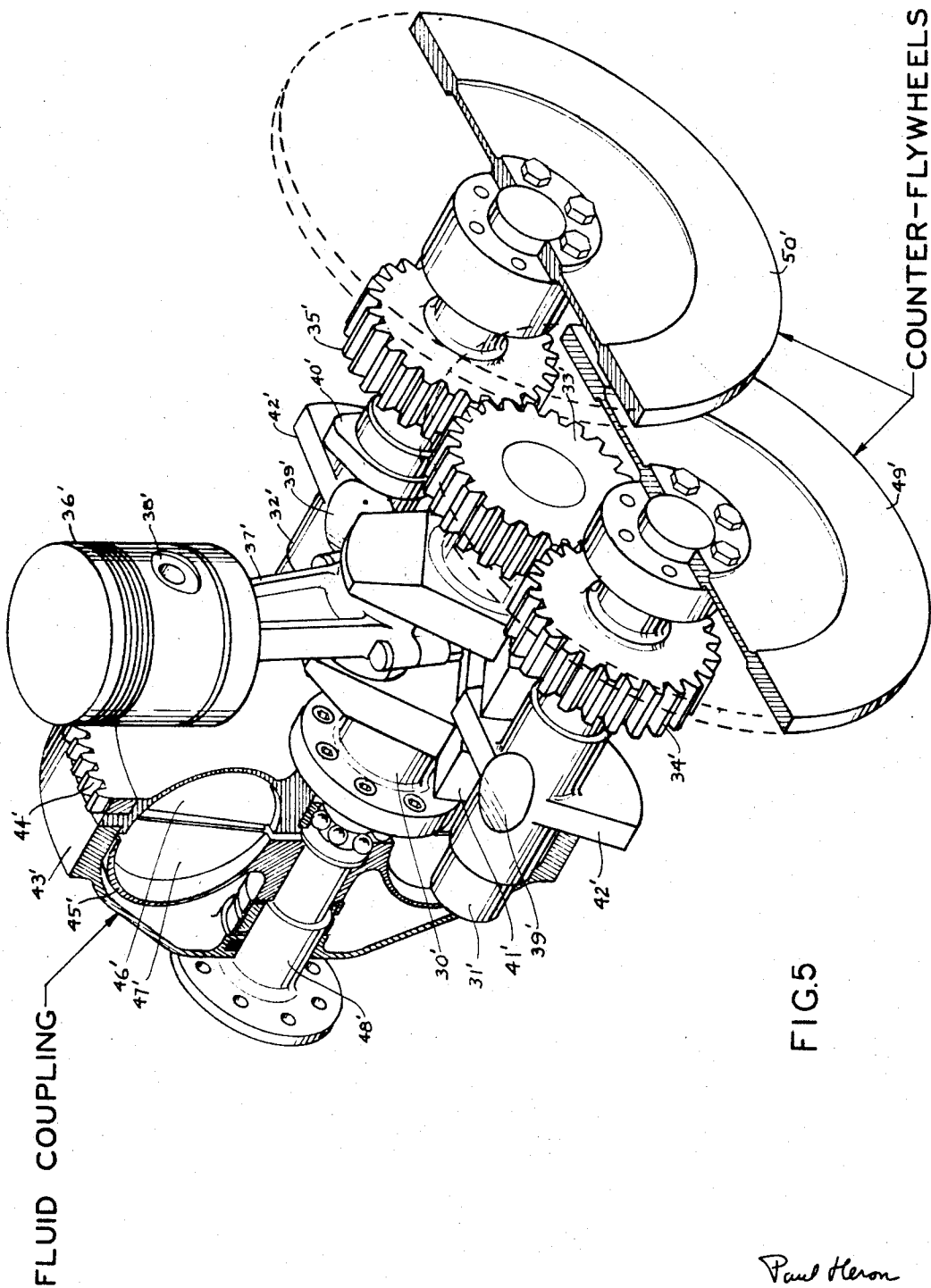
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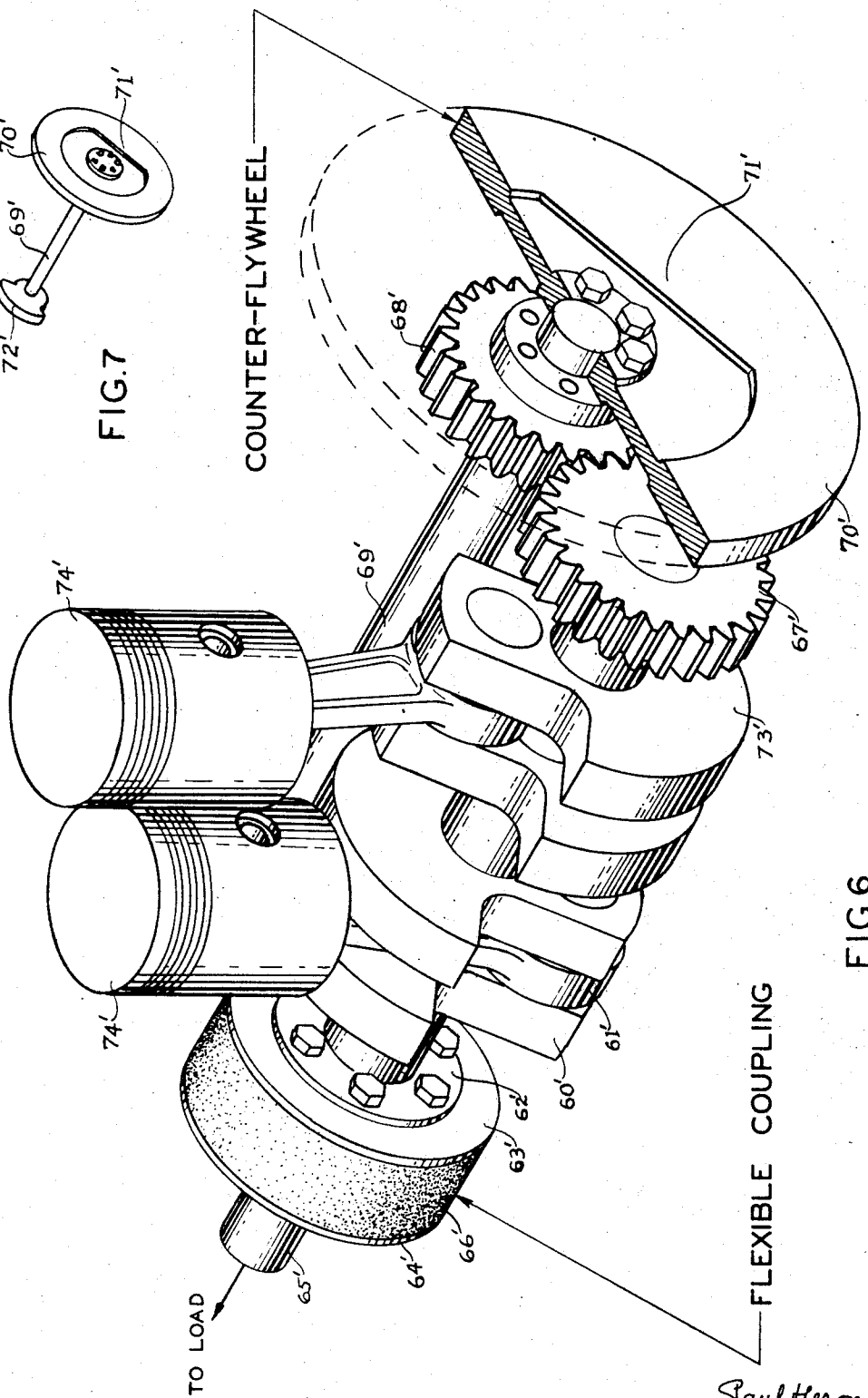
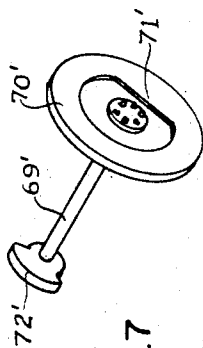
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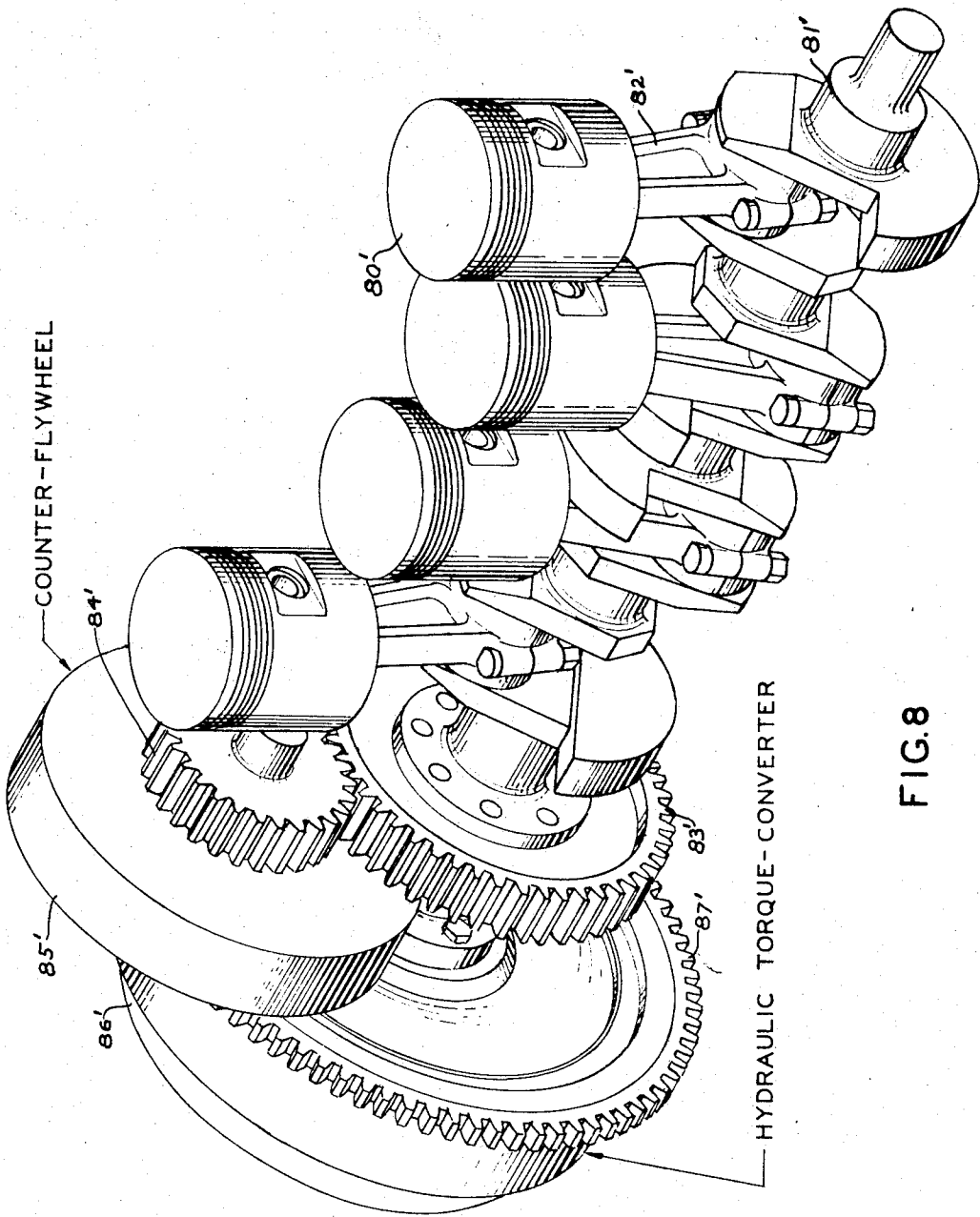
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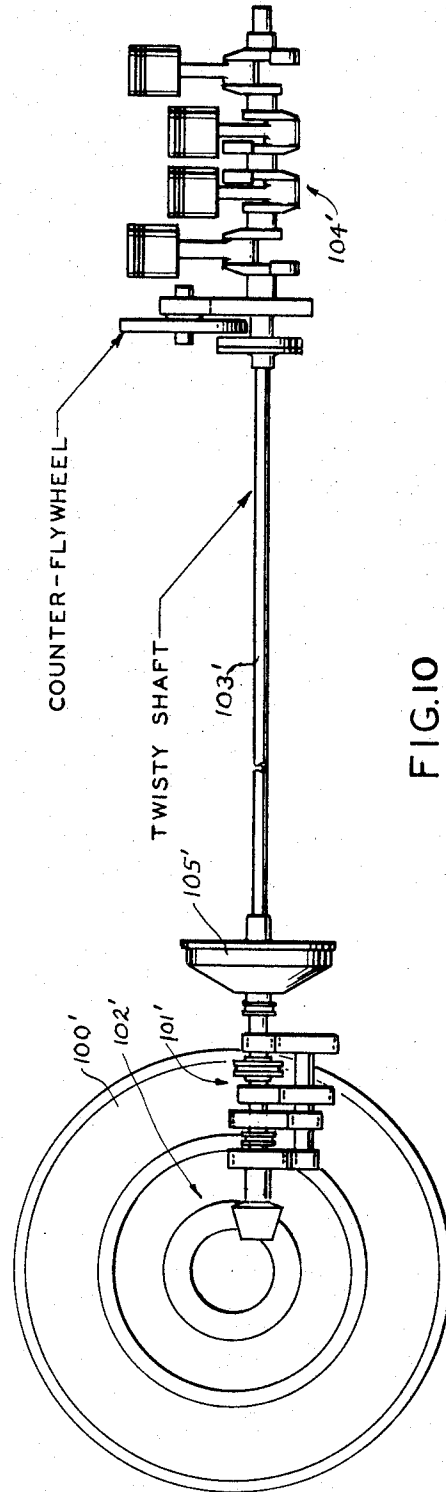
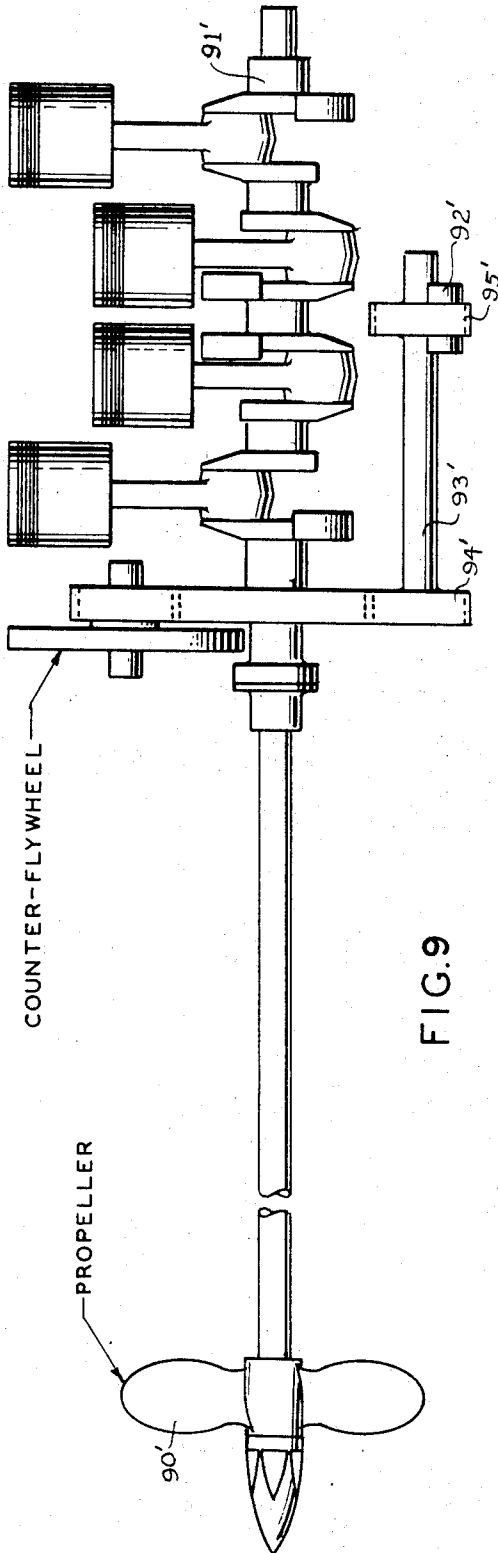
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Paul Heron

