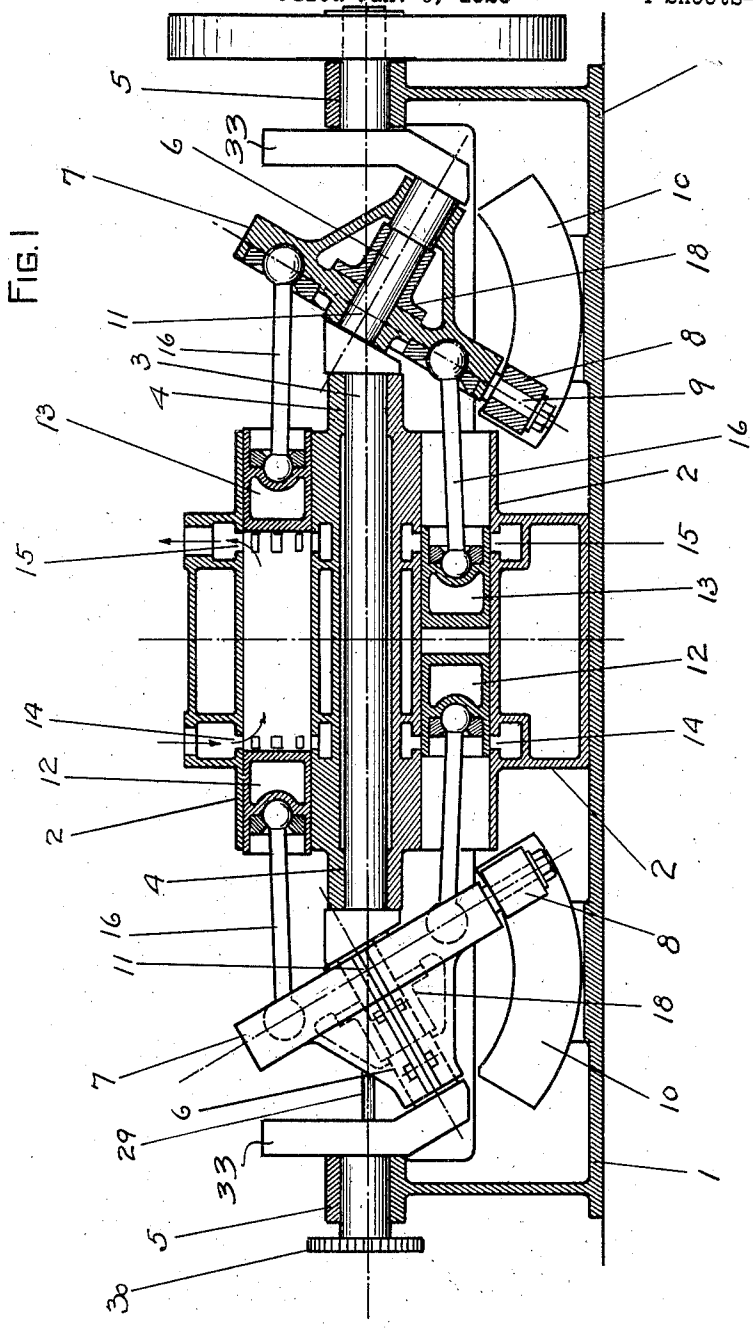
Jan. 17, 1928. 1,656,884

G. K. DAVOL

FORM OF INTERNAL COMBUSTION ENGINE

Filed Jan. 5, 1925 4 Sheets-Sheet 1

FIG. 1

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