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3,402,707

VIBRATIONLESS ENGINES

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Continuation-in-part of application Ser. No. 140,972,
Sept. 21, 1961, which is a continuation-in-part of
application Ser. No. 366,927, July 9, 1953. This
application Sept. 18, 1964, Ser. No. 397,587
29 Claims. (Cl. 123—192)

The following specification is a continuation-in-part of
an earlier application, Ser. No. 140,972, filed on Sept. 21,
1961, which, in turn, was a continuation-in-part of a still
earlier application, Ser. No. 366,927, filed on July 9,
1953.

These inventions and the mechanical principle dis-
covered in them are chiefly concerned with internal com-
bustion engines, such as gasoline and diesel engines, in
which power is created by a series of explosions that act
on one or more pistons that move in cylinders and are
connected to and turn a crankshaft. The main object of
these inventions is to eliminate the vibration that is gen-
erally caused in such engines by the series of explosions,
and the mechanical principle that has been discovered is
a law of motion that teaches how vibration can theoret-
ically be eliminated completely from any kind of engine
or compressor or similar machine.

Another object of these inventions is to reduce the cost
of engines, particularly small and medium-size diesel
engines, by making it practical to use engines with fewer
(although larger) cylinders. One large cylinder is cheap-
er than two small ones, particularly if they have diesel
fuel injection equipment.

Among the more specific objects of these inventions are
to make diesel engines really practical for automobiles,
light trucks and small tractors, to provide little electric
generating sets for boats and house trailers etc. that will
not annoy people by their vibration, and to eliminate the
vibration from such things as chain saws, scooters, motor
bicycles, and small airplanes.

There are four principal sources of vibration in gaso-
line and diesel engines: (1) The moving parts of the en-
gine may not be in ordinary static and dynamic balance,
and this causes the engine to vibrate bodily up and down
or from side to side or to rock or twist about its center
of gravity. (2) The moving parts of the engine, such as
the crankshaft, may bend or twist when the engine is
running, and this spoils the balance of the moving parts
and so causes vibration. (3) The frame or crankcase of
the engine may not be stiff enough to resist the explosion
or inertia forces in the engine without bending apprecia-
bly, and so the variation in these forces causes the
frame or crankcase to vibrate. (4) The successive explo-
sions in the cylinders, that push the pistons down and
turn the crankshaft, act also on the cylinders and the
engine block or frame and make it vibrate.

The first of these sources of vibration (unbalance) can
be practically eliminated by providing several cylinders
and pistons and arranging these about the crankshaft so
that the pistons balance each other, as in ordinary six-
cylinder in-line engines or ordinary V-eight engines, or
are balanced by counterweights on the crankshaft, as
in ordinary radial aircraft engines. This source of vibra-
tion can also be practically eliminated in four-cylinder in-
line engines by using the balancer invented by Dr. F. W.
Lanchester and shown in his U.S. Patent No. 1,163,832,
and it can be completely eliminated in one-cylinder and
two-cylinder in-line engines by using the balancer in-
vented by Sir Harry Ricardo and shown in his U.S. Pat-
ent No. 1,310,090. Many other ways of eliminating this
source of vibration have been devised, and whole books
have been written on the subject. It is well understood
by good engine designers.

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The second source of vibration (distortion of the mov-
ing parts of the engine) can be practically eliminated by
making those parts very stiff, like the short heavy crank-
shafts in V-eight automobile engines. If some parts, such
as the long crankshaft in a six-cylinder in-line engine, can-
not be made stiff enough, the vibration from this source
can be kept small enough to be unnoticeable by dampers
like the one invented by Dr. F. W. Lanchester and shown
in his U.S. Patent No. 1,085,443.

The third source of vibration (bending or twisting of
the frame or crankcase of the engine) can be practically
eliminated by making the crankcase or frame stiff enough.
The necessary stiffness can be secured by using more
metal in the frame or crankcase, changing the design so
that the metal carries the forces more directly, or by
using a stiffer metal, such as steel in place of cast iron
or aluminum.

The fourth source of vibration (the successive explo-
sions in the cylinders) is the one with which the present
inventions and discovery are concerned. Until now, prac-
tically the only ways in which vibration from this source
have been lessened are (1) by making engines heavy,
and (2) by making engines with many cylinders, with as
many as sixteen cylinders in certain American auto-
mobiles in the late 1920's. The adoption of flexible mount-
ings for automobile engines in the early 1930's permitted
those engines to vibrate a moderate amount without too
much of the vibration being transmitted to the driver and
passengers, and twelve and sixteen cylinder engines soon
became obsolete. But the amount of vibration that can
be insulated by flexible mountings is limited. In ordinary
automobiles today, the vibration of a six-cylinder engine
can be felt at low engine speeds, and eight has become
the standard number of cylinders for American auto-
mobiles. In less wealthy parts of the world, most auto-
mobile users put up with the vibration from six-cylinder
and four-cylinder engines, some with two-cylinder en-
gines, and some even with one-cylinder engines in tiny
cars and scooters. In small airplanes, six-cylinder engines
have become almost standard in order to keep the vibra-
tion down to tolerable levels, even though engines with
fewer large cylinders would be cheaper to buy and to
run.

These inventions deal with this fourth source of en-
gine vibration (the successive explosions in the cylinders)
in a different way. They do not merely lessen it, as does
the use of many cylinders, nor do they make it merely
tolerable, as does the use of flexible engine mountings.
These inventions virtually eliminate that vibration right
in the engine itself; they make the engine practically vi-
brationless, like an electric motor or a steam or gas tur-
bine. In some of these new inventions, this is done by
balancing, within the engine, all of the forces left to
vibrate the engine. In others, it is done by combining the
engine with an electric generator or with a pump or com-
pressor and then balancing, within the engine-and-
generator or engine-and-pump or engine-and-compressor,
all of the forces exerted by the explosions so that there
are no unbalanced forces left to vibrate the combined
machine. In others, it is done by having the engine drive
a power-transmitting device (like a marine or airplane
propeller or the impeller of a centrifugal pump or blower)
that is free to vibrate with the power impulses transmitted
to it and that has a moderate moment of inertia or fly-
wheel effect and then balancing, within the assembly of
the engine and the propeller or impeller, all of the forces
exerted by the explosions, except the practically con-
stant reaction of the water or air or other fluid on the
propeller or impeller, so that there are no unbalanced
forces left to vibrate the engine. In still others, it is done
by combining the engine with some power-transmitting
device (such as a hydraulic coupling or torque converter,

electro-magnetic coupling, or resilient coupling) that allows the power output shaft of the engine to vibrate with the power impulses created by the explosions in the engine while exerting a practically constant torque reaction on the power output shaft and then balancing, within the assembly of the engine and the part of the power-transmitting device fixed to the power output shaft, all of the forces exerted by the explosions except the reaction of the power-transmitting device, so that there are no unbalanced varying forces left to vibrate the engine.

In each of these new engines, the invention consists in having the moving parts in balance in the three principal linear directions (up-and-down, side-to-side, and front-to-back) and in balance in the three principal rotational directions (about the longitudinal horizontal axis, about the transverse horizontal axis, and about the vertical axis) and in having some way of taking the power from the engine in some sort of smooth flow that does not react back on the engine and vibrate it.

There is one broad principle that underlies the vibrationless running of all these engines. That principle is this:

The frame or body of a machine will not vibrate if that frame or body is rigid and if (1) the algebraic sum of the momentum of all the moving parts in and on the machine in each of three directions at right angles to each other is always zero, (2) the algebraic sum of the angular momentum of all the moving parts in and on the machine about each of three different axes at right angles to each other is always zero, and (3) the machine does not exert a vibrating force or torque on anything outside itself and nothing outside of it exerts a vibrating force or torque upon it.

This principle is stated above in terms of momentum, which is the product of mass and velocity. It can also be stated in terms of mass and relative velocities, as follows, and it is then sometimes easier to understand and apply:

The frame or body of a machine will not vibrate if that frame or body is rigid and if (1) the center of gravity of the moving parts of the machine moves neither vertically nor longitudinally nor transversely, (2) the algebraic sum of the moments of inertia of all the moving parts of the machine about each of the vertical and transverse and longitudinal axes of the machine, multiplied by their relative rotational speeds about those axes is zero, and (3) the machine does not exert a vibrating force or torque on anything outside itself, and nothing exerts a vibrating force or torque upon it.

In ordinary engines that are supposed to be well balanced, the first of these three main conditions is met. In an upright six-cylinder engine, for example, the momentum of the pistons and connecting rods moving down is balanced by the momentum of those moving up, and the algebraic sum of their momentum up and down is zero. Similarly, the momentum of the big ends of some of the connecting rods moving towards one side is balanced by the momentum of the big ends of the other connecting rods moving towards the other side, and the algebraic sum of their momentum sideways is zero. Nothing moves endwise of the engine, so the momentum of the moving parts in that direction is zero. But the second of these three main conditions is only partly met. Since this engine is symmetrical about a plane perpendicular to the axis of the crankshaft at its center, the angular momentum of the moving parts on one side of that plane about either a vertical or a horizontal axis in that plane will be balanced by the angular momentum of the similar moving parts on the other side of that plane, and the algebraic sum of their angular momentums about either of those two axes is zero. But the algebraic sum of their angular momentums about the axis of the crankshaft is not zero; the crankshaft, the counterweights, the big ends of the connecting rods, the flywheel, and perhaps even the camshaft all turn in the same direction, and their angular

momentums all add up to a large quantity when the engine is running. Thus the second of these three main conditions is not met in an ordinary engine. The third of these three main conditions may or may not be met, depending upon what the engine drives and how it drives it. If the engine drives the rear wheels of an automobile through a friction clutch, a gear box, a propeller shaft, and a rear axle, it exerts a vibrating torque upon the propeller shaft and rear axle, and the reaction to this will vibrate the engine. However, if it drives the rear wheels of an automobile through an automatic transmission that includes a torque converter, as most such transmissions do, the torque exerted by the impeller in the torque converter will be practically constant over a short period of time, and the third condition will be met. However, the failure to meet the second condition will be a source of vibration.

Although this fundamental principle of balancing engines and other machines was not discovered until recently, a few engines which embodied it, or came close to embodying it, had previously been conceived, and some had been made. The earliest was probably Dr. F. W. Lanchester's two-cylinder balanced automobile engine of 1896, shown in his U.S. Patent No. 613,769 and described in detail in the Dec. 9, 1955, issue of the London "Autocar." In that engine, the masses and moments of inertia were practically all balanced in all directions, thus meeting the first two of the three main conditions stated above, but the engine exerted a varying torque on the shaft that transmitted its power to the gearbox and rear axle, and the reaction to this torque must have vibrated the engine when it was driving the automobile. However, when the engine was idling, this varying torque and its reaction were absent, and the engine is reported to have been practically vibrationless then.