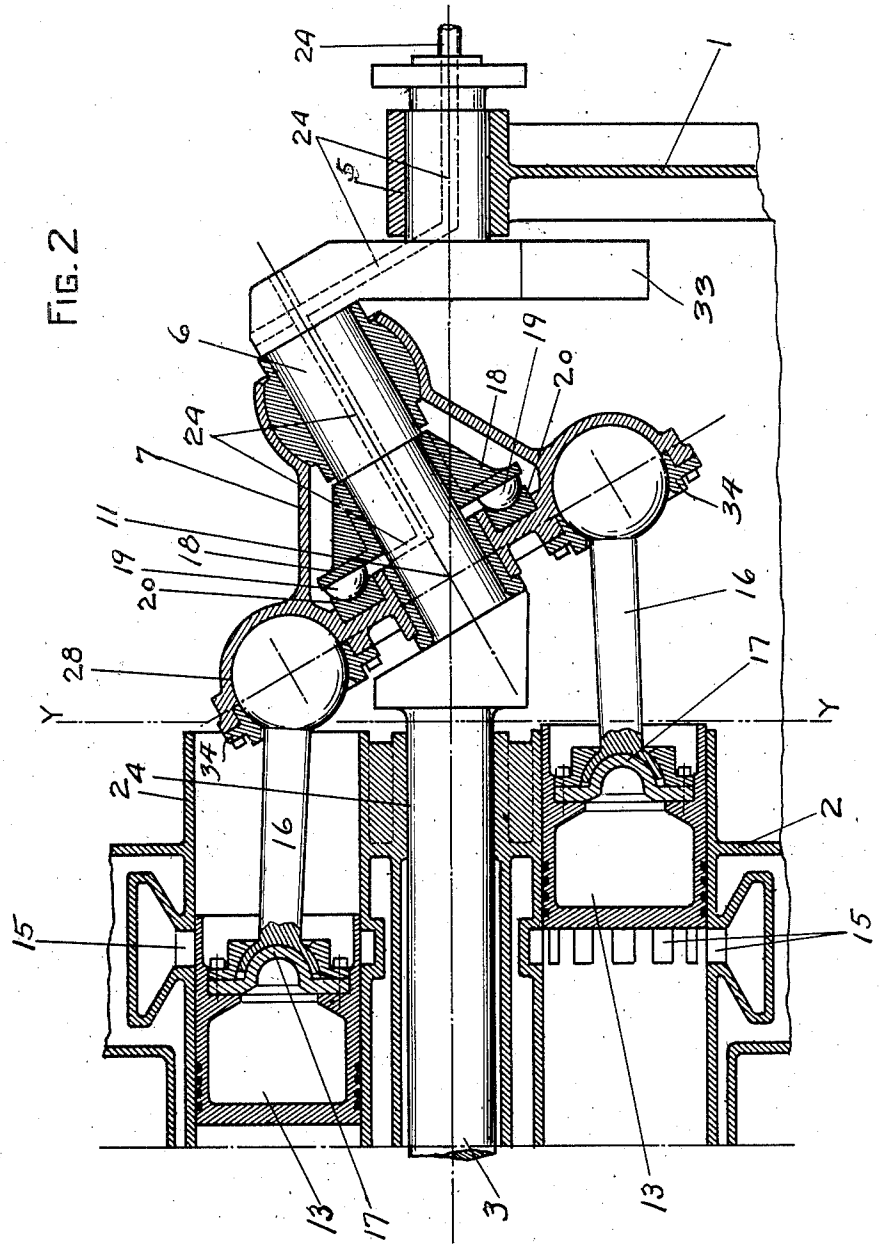
Filed Jan. 5, 1925 4 Sheets-Sheet 2

FIG. 2

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Filed Jan. 5, 1925 4 Sheets-Sheet 3

FIG. 3

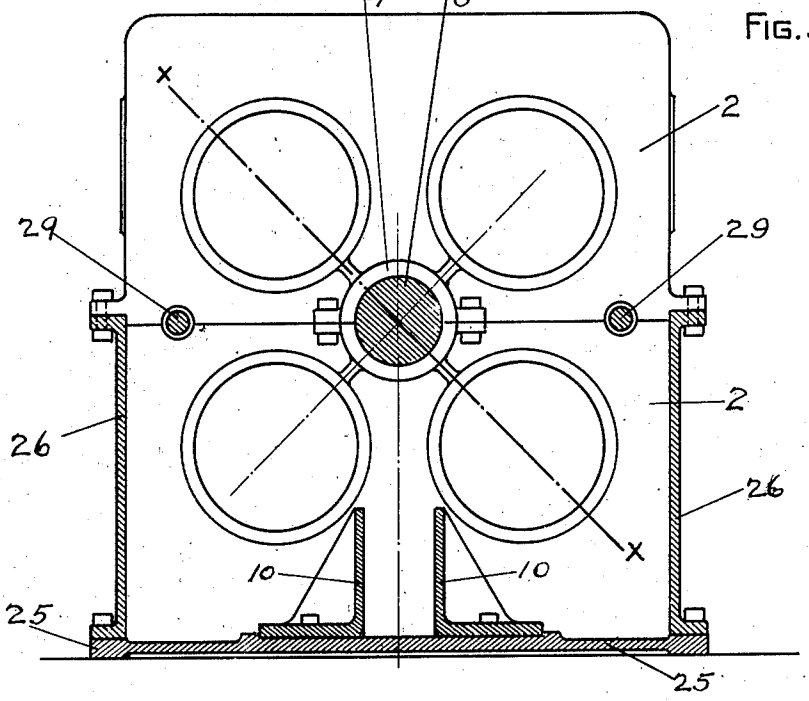


FIG. 4

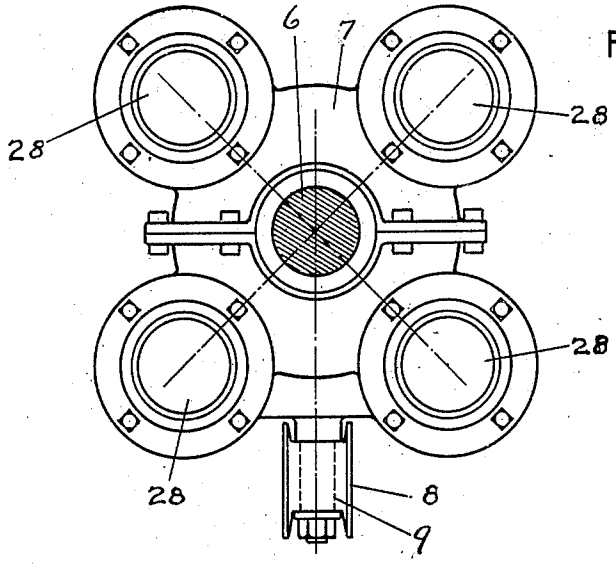


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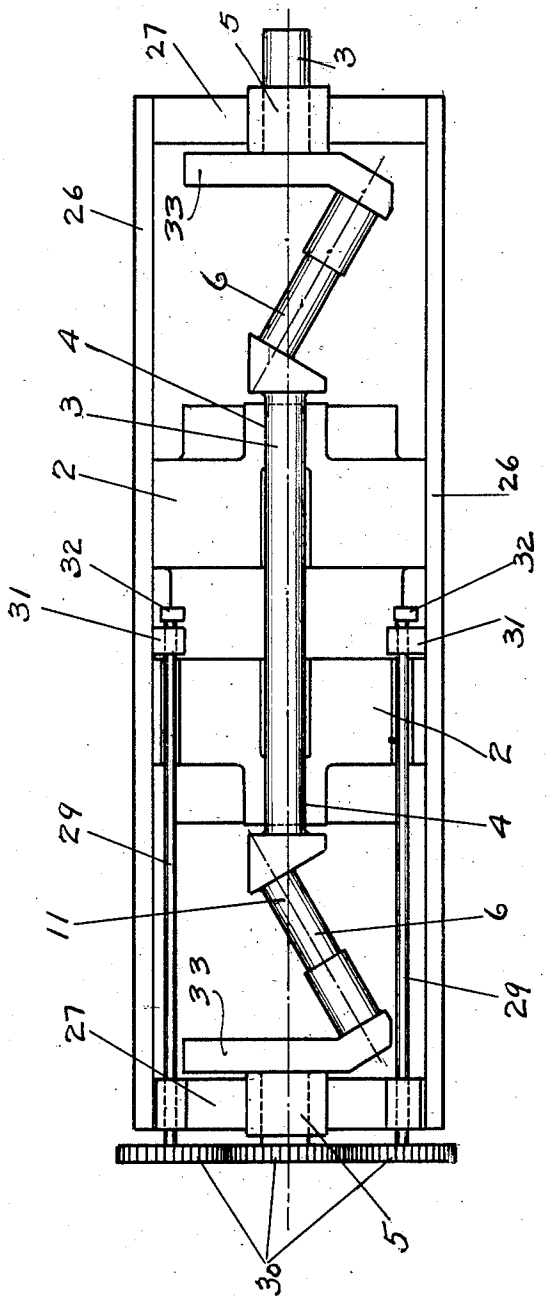
FIG. 5