Engines with complete or almost complete balance both linearly and rotationally (as in Lanchester's engine) but with the power take-off balanced so that the reactions to the varying torques exerted by the engines would not vibrate them are shown in the U.S. patents to J. W. Cloud (No. 968,127), H. Lemp (No. 1,471,901), and P. Heftler (No. 2,255,773). In each of these engines, there are two crankshafts turning in opposite directions, and the pistons are arranged in pairs with common combustion chambers so that the inertia forces and explosion forces are all practically balanced. Cloud's engine would not be in complete balance vertically, but that unbalance could easily be cured with a Lanchester balancer. Lemp's engine, if it were built as it would be designed by a skilled engineer who did not know what is disclosed here, would be somewhat out of balance because the two crankshafts would be connected out of phase in order that the exhaust ports at one end of each cylinder would be uncovered before the intake ports at the other end; this would put the pistons only a little out of balance because the four pistons on each crankshaft balance each other fairly well, but the crankshaft that would be ahead of the other would get most of the power from each explosion and momentarily accelerate more than the other, and this would destroy the rotational balance of the engine. Heftler's first engine, which is otherwise similar to Lemp's, avoids this unbalance by having the two crankshafts connected positively and in phase. Both of Heftler's engines are theoretically in practically perfect balance (except for the valve gear and perhaps the accessories) and should be practically vibrationless.

The important thing about Cloud's, Lemp's and Heftler's engines is that the two crankshafts of each engine delivered their power to devices that could absorb rotational vibration from the crankshafts without transmitting it to any other part of the structure. Cloud's engine drive two airplane propellers which, if they were turned jerkily, merely stirred up the air a little more. Lemp's engine drove two electric generators which, if they were turned jerkily, merely produced alternating current that was not pure sine-wave in its alternations. Heftler's engine drove

through two hydraulic couplings, which are remarkably efficient devices for averaging out torque and eliminating vibration from power transmitted by them, so the power that came out from them was vibrationless.

However, these engines, which were in good balance both linearly and rotationally and which delivered their power to devices which could absorb the rotational vibration caused by successive explosions, had one great fault: Having two crankshafts and two propellers or two generators or two hydraulic couplings and gear boxes, they were complicated and expensive. The new inventions described here are vibrationless engines with only one crankshaft and only one device for taking the power from the crankshaft without transmitting its vibration to any other part of the structure. The important discovery involved in these inventions is that it is not necessary to have a symmetrical arrangement of moving parts in the engine in order to balance out the vibrating forces; all that is necessary is that the moving parts of the engine and the part of its load that is fixed to or geared to its crankshaft be in balance both linearly in the three principal directions (front-to-back, side-to-side, and up-and-down) and rotationally about axes extending in those three directions and that the power of the engine be absorbed or transmitted without the vibrations in that power being reflected back into the engine.

It is important that "the part of the load fixed to or geared to its crankshaft" be included in the balancing of the engine. Such a part of the load (like a propeller or the rotor of an electric generator or the impeller of a hydraulic coupling or torque converter) acts like a flywheel on the engine, and, together with the crankshaft and other rotating parts, it must be balanced rotationally by a mass rotating in the opposite or contrary direction. Such a mass is called a "counter-flywheel," and the principal invention disclosed here is simply the addition of a counter-flywheel of the right size, to an ordinary engine that drives a load whose mass fixed to or geared to the crankshaft of the engine is small enough to be balanced by a counter-flywheel of reasonable size. When the engine drives a heavy load, like an automobile, the greater part of that load must be connected to the crankshaft of the engine only by some device, such as a hydraulic coupling or torque converter, that allows the crankshaft to vibrate rotationally without vibrating most of the load; then the part of the load fixed to the crankshaft, such as the input element of the hydraulic coupling or torque converter, is light enough, along with the crankshaft and other parts in the engine, to be balanced rotationally by a practical counter-flywheel.

Counter-flywheels are not new; one is shown, for example, on a one-cylinder engine in E. Ryder's U.S. Patent, No. 2,407,102. What is new is the combination of (1) a load having a limited mass fixed or geared to the crankshaft of an engine and (2) a counter-flywheel on the engine big enough to balance that mass in addition to the masses of the crankshaft and other parts turning with the crankshaft.

Down to this point, only engines with crankshafts have been discussed. However, the method of balancing engines disclosed here can be applied to other types of engines, such as those in which the pistons act on a swashplate or a cam and even to those in which there are no pistons. More importantly, this method of balancing can be applied to compressors and pumps and to combinations of engines and compressors or pumps. Especially promising applications, besides engines, are refrigeration compressors, particularly those combined with their own small engines and used for cooling or air-conditioning the interior of vehicles used for transporting food or people.

However, the greatest importance of these inventions seems to be that they will probably make the small diesel engine much more practical. Many tests have shown that an automobile or light truck with a diesel engine will go

about twice as far on a gallon of fuel as a similar one with a gasoline engine, but very few such vehicles are equipped with diesel engines. That is because diesel engines are much more expensive than gasoline engines and because they vibrate much more. Six-cylinder diesel engines are too expensive to be used at all in automobiles and light trucks, so four-cylinder ones are used. These are still too expensive to be used much, and, because of their much higher cylinder pressures, they vibrate more than four-cylinder gasoline engines and much more than V-eight gasoline engines. But, with these inventions, diesel engines for automobiles and light trucks, with only one or two or three cylinders, can probably be made to vibrate less than the present V-eight gasoline engines, and, having so few cylinders, they will probably be as cheap or cheaper than the present gasoline engines with four, six, or eight cylinders. Then diesel engines with these inventions may make large and medium-size gasoline engines obsolete.

Some of the different ways in which the inventions described broadly above can be used in engines, compressors, and combined engine-compressors are illustrated by specific examples described further on in this specification. These are only examples, and good engineers who learn what is disclosed in this specification will be able to design many other engines and other machines working according to the principle disclosed here and using one or more of the inventions.

In the drawings accompanying this specification, FIGURE 1 is a plan view of the main rotating parts of a one-cylinder engine-generator set embodying the present discovery;

FIGURE 2 is a section on the line II—II in FIGURE 1;

FIGURE 3 is a plan view of the main moving parts of a one-cylinder diesel engine-generator set embodying the present discovery and in almost theoretically perfect balance; and

FIGURE 4 is a plan view of the main moving parts of a combined engine-compressor embodying the present discovery and in almost theoretically perfect balance.

FIGS. 5-10 are illustrations of additional embodiments of the present invention.

The generating set illustrated in FIGURES 1 and 2 consists of a one-cylinder four-cycle gasoline engine and an electric generator with the rotor 1 of the generator mounted on an extension of the crankshaft 2 of the engine. The crankshaft is carried by its journals 3 and 4 in tapered roller bearings, like the crankshaft in the Wisconsin AGH engine, and all of the parts of this engine that are not necessarily different are taken from that engine. Pressed and keyed onto the crankshaft, between the front journal and the front crankweb, is a main gear 5 that drives two similar gears 6 and 7 mounted on two countershafts 8 and 9 located at either side of the crankshaft. The countershafts are mounted on bearings like those of the crankshaft but smaller, and they extend out through the front of the crankcase and carry counter-flywheels 10 and 11. The main flywheel of the engine is formed by the rotor 1 of the generator, pressed onto the rear end of the crankshaft, which is made with a standard S.A.E. taper so that the rotor can be removed from the crankshaft and the rear main bearing can be removed, if necessary for servicing. One of the countershafts carries a gear 12 for driving a gear twice its size on the camshaft, which is located above and to one side of the crankshaft in the usual position.

The crankshaft carries counterweights 15 and 16 which are heavy enough to balance all the weight of the crankthrow and the big end of the connecting rod 17 and half of the weight of the little end of the connecting rod, the wrist pin, and the piston and its rings. The two countershafts carry flyweights 20 and 21 which are heavy enough to balance the other half of the weight of the little end of the connecting rod, the wrist pin, and the piston and

its rings. These flyweights lie in the same transverse plane as the crankpin and connecting rod, and they swing in between the counterweights on the crankshaft as they all rotate and swing out of the way when the connecting rod comes around. The countershafts have large notches 22 and 23 on the sides opposite the flyweights to provide clearance for the big end of the connecting rod 17 as it swings around on the crank, and the strength and stiffness lost by the notches is made up by increasing the diameter of the central portions of the countershafts. The engine could be made without notches in the countershafts, but they permit the engine to be made more compact and so are worthwhile.

The balance of this engine in the vertical direction is about as good as that of an ordinary four-cylinder in-line engine, but it can be made as good as that of a V-eight by adding a Lanchester balancer to cancel out the secondary unbalance and by raising the countershafts a little to compensate for the swinging of the connecting rod. In the horizontal directions, the balance of the engine is theoretically perfect.

Theoretically perfect rotational balance of the engine is secured by making the sum of the moments of inertia of the two countershafts, countershaft gears, and counter-flywheels equal to the sum of the moments of inertia of the crankshaft, big end of the connecting rod, crankshaft gear, and generator rotor and half of the moment of inertia of the camshaft and camshaft gear. Then, when the engine-and-generator is running, the algebraic sum of the moments of momentum of its moving parts will be zero, and their sudden accelerations caused by explosions in the cylinder will be balanced in those moving parts and cause no movement in the rest of the engine-and-generator. Hence the engine will run without vibration.

The generator in this particular generating set is a Leece-Neville type of high-frequency alternator with a multi-polar rotating field and with rectifiers so that its final output is direct current for use with storage batteries, but any other type of generator may be used. It could be a four-pole alternator with either a permanent magnet or a wound rotating field and be run at 1800 r.p.m. to produce 60-cycle current. For intermittent duty, the generator could have only two poles and the set could be run at 3600 r.p.m. to produce 60-cycle current. For European use, the set could be run at 1500 r.p.m. or 3000 r.p.m. to produce 50-cycle current.

The engine, instead of being a gasoline one, could be a diesel, in which case it might be desirable to increase the sizes of the crankpin, connecting rod, and countershaft drive gearing. The generating set then would be more suitable for use on boats having diesel main engines and on trucks and buses driven by diesel engines and for use in continuous service.

The engine, instead of being a four-stroke-cycle one, could operate on the two-stroke cycle, particularly if the generating set were intended for light duty or intermittent service, as in a house trailer, summer cottage, or weekend yacht. If it were a two-stroke-cycle engine, its crankcase should preferably be split in a plane perpendicular to the axes of the shafts and passing close to or through the axis of the cylinder so that the interior of the crankcase could be made to enclose the moving parts with small clearances. This is desirable in order to reduce the "dead space" in the crankcase, which acts as the scavenging pump in the usual manner. For a similar reason, the crankshaft should be made with disc cranks, notched out at the sides of the crankpin just enough to provide balancing.

The generating set illustrated in FIGURE 3 consists of a one-cylinder two-stroke-cycle horizontal diesel engine with a reciprocating scavenging air pump and driving an electric generator through step-up gears.

In this engine, the crankshaft 31 has a single throw formed by the crank cheeks 32 and the crankpin 33, and, on each side of this crankthrow, there is an eccentric 34.

In this particular example (for the sake of simplicity of explanation), the eccentricity of the eccentrics is exactly half that of the crankpin, and the eccentrics are spaced exactly 180° from the crankpin. At the outer sides of the eccentrics are the crankshaft journals 36 and 37. Beyond one of the journals, the crankshaft has a cylindrical portion 38 that extends through a seal in the back of the crankcase and a tapered end that carries a flywheel 39. Beyond the other journal, the crankshaft has another tapered end that carries a large gear 40 and a fuel-injection cam 41, that may be made integral with the gear 40.

The crankpin 34 carries the big end of a conventional connecting rod 42, and the other end of the rod is connected to a piston 43 by a wristpin 44 held in place by snaprings 45. The eccentrics 35 each carry a connecting rod 46, whose little end is connected to a scavenging-air pump piston 47 by a wristpin 48, the two rods 46 being connected to the one large piston 47 near its sides and leaving a clear space at the center of the piston for the main crank throw and big end of the main connecting rod 42 to swing through. The wristpins 48 in the pump piston are of hardened steel, but they are provided with button heads of aluminum alloy that fit in counterbores in the sides of the piston. These heads have stems that are press-fitted into the bores of the wristpins, and they keep the wristpins from moving either in or out, the in-movement being prevented by the bottoms of the counterbores and the out-movement being prevented by the walls of the cylinder in which the pump piston 47 moves.

The cylinder in which the pump piston 47 moves is a conventional air pump cylinder with reed valves controlling the inlet and outlet, and its diameter is almost twice the diameter of the cylinder in which the power piston 43 moves. In the particular example shown, the power piston is 3.5 inches in diameter, and the pump piston is 6.25 inches in diameter. Because of this large difference in diameter, the displacement of the pump piston, even though its stroke is only half as long as the stroke of the power piston, is about 160% of that of the power piston, and enough air is pumped to scavenge the power cylinder well. This air, however, cannot go directly from the pump cylinder to the power cylinder, because the phase relation is not right for that. Instead, a receiver is provided in the air passage between the two cylinders to store the air between the time when it is pumped out of the pump cylinder and the time when it is admitted to the power cylinder. The power cylinder may be a conventional two-stroke-cycle one with loop scavenging and any suitable type of combustion system.

The large gear 40 on the crankshaft drives a small gear 49 on the counter shaft 50, which is formed with two journals 51 and 52, one next to the gear and the other at the outer end of the shaft. Next to the journal near the gear is the cylindrical portion 53 that passes through a shaft seal in the front wall of the crankcase, which also forms the gearcase. The central part of the countershaft has the rotor 54 of the generator pressed upon it, and the outer end of the countershaft is formed into journal 52 that is carried by the outboard bearing of the generator. In order to show it in the space available, most of the laminations 56 of the rotor have been omitted from the drawing, but the ends 57 and 58 of the windings and the commutator 59 are shown in their correct proportions.

The linear balance of this engine-generator set is simple and is theoretically perfect, with the exception of the negligible mass of the injection pump cam follower and plunger. The two eccentrics balance the crank throw, the exact balance being secured by adjusting the shape of the crank webs where they extend along the inner sides of the eccentrics. The two pump connecting rods 46 weigh twice as much as the main connecting rod 42, and the pump piston and its wrist pins weigh twice as much as the power piston 43 and its wrist pin, but they all balance each other because the stroke of the power piston is twice

as great as the stroke of the pump piston. The working length of the pump connecting rods **46** is exactly half that of the main connecting rod so the secondary unbalance of the pump piston, that has half the stroke of the power piston, will be exactly equal to the secondary unbalance of the power piston and will balance it exactly.

Rotational balance of the engine-generator is secured by making the moment of inertia of the crankshaft assembly exactly equal to the moment of inertia of the countershaft assembly multiplied by the ratio of the gears between them. In this particular example, the gears have 23 and 13 teeth, so the flywheel **39** is made of such a size that the moment of inertia of the crankshaft assembly is 23/13 or about 1.77 times that of the countershaft assembly.

This generating set is designed to run with the generator at 3600 r.p.m. and the engine at 2035 r.p.m. and to generate both alternating current at 60 cycles per second and 110 volts and direct current at 12 to 14 volts for charging storage batteries. The generator is also provided with windings that enable it to act as a 12 volt motor for starting the generating set. These characteristics and its vibrationless running make it ideal for use in boats, house cars and house trailers.

For the sake of clarity of illustration, the countershaft **50** has been shown in the same horizontal plane as the crankshaft. Actually, it should be below or above this plane so that its inboard end will not infringe on the space needed for the cooling water jacket and intake and exhaust passages of the power cylinder.

The combined engine compressor illustrated in FIGURE 4 has one diesel power cylinder, in which the power piston **71** operates, and first and second stage air compressor cylinders, in which the large and small air compressor pistons **72** and **73** operate. These cylinders lie in a horizontal plane passing through the axis of the crankshaft **74**, to which the pistons are connected by connecting rods **75**, **76**, and **77**. The big ends of all the connecting rods are split on angles of 45° so that they can be withdrawn through the cylinders, and the crankpin on which the second stage compressor connecting rod **77** is mounted is smaller in diameter than the others so that that rod can be withdrawn through its smaller cylinder.

The crankshaft **74** has five journals **78** to **82** supported by bearings in the crankcase, and it overhangs these bearings at both ends. At one end, it passes through a seal in the end wall of the crankcase and carries a heavy flywheel **83** spigotted and bolted to it. At the other end, it carries a small gear **84** that drives the camshaft gear **85** and the camshaft **86** at half the crankshaft speed. The camshaft is located above and to one side of the crankshaft and carries inlet and exhaust cams **87** and **88** and a fuel injection pump cam **89**.

Between the two journals **78** and **79** near the flywheel end of the crankshaft, the crankshaft is formed with an integral flange to which is bolted a large gear **91**. This gear engages a smaller gear **92** on a sturdy countershaft **93**, that extends out of the other end of the crankcase and carries there a steel plate counter-flywheel **94** spigotted and bolted to a flange on its end. The countershaft is located above the crankshaft and on the other side from the camshaft, and it has three journals **95**, **96**, and **97** by which it is supported in bearings in the crankcase. The flange **98** on its end fits in a seal in the wall of the crankcase.