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Patented Jan. 17, 1928. 1,656,884

# UNITED STATES PATENT OFFICE.

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## FORM OF INTERNAL-COMBUSTION ENGINE.

Application filed January 5, 1925. Serial No. 537.

My invention consists of a combination and arrangement of parts, which has the effect of producing a very compact and small engine of light weight for the power produced, as well as an engine that can be manufactured at an exceptionally low cost.

My invention not only produces a small, compact and light engine for the power produced, but also a form of engine that is particularly adapted for certain purposes where space is restricted.

My invention has to do with that class of internal combustion engines which employs "opposed pistons", or two pistons reciprocating in opposite directions in one open ended cylinder, and is particularly concerned with the manner of transmitting the movement of the opposed pistons to the revolving shaft of the engine.

My invention is not concerned with the manner of introducing the fuel into the cylinder, or with the ignition of the fuel, and it is applicable to either the fuel injection, or Diesel type of engine, or to the gas, or carburetting engine.

More particularly, my invention is embodied in an engine having a main shaft with two inclined crank pins whose axes are inclined at an angle to, and intersect the main axis of the shaft. On each of these inclined crank pins, a wabbling member is loosely or revolvably mounted, but prevented from turning with the shaft by suitable means. Arranged parallel to and surrounding the shaft and disposed between the two inclined crank pins are a number (preferably four) of open ended cylinders, each cylinder having two pistons reciprocating in opposite directions within it. Suitable connections between each of the said pistons and one of the said wabbling members serves to complete the transmission of movement of the pistons to the shaft.

One of the important features of my invention lies in the arrangement of parts whereby the reaction of the thrust of the two pistons in opposite directions, in any one of the cylinders, is taken by two thrust bearings on the main shaft, so that the effect of the two opposed thrusts is to produce a longitudinal tension in the shaft. The frame of the engine is relieved in this manner of the necessity of reacting against these thrusts.

For more detailed description of my invention, I refer to the accompanying drawings, in which:

Fig. 1, shows a longitudinal section of a two cylinder engine, embodying my invention, the section being taken in the plane of the axes of the cylinders and shaft. For the sake of clearness, this figure is made to some extent diagrammatical.

Fig. 2, is a partial longitudinal view of a a four cylinder engine, taken in the plane of two of the cylinders and the shaft, and showing only one half of the cylinders and shaft.

Fig. 3, is a cross sectional view, taken in a plane perpendicular to the axis of the shaft of a four cylinder engine, looking towards the open ends of the cylinders, or on line $y$—$y$ in Fig. 2.

Fig. 4, is an end view of one of the parts designated as "wabbling knuckles" taken in a plane perpendicular to the axis of the knuckle, or to the axis of the crank pin.

Fig. 5, is a longitudinal plan view, with the upper part of the cylinder holding body removed, and is intended particularly to show the arrangements provided for operating the fuel valves, or for operating starting valves, or other devices which require cyclic operation.

All parts shown and referred to are given the same reference numbers in all the drawings.

Referring to Fig. 1, the main frame (1) carries a cylinder holding body (2) which is preferably made in two parts. In this case there is one cylinder in each part, one above and one below and both parallel to the shaft. The shaft (3) passes through the cylinder holding body along the junction or joint between the upper and lower parts.