This engine-compressor is in theoretically perfect linear balance because the air compressor cranks, connecting rods, and pistons are made to balance the engine or power crank, connecting rod, and piston. The two compressor crank throws **99** and **100** are spaced at equal distances along the crankshaft on opposite sides of the power crank throw **101** and are at 180° from it. One compressor crankpin is but half the length of the power crankpin, and the other is much smaller in diameter, so

the combined weights of the two compressor crankpins is about equal to the weight of the one power crankpin. Any difference in weight and the extra weight of the compressor crank cheeks is balanced by small counterweights **102** on the compressor cranks. Each compressor connecting rod **76** or **77** is made exactly half the weight of the power connecting rod **75**, and each compressor piston **72** or **73** is made exactly half the weight of the power piston **71**.

The engine-compressor is in theoretically perfect rotational balance because the flywheel **83** and counter-flywheel **94** are made to balance each other and all the other parts that rotate in the machine. The counter-flywheel **94** is much thinner than the flywheel **83** because it is geared up relative to it, the gear ratio in this example being 41 to 15. The algebraic sum of the moments of inertia of all the rotating parts multiplied by the speed of each part relative to the speed of the crankshaft is made to be zero.

For the sake of simplicity of explanation, this engine-compressor was designed with equally-spaced equal throws of the crankshaft and with first and second stage compressor pistons and rod exactly half as heavy as the power piston and rod. All of these proportions can be varied and the parts still kept in balance. The number of cylinders and their arrangement may be changed; for example, the crankshaft could have a single counter-weighted crank, to which would be connected the pistons of one power cylinder and one compressor cylinder at 90° to each other. In this form, the crankcase could act as a scavenge pump, and the power cylinder could operate on the two-stroke cycle.

Another invention, embodying the same principles as those already described above and particularly analogous to those illustrated in FIGURES 3 and 4, is a portable engine-and-water-pump balanced so as to be practically vibrationless and particularly useful in firefighting and marine salvage operations. This machine consists of a horizontally-opposed two-cylinder two-cycle engine of the type widely used for outboard boat motors before it was realized that most of the vibration of such motors came from the simultaneous power impulses and not from their dynamic unbalance. To the crankshaft of this engine is geared a countershaft to run at the same speed as the crankshaft but in the opposite direction, and this shaft is provided with a pair of flyweights like the flyweights **20** and **21** in the engine-generator illustrated in FIGURES 1 and 2, but these flyweights are both on one shaft and are 180° from each other. Together with the counterweights on the crankshaft, they balance out all of the primary unbalance of the pistons and connecting rods, leaving only a secondary couple to cause a small amount of vibration. The countershaft also carries, on the outside of the crankcase, the impeller of a centrifugal pump and a counter-flywheel, and the counter-flywheel is of such a size that the moment of inertia of the countershaft assembly is equal to the moment of inertia of the crankshaft assembly, and hence the combined machine is in rotational balance, and the only vibration will be the slight one caused by the secondary unbalance of the pistons. The flyweights are preferably in the planes of the two crank throws, and each balances out half of the primary unbalance of the piston and small end of the connecting rod on the crank throw in line with it; the other halves of these primary unbalances are balanced out by each other and by the counterweights. The counterweights are big enough to also balance the parts of the weights of the crank pins and big ends of the connecting rods that are not balanced by each other.

Still another invention, embodying the same principles as those already described above and particularly analogous to the air compressor set illustrated in FIGURE 4, is a power-gas generator. This is a machine that produces hot gas under pressure, that can be fed to a turbine to produce mechanical power. Free-piston

engines have been used as power-gas generators, but they are tricky machines and too complicated for use in small sizes. The present invention consists of a diesel engine balanced according to the principle disclosed in the first part of this specification and delivering its exhaust under pressure to a turbine. The engine could be a standard four-cycle diesel engine with a different camshaft that would operate the valves without overlap and with a counter-flywheel geared to the crankshaft so as to turn in the opposite direction and having the proper moment of inertia to satisfy the conditions explained in the first part of this specification. Alternatively, it could be a two-cycle diesel engine of a standard type but with a somewhat enlarged scavenging pump and with a counter-flywheel of the right moment of inertia geared to its crankshaft so as to turn in the opposite direction. In either case, the exhaust pipe of the engine would be connected to the inlet of a suitable turbine, which would convert the gas power into mechanical power, and the counter-flywheel could be connected to the crankshaft as it is in the engine-compressor illustrated by FIGURE 4. Alternatively, an engine like the one shown in FIGURE 3 could be used, the only change necessary being the substitution of a simple counter-flywheel for the generator rotor.

Another group of inventions embodying the general principle disclosed in this specification are engines driving marine or aircraft propellers. In these, the power is applied as a thrust upon the water or air moving past the vehicle rather than as a flow of electric current, gas, or liquid under pressure, as in the specific forms of the inventions discussed above. One example of this group of inventions can be made simply by taking the engine illustrated in FIGURES 1 and 2, replacing the generator rotor 1 by a flywheel, connecting the crankshaft 2 to a propeller shaft and a propeller, and adjusting the sizes of the new flywheel and the counter-flywheels 10 and 11 so that the moments of inertia of the parts rotating in opposite directions will be in balance. Another example can be made by taking the engine illustrated in FIGURE 3, replacing the generator rotor 54 by a counter-flywheel, connecting a propeller shaft and propeller to the countershaft 50, and adjusting the sizes of the new counter-flywheel and the flywheel 39 so that the moments of inertia of the parts rotating in opposite directions will be in balance. This example can be improved for many applications by first changing the ratio of the gears so that they step down the speed from the crankshaft and thus provide a reduction gear to the propeller shaft, and the countershaft and the propeller shaft can be made hollow so that they will accommodate the control rod for a variable-pitch feathering and reversing propeller. For small airplanes, the principle here disclosed can be applied by taking a standard airplane engine with a simple gear drive to the propeller, such as the Continental GO-300-E engine or the Lycoming GO-435-C2B2-6 engine, and rebuilding the nose of the engine with a flywheel on the crankshaft immediately behind the reduction gears, the flywheel being of such a size that the moment of inertia of the crankshaft assembly will balance that of the propeller shaft assembly. It is essential, in getting this balance, that the reduction gearing be of the simple spur or helical type that makes the propeller turn in the opposite direction from the crankshaft.

Another group of inventions embodying the general principle disclosed in this specification are engines that deliver mechanical power through some device that eliminates or greatly reduces the vibration in that power and that have counter-flywheels geared to their crankshafts to balance them rotationally. The device that smooths out the power delivered by the engine can be a hydraulic coupling, a hydraulic torque converter, an electromagnetic coupling, a resilient coupling, a twisty shaft, or anything else that will absorb quick fluctuations in torque. An example of such an embodiment of the invention is shown in FIG. 5. In this engine, the crank-

shaft 30' lies between two countershafts 31' and 32', and it carries a bear 33' at its front end that meshes with similar gears 34' and 35' on the countershafts. These gears drive the countershafts at the same speed as the crankshaft but in the opposite direction.

The crankshaft is connected to a piston 36' by a connecting rod 37' and wrist pin 38', and the piston operates in a conventional cylinder in the conventional way. The countershafts are placed as close to the crankshaft as possible in order to keep the volume of the crankcase small and get good compression of the air in the crankcase for scavenging the cylinder, and each countershaft is cut away at 39' on the side opposite its counterweight to provide clearance for the bolts on the lower end of the connecting rod as they swing around with the crank. Fuel is injected into the cylinder at the proper time in each cycle of operation by an injection pump that is worked by a cam 40' on one of the countershafts.

The crankshaft carries a pair of counterweights 41' that balance the weight of the crank cheeks, the crank pin and the lower end of the connecting rod and half of the weight of the upper end of the connecting rod, the piston, and the wrist pin. The countershafts carry little counterweights 42' that balance the other half of the weight of the upper end of the connecting rod, the piston, and the wrist pin. With this arrangement of counterweights, this little one-cylinder engine is balanced vertically and horizontally as well as an ordinary four-cylinder in-line engine.

For taking power from the crankshaft in a steady flow, even though the power is created intermittently by successive explosions, there is a fluid coupling on the rear end of the crankshaft. The housing 43' of the coupling is in two parts bolted together, and the front part is bolted to the crankshaft flange and carries a ring gear 44' for an electric starter. Within the housing, there is a runner 45', and the runner and the front part of the housing are shaped so as to enclose a toroidal space between them. Within this space are a set of semicircular vanes 46' fixed to the housing and another set of semicircular vanes 47' fixed to the runner. When the fluid coupling is operating, the vanes 46' in the housing form a centrifugal pump that throws oil against the vanes 47' in the runner and turns the runner. The runner is fixed to an output shaft 48' with a flange that can carry a friction clutch or any other means for transmitting power from the engine.

The forward ends of the countershafts carry counter-flywheels 49' and 50', and these are of such a size and mass that the sum of the moments of inertia of all the parts turning with and vibrating with the countershafts is equal to the sum of the moments of inertia of all the parts turning with and vibrating with the crankshaft. This includes the lower end of the connecting rod and some of the fluid entrained by the impeller vanes of the fluid coupling. Thus this engine is in dynamic rotational balance in the same way as the first example described above, and the power impulses applied to the crankshaft will cause vibrations only in the shafts and the parts fixed to them and will cause no vibration of the engine block and crankcase.