As shown in the drawing the cylinders are bored directly out of the cylinder holding body (2), and that part might properly be said to constitute the cylinders, but I prefer to refer to it as a cylinder holding body, as it may be advantageous to form the cylinders themselves of separate tubular parts, which may be inserted in and held in place by this cylinder holding body. It will be understood that in this description, and in the claims which follow, this part, referred to as a cylinder holding body, may con-

stitute the cylinders themselves, or a part in which the cylinders proper are inserted and held.

The shaft (3) is carried in bearings (4) in the cylinder holding body, and in bearings (5) in the main frame (1).

Those portions of the shaft between the end bearings (5) and the cylinder holding body comprise cranked portions, or crank pins (6), one at each end of the shaft. These cranked portions of the shaft, or crank pins, have their axes inclined at an angle to the main axis of the shaft, and are preferably formed in the same plane.

Mounted on each of these crank pins, or crank portions of the shaft (6), is a part (7) which I term a "wabbling knuckle." This wabbling knuckle is preferably made in halves joined in a suitable manner, so that they can be put in place to embrace and ride upon the crank pins (6) on which they have a suitable running fit.

The wabbling knuckle at one end of the engine is shown in Fig. 1 in section, while the knuckle at the other end is shown in side view, with the interior chambered portion shown by dotted lines. It will be understood that these two knuckles are intended to be identical, in form and construction, as well as are the thrust bearings within them.

These wabbling knuckles (7) while riding loosely on the crank pins (6) are prevented from turning with the revolving shaft and crank pins, by any suitable means. The means I prefer to employ, and which I show in the drawings, comprises a sliding block (8) mounted on a pin (9) attached to the wabbling knuckles, (Fig. 1 and Fig. 4). This sliding block (8) is constrained to move in one plane, by means of a guide (10), composed, as here shown, of two plates in the form of sectors of a circle (Fig. 1). Between these plates (Fig. 3) the sliding block travels back and forth.

As shown in Fig. 1, the inclined axes of the cranked portions of the shaft (6), or the crank pins, intersect the main axis of the shaft at the points (11). The axes of the pins (9) on which the sliding blocks (8) are mounted should also pass through these same points (11). If this arrrangement is accuately carried out, the blocks (8) can be mounted on the cylindrical pins (9), but if the axes of the pins (9) do not intersect the points (11) then a universal movement will have to be provided for between the blocks (8) and their points of attachment to the wabbling knuckles (7).

In each of the cylinders, two pistons (12) and (13) reciprocate. The pistons (12) at one end of the cylinders, uncover or override the inlet ports (14) at the outer ends of their strokes, and the pistons (13) at the other ends of the cylinders uncover or override the exhaust ports (15) at the ends of their strokes.

Scavenging air under suitable pressure is supplied from any suitable source to the inlet passages and ports (14), and the action of exhausting and scavenging the cylinder with air, as the ports are uncovered in turn by the reciprocating pistons, is exactly the same as in any opposed piston engine, operating on the two stroke cycle. On the outward stroke of the two pistons, the exhaust ports (15) are first uncovered by the pistons (13) and the gases within the cylinder permitted to escape. The inlet or scavenging ports are then uncovered by the pistons (12), and the scavenging air under pressure enters the cylinder through the ports (14), as indicated by the arrows in Fig. 1.

The pistons at one end of the engine are all connected to the wabbling knuckle at that end of the shaft by means of the connecting rods (16). These rods have connection to the pistons through ball and socket joints, or some equivalent arrangement, permitting universal movement. In Fig. 1, the ball is formed on the end of the rod, while in Fig. 2 the socket is shown formed in the end of the rod and the ball on the part (17) which is secured to the piston.

The outer ends of the rods, which engage with the wabbling knuckles, do so through ball and socket joints, as shown in Figs. 1 and 2. Any suitable equivalent arrangement, permitting universal movement, can be employed.

If the shaft (3) be revolved, the wabbling knuckles, carried on the cranked portions (6) of the shaft, and prevented from turning with the shaft by the sliding blocks (8), will be given a wabbling movement, which, through the connecting rods (16), imparts a reciprocating movement to the pistons with which they are connected. In actual operation this action is reversed and the reciprocating movement of the pistons cause the shaft to revolve.

The thrust of the pistons, through their connections against the wabbling knuckles, is counteracted by the thrust bearings or collars (18) which are formed, or mounted rigidly on the crank pins, or cranked portions of the shaft. The pressure of the two wabbling knuckles against the thrust bearings on the shaft, constitutes two equal and opposed forces which balance each other, and produce a tension in the center portion of the shaft.

The thrust bearings on the cranked portion of the shaft shown in Fig. 1 are there shown in the elementary form of plain faced collars 18 against which the inside face of the wabbling knuckles 7 directly bear. This serves to illustrate in the most simple form the function of the bearing and the coopera-

tion of parts. In a practical working design however, it is very essential that a form of thrust bearing be provided, that will continuously sustain the bearing pressures exerted by the pistons against the wabbling knuckle without undue heating and without failure.

In an engine operating on the two-stroke cycle for which my invention is primarily intended, the pistons always exert an outward force, in the form here described, a continuous force against the wabbling knuckles, and this force from the combined action of four pistons as illustrated in Figs. 2 and 3, is very great, and has to be counteracted by the thrust bearing and so transmitted to the shaft.

The practical success of this type of engine, particularly in medium and large sizes, is therefore largely dependent upon the use of a form of thrust bearing capable of continuously holding up under this very severe service. I do not consider in large sizes, any form of ball or roller thrust bearing suitable, while the plain collar type of thrust bearing in this application would be entirely unsuitable.

I have therefore provided, combined with and housed within the wabbling knuckle, a thrust bearing comprising a number of separate, pivotally or universally supported shoes, which together take the end or axial thrust of the wabbling knuckle and transmit it to the thrust collar formed on or secured to the crank pin.

In Fig. 2, I have shown in elementary form such a type of thrust bearing. Here I have shown separate bearing shoes 19 spherically formed on their backs and carried in sockets 20 attached to the wabbling knuckles, thus providing for each bearing shoe a support permitting a universal movement and so allowing the shoe to adjust itself to the forms bearing on it.

For the sake of simplicity, I have omitted in the drawing the equalizing devices such as are commonly embodied in bearings of this type, whereby the total pressure on the bearing is equalized among the separate shoes employed, even though the parts, constituted in this instance by the knuckle and thrust collar, may not run exactly "true" or coaxially. In actual practice such equalizing devices would be provided.

This form of bearing not only shows small frictional losses, and can continuously function under the heavy loads which this application imposes, but also permits of the use of a split thrust collar 18 or one made of halves and clamped around its seating on the shaft or crank pin, which is the intended manner of holding the collar 18, as shown, in place. This allows the making of the crank pin in one piece with the crank arms, which form of construction could not be advantageously followed to combine with the use of any form of ball or roller thrust, requiring hardened ball or roller races made in one piece. The thrust collar on the pin may, of course, if desired, be made integral with the pin.

It is preferable that the axes of the crank pins (6), or the axes of the wabbling knuckles intersect the main axis of the shaft, as indicated in the drawings, Figs. 1, 5 and 6, and also that the axes of the pins (9) carrying the sliding blocks (8) intersect the axis of the shaft at the same point, as indicated in Fig. 1, but this exact intersection of these axes is not absolutely essential, as a limited deviation from exact intersection is allowable, if the attachment of the sliding blocks (8) to the wabbling knuckles allow for universal movement.

It is also preferable that the points of connection of the connecting rods (16) to the knuckles (7) all lie in a plane perpendicular to the axis of the crank pin and passing through the point of intersection of the axis of the crank pin with the axis of the shaft, as shown in Fig. 1.

In engines of this type, in which open ended cylinders are arranged parallel to the shaft and between two wabbling members carried on inclined crank pins at opposite ends of the shaft, and having in each cylinder two oppositely reciprocating pistons connected to the wabbling members, the shaft should properly be required to meet a number of conditions, all of which have not heretofore in any disclosed design, been completely or properly provided for.

I wish here to explain that in this specification and in the claims that follow, when referring to the crank pins 6 and the wabbling knuckles 7, I use the term "outer" to designate the direction toward the end of the engine or away from the cylinders, and the term "inner" to designate the opposite direction, or toward the cylinders or center of the engine. These terms as applied are to be so understood.