An additional embodiment of the invention is shown in FIGS. 6 and 7. The crankshaft 60' of this engine is built up of separate pieces pressed together, and this permits the lower ends of the connecting rods 61' to be made in one piece and have roller bearings. The rear end of the crankshaft has an integral flange 62' to which one side 63' of a flexible coupling is fixed by capscrews. The other side 64' of the flexible coupling is similarly fixed to a drive-shaft 65' that delivers the power of the engine to the load; it may, for example, go to the clutch, transmission, and driving wheels of a small automobile.

The central part of the flexible coupling is a short cylinder of rubber 66' or similar material with its faces bonded to the two sides 63' and 64' of the coupling, and there is no other connection between the two sides. The rubber permits the input side 63' of the coupling and

the crankshaft and all the other parts connected to it to vibrate rotationally with respect to the output side 64' and the drive shaft 65', and, at the same time, it transmits the power of the engine. The front end of the crankshaft carries a gear 67' that meshes with a similar gear 68' on a countershaft 69'. This drives the countershaft at crankshaft speed but in the opposite direction and makes it vibrate rotationally in exact synchronism with the crankshaft.

The forward end of the countershaft has a counter-flywheel 70' fixed to it, and one side of the recessed face of the counter-flywheel is filled in to form a small counterweight 71'. The rear end of the countershaft 69' (as shown in FIGURE 7) carries a small counterweight 72' at 180° from the counterweight 71'. The two counterweights on the countershaft cooperate with the counterweights 73' on the crankshaft to balance the weights of the pistons 74' both statically and dynamically, except for the small unbalance caused by the changing angularity of the connecting rods during the strokes of the pistons. Thus this two-cylinder engine is as well balanced vertically and horizontally as an ordinary four-cylinder engine.

To balance the engine rotationally, the moment of inertia of the countershaft and counter-flywheel assembly is made equal to the moment of inertia of the crankshaft assembly, including the lower ends 61' of the connecting rods and half of the flexible coupling. As a result of this, the total angular momentum of the moving parts of the engine, back to the center of the flexible coupling, adds up algebraically to zero. If the crankshaft turns clockwise, its angular momentum is negative, and that of the countershaft is equal to it but positive, and their sum is zero.

Another engine embodying the principles of the present invention is shown in FIGURE 8. It has four cylinders in line, in which the four pistons 80' move, and they drive a crankshaft 81' through connecting rods 82'. The rear end of the crankshaft carries a large spur or helical gear 83', which meshes with a smaller gear 84' fixed to a counter-flywheel 85'.

The crankshaft extends beyond the counter-flywheel drive gears 83' and carries a hydraulic torque converter of the type that usually forms the first part of the automatic transmission of an automobile. The housing 86' of the torque converter, the parts inside fixed to the housing, some of the liquid within the housing, and the starter ring gear 87' on the outside of the housing all turn with the crankshaft and act as a flywheel that vibrates rotationally with the crankshaft.

The counter-flywheel rotates and vibrates rotationally in exact synchronism with the crankshaft, but at a greater speed because of the step-up in the gears 83' and 84'. The moment of inertia of the counter-flywheel assembly is smaller than that of the crankshaft and converter housing assembly, and their ratio is the same as that of the gears. Hence, when the engine is running, the algebraic sum of the angular momentum of all the rotating parts is zero and remains zero even when explosions in the cylinders cause those parts to accelerate quickly.

Besides all of the applications of the invention described above, there are some ways in which the invention probably can be partly applied with some benefit. These are installations in which the crankshaft of the engine is only partly free to vibrate independently of the load or in which the thing to which the power is applied is itself yielding. One example, shown in FIG. 7, is a marine engine driving a propeller 90' through a shaft which has some flexibility; here the propeller, turning in the water, can vibrate to some extent with the crankshaft 91', and also, the crankshaft is free to vibrate somewhat independently of its load because of the flexibility of the propeller shaft. In this example of the invention, there is shown one form of the Lanchester balancer mentioned above. It consists of a pair of small counterweights 92' directly under the center of the engine and driven by

a shaft 93' and gears 94' and 95' so as to rotate at twice the speed of the crankshaft. Another example is an aircraft engine with the propeller mounted directly on the crankshaft; here the propeller forms a part of the crankshaft vibrating system, but the air on which it acts lets it vibrate with some freedom. A third example, shown in FIG. 8, is in an automobile having independently sprung rear wheels 100' or a DeDion rear axle, the transmission 101' at the rear in a unit with the final drive and differential 102', and a torsionally flexible propeller shaft 103' connecting the engine 104' to the transmission. The clutch 105' can be at either end of the twisty propeller shaft 103'. In all these installations, the crankshaft system is somewhat free to vibrate independently of the load, and it is probable that a great reduction in the vibration of the engine block could be effected by providing counter-flywheels as described above. It might be difficult to calculate the exact moment of inertia for the counter-flywheels that would be best in these cases, so it might be advisable to experiment with counter-flywheels whose moments of inertia could be varied, as by bolting additional steel discs onto their faces.

In any case, in determining the best moment of inertia for the counter-flywheels, the moments of inertia and the relative speeds of every rotating part in the engine should be considered. For example, if the engine is a four-cycle one with a camshaft turning at half the speed of the crankshaft, one-half of its moment of inertia (including its driving gear) should be subtracted from the moment of inertia of the crankshaft system if it turns in the opposite direction or added if it turns in the same direction. But, if the drive to the camshaft is somewhat flexible, as it is when the drive is by chain, somewhat less than one-half of the moment of inertia of the camshaft and gears should be counted.

There is one more group of inventions embodying the general principle disclosed in this specification, that should be described. These are engines with two crankshafts turning in opposite directions, flywheels on both crankshafts so that the engines are in rotational balance as taught in this specification, and some means of taking the power from the engine while permitting the crankshafts to vibrate rotationally. That means can be a single marine or aircraft propeller, a single hydraulic coupling or torque converter, one or more air-compressor cylinders, a high-pressure exhaust-gas pipe leading to a turbine, a resilient coupling, a twisty shaft, or any similar device. The engines can have the crankshafts at the top and the bottom and have opposed pistons in each cylinder, as in the Junkers "Juno" airplane diesels used in the pre-war German South Atlantic air mail service. They can have the crankshafts side by side at the bottom with separate vertical cylinders for the different cranks, as in the British Ariel "Square Four" motorcycle engine. They can have the crankshafts side by side with the cylinders inclined towards each other and having common combustion chambers and with a single fuel injection pump and nozzle for each pair of cylinders. In each of these engines, there are already two vibrating rotary systems that rotate and vibrate rotationally at the same speed and that have approximately the same moment of inertia; to the crankshaft of each system should be added a flywheel, and the weights of the flywheels should be adjusted so that their moments of inertia will balance each other and all the other masses fixed to or geared to the crankshafts, as taught in this specification.

I claim, as my invention and discovery:

1. In an engine having a single main power output shaft, such as a crankshaft, that turns in a given direction and to which periodic power impulses are applied when the engine is supplying power to a load, one or more rotary masses drivingly connected to the power output shaft so as to turn in the opposite direction at speeds in constant proportion to the speed of the power output shaft and to vibrate rotationally in phase with the power

output shaft but in the opposite direction, the sum of the moments of inertia of those masses multiplied by the ratio of their speeds to the speed of the power output shaft being approximately equal to the sum of the moment of inertia of the power output shaft and the moments of inertia of all other masses in or on the engine that turn in the same direction as the power output shaft, including any part of the load fixed to the power output shaft, multiplied by the ratio of their speeds to the speed of the power output shaft.

2. In an engine having a single main power output shaft, such as crankshaft, that turns in a given direction and to which periodic power impulses are applied when the engine is supplying power to a load, the power output shaft having fixed to it a power transmitting element free to vibrate rotationally relative to the load, one or more rotary masses geared to the power output shaft so as to turn in the opposite direction but at the same speed, the total moment of inertia of those rotary masses being approximately equal to the total moment of inertia of the power output shaft and the other parts connected to turn with it in the same direction, including the power transmitting element fixed to it.

3. In combination, a reciprocating engine having a single main power output shaft and a power transmitting mechanism having a power input element fixed to the engine power output shaft, the engine having at least one mass drivingly connected to the output shaft so as to rotate in the opposite direction at a speed with a fixed negative ratio to the speed of the output shaft, the algebraic sum of the moments of inertia of all the moving parts of the engine and of the power input element of the power transmitting mechanism multiplied by the ratio of their speeds being approximately zero, and the power transmitting mechanism being of such a type that the torque reaction on the power input element is independent of its instantaneous acceleration.

4. A combination as defined in claim 3 and in which the power transmitting mechanism is an electromagnetic device in which the torque reaction on the power input element is created by a magnetic field.

5. A combination as defined in claim 3 and in which the power transmitting mechanism is a screw propeller.

6. A combination as defined in claim 3 and in which the power transmitting mechanism is a resilient coupling.

7. A combination as defined in claim 3 and in which the power input element is a centrifugal pump rotor.

8. An engine assembly, including an engine with at least one power output shaft, at least one power transmitting element fixed to at least one power output shaft, and at least one other shaft drivingly connected to turn in the opposite direction to one power output shaft at a fixed negative speed ratio, in which the algebraic sum of the moments of inertia of all the moving parts, including all power transmitting elements fixed to or geared to any power output shaft, about any axis, multiplied by their relative speed ratios, is approximately zero.

9. An engine assembly as defined in claim 8 and in which the power transmitting element is the rotor of an electrical machine.

10. An engine assembly as defined in claim 8 and in which the power transmitting element is a fluid impeller.

11. An engine assembly as defined in claim 8 and in which the power transmitting element is the input element of a coupling of a type in which the torque transmitted is independent of the instantaneous acceleration of the input element.

12. An engine assembly as defined in claim 8 and in which the power transmitting element is one side of a resilient coupling.

13. A machine for transferring energy in one direction or the other between gas under pressure and an electrical circuit, comprising a crankshaft, at least one piston connected to the crankshaft, a countershaft geared to the crankshaft so as to rotate in the opposite direction and

at a fixed speed ratio, an electrical machine rotor fixed to one of the shafts, and a flywheel mass fixed to one of the shafts so that the sum of the moments of inertia of the countershaft and all other parts rotating in the same direction multiplied by the ratio of their speeds to the speed of the crankshaft is approximately equal to the sum of the moments of inertia of the crankshaft and all other parts rotating in the same direction multiplied by the ratio of their speeds to the speed of the crankshaft.

14. An electric generating set comprising a single crankshaft, at least one piston connected to the crankshaft, a generator rotor fixed to the crankshaft, at least one countershaft geared to the crankshaft so as to rotate in the opposite direction and at a fixed speed ratio, and at least one counter-flywheel mass fixed to at least one countershaft, the sum of the moments of inertia of the countershafts and all parts fixed to them multiplied by the ratio of their speed to the speed of the crankshaft being approximately equal to the sum of the moments of inertia of the crankshaft and all parts fixed to it.

15. An electric generating set comprising a single crankshaft, a single piston and connecting rod connected to the crankshaft, a generator rotor fixed to the crankshaft, a pair of countershafts lying parallel to and at either side of the crankshaft and geared to the crankshaft so as to rotate at the same speed but in the opposite direction, counterbalancing masses on the crankshaft and countershafts for counterbalancing the weight of the piston and connecting rod, and one or more counter-flywheels fixed to the countershafts, the sum of the moments of inertia of the countershafts and all parts fixed to them being approximately equal to the sum of the moments of inertia of the crankshaft and all parts fixed to it.

16. A single-cylinder reciprocating machine that is almost completely balanced in all the six possible directions of movement, comprising a single crankshaft, a piston and connecting rod connected to the crankshaft, a pair of countershafts at either side of the crankshaft and geared to it to run in the opposite direction and at the same speed, counterweights on the three shafts for counterbalancing the piston and connecting rod, and a flywheel on at least one of the countershafts, the masses and dimensions of the moving parts in the machine or fixed to its shafts being such that their center of gravity remains practically in a fixed position relative to the axes of the shafts and the algebraic sum of their moments of inertia about any axis is practically zero.

17. A reciprocating engine having a crankshaft, a countershaft geared to the crankshaft so as to turn in the opposite direction, one of those two shafts extending out of the engine and forming a power output shaft to which a power absorbing or transmitting member can be fixed, and flywheel masses fixed to the shafts and having moments of inertia such that the sum of the moments of inertia of the masses connected to turn in the same direction as the power output shaft multiplied by the ratio of their speed to the speed of the power output shaft is substantially smaller than the sum of the moments of inertia of the masses connected to turn in the opposite direction multiplied by the ratio of their speeds to the speed of the power output shaft.

18. A reciprocating engine having only one crankshaft, the crankshaft extending out at one end of the engine to act as a power output shaft to which a power absorbing or transmitting member can be fixed, a countershaft geared to the crankshaft so as to turn in the opposite direction and projecting out beyond the crankshaft at the other end of the engine, and a large flywheel fixed to the projecting part of the countershaft and overlapping the end of the crankshaft.

19. In an engine, a single main power shaft, power producing means that apply rotative pulsating forces to said shaft to effect rotation of the latter, supporting means for said main power shaft and said power producing

means whereby said supporting means tends to be subject to a reaction to said rotative pulsating forces, means coupled to said shaft for rotation in the opposite direction to that of the shaft and for vibration in phase with but in opposite angular direction to said single main power shaft for at least partially compensating said supporting means for said reaction to said rotative pulsating forces, a load, and means connecting said single main power shaft to the load for transmitting torque to the load while absorbing at least some of the vibration to thus enable said rotatable massive means to at least partially compensate for the rotative pulsating forces.

20. In an engine having a single main power output shaft, such as a crankshaft, that turns in a given direction and to which periodic power impulses are applied when the engine is supplying power to a load, one or more rotary masses drivingly connected to the power output shaft so as to turn in the opposite direction at speeds in constant proportion to the speed of the power output shaft and to vibrate rotationally in phase with the power output shaft but in the opposite direction, the sum of the moments of inertia of those masses multiplied by the ratio of their speeds to the speed of the power output shaft being approximately equal to the sum of the moment of inertia of the power output shaft and to the moments of inertia of all other masses in or on the engine that turn in the same direction as the power output shaft, including any part of the load fixed to the power output shaft, multiplied by the ratio of their speeds to the speed of the power output shaft.

21. In an engine having a single main power output shaft, such as a crankshaft, that turns in a given direction and to which periodic power impulses are applied when the engine is supplying power to a load, said engine including supporting means therefor subject to angular vibration resulting from said periodic power impulses, one or more rotary masses drivingly connected to the power output shaft so as to turn in the opposite direction at speeds in constant proportion to the speed of the power output shaft and to vibrate rotationally in phase with the power output shaft but in the opposite direction, the sum of the moments of inertia of those masses multiplied by the ratio of their speeds to the speed of the power output shaft being a substantial percentage of the sum of the moment of inertia of the power output shaft and the moments of inertia of all other masses in or on the engine that turn in the same direction as the power output shaft, including any part of the load or power transmitting means fixed to the power output shaft, multiplied by the ratio of their speeds to the speed of the power output shaft to thus effect cancellation of at least a substantial percentage of the angular vibration of the supporting means that would otherwise result from said periodic power impulses.

22. An electric generating set comprising a single crankshaft having a crank and two eccentrics at the sides of the crank, a power piston connected to the crank, a scavenging air pump piston connected to the two eccentrics and located on the opposite side of the crankshaft from the power piston, the ratio of the mass of the pump piston to the mass of the power piston being approximately equal to the ratio of the throw of the crank to the throw of the eccentrics, a countershaft geared to the crankshaft so as to rotate in the opposite direction, a flywheel on the crankshaft, and a power converter element fixed to the countershaft, the ratio of the moment of inertia of the crankshaft and flywheel to the moment

of inertia of the countershaft and the power converter element being approximately the same as the ratio of the gearing of the countershaft to the crankshaft.

23. A power plant comprising an internal combustion engine having two shafts, mechanism for applying power impulses to at least one of the shafts, a rigid mechanism interconnecting the two shafts for making them turn in opposite directions at speeds that have a fixed ratio to each other and for making them accelerate and decelerate together in response to the power impulses, and flywheel means fixed to the shafts, and means for abstracting most of the power of the engine from one of the two shafts without interfering with said acceleration and deceleration of said shafts, the ratio of the moments of inertia of the two shafts and the parts connected to them to accelerate and decelerate with them being substantially the inverse of the ratio of their speeds.

24. An engine installation comprising an internal combustion engine having two shafts, mechanism for applying power impulses to at least one of the shafts, a rigid mechanism interconnecting the two shafts for making them turn in opposite directions at speeds that have a fixed ratio to each other and for making them accelerate and decelerate together in response to the power impulses, flywheel means fixed to the shafts, and a power transmitting element fixed to one of the shafts and proportioned to transmit most of the power from the engine, the power transmitting element being of a type whose rate of power transmission varies with its speed of rotation but not with its instantaneous acceleration or deceleration, and the ratio of the moments of inertia of the two shafts and the parts fixed to them, including the power transmitting element, being substantially the inverse of the ratio of their speeds.

25. A combination as defined in claim 3 and in which the power input element is the rotor of an electric generator and in which a crankshaft is the power output shaft.

26. A combination as defined in claim 3 and in which the power input element is the rotor of an electric generator and in which a crankshaft forms part of the mass connected to turn in the direction opposite to the output shaft.

27. A combination as defined in claim 3 and in which the power transmitting mechanism includes a compressor crank, cylinder, and piston.

28. A combination as defined in claim 3 and in which the power transmitting mechanism is a hydraulic coupling.

29. A combination as defined in claim 3 and in which the power transmitting mechanism is a hydraulic torque converter.

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