The form of shaft which my invention discloses, and which is shown in Fig. 1, I claim as being distinctly different from shafts heretofore suggested for or employed in engines of this type, and that it is particularly designed to care for the conditions and requirements listed below.

First: It is very important that the inclined crank pins be long enough to permit the bearings of the wabbling knuckle being spaced far enough apart to avoid excessive pressures on them, due to the tilting action of the thrust of the pistons on the knuckle, and also long enough to provide for proper length of the knuckle bearings and for the thrust bearing parts between them.

A diagram of forces will disclose, that for a given length of crank pin, or for a given

distance between centers of bearings of the wabbling member on the crank pin, the more the outer end of the crank pin is extended away from the shaft and toward the axis of the cylinder, the less will be the maximum and the average pressures on these bearings of the wabbling member on the pin.

In the form of shaft I provide, the crank pins are long and the point of intersection 11 with the shaft axis is toward their inner ends, so placing the "outer" bearing of the wabbling knuckle on the pin, a considerable distance from the shaft axis, and close to the cylinder axis, while the inner bearing is close to, or as shown in the drawings, almost centers on the main shaft axis.

This manner of reducing bearing pressures on the crank pin may be carried out to a greater degree than by the proportion of parts shown in Figs. 1 and 2. The crank pins and shaft may be so designed, for example, that the entire crank pin may lie to one side of the shaft axis, and the intersection of the axes of the pin and shaft would then come on a continuation or extension of the crank pin axis inwardly beyond the inner bearing on the pin. Such proportions and arrangement would, of course, increase the "throw" of the outer end of the crank pin, and with the same length of pin as shown in Fig. 2, for example, would have the effect of reducing the bearing pressures on the pin below that which results in the proportions and arrangement shown in Fig. 2.

It is to be understood therefore that the intersection of the axes of the pin and shaft need not necessarily lie on the pin itself as shown in Fig. 2.

The final and best proportions of these parts for any engine will be arrived at with due consideration being given not alone to bearing pressures but to other features and values as well.

Second: A very heavy tension is produced in the shaft by the opposed thrust of the pistons acting on the wabbling knuckles and being taken by the thrust collars 18, and it is important that this tension be transmitted as directly as possible through the shaft, from one thrust collar to the other at the opposite end of the shaft.

In the form of shaft which my invention provides, this tension is not transmitted through any offset crank arm, required thereby to sustain bending stress, but in a very direct line, as shown in Fig. 1 through the center portion of the shaft and the two massive wedge shaped blocks connecting the center portion of the shaft to the two crank pins. This results in the practical elmination of bending stress in the shaft due to this tension.

Third: It is very desirable in an engine of this type that the cylinders be placed as closely to the shaft as possible. This renders the engine compact, light, and economical of construction, and for a given length of stroke, lessens the bending moment on the shaft due to the thrust of the pistons.

It is however, very desirable to provide for the withdrawal of any one of the pistons when that point on the wabbling knuckle which it is connected to is at the outer end of its swing or stroke, and if the inner crank arm or the crank arm nearest the cylinder is made long, it interferes with the withdrawal of the piston when the knuckle is in this position.

With the form of shaft I provide, carrying crank pins the outer portions of which, measuring from the point of intersection 11 of their axes with the axis of the shaft, are much longer than their inner portions measuring from the same point, the inner crank arms become either exceedingly short or are entirely absent, and the pistons on being withdrawn have only to clear the wedge shaped cylindrical part which serves as the inner crank arm, or as a means of uniting the center portion of the shaft with the crank pin. This permits of placing the cylinders as closely to the shaft as other conditions will allow. This feature is of particular importance in engines of short stroke relative to cylinder bore.

Fourth: As before stated, it is very desirable, if not absolutely necessary, for practical results of this type, to use the separately supported shoe type of thrust bearing for taking the actual thrust of the wabbling member on the crank pin. Such bearings have thrust collars of large diameter. This is indicated in Fig. 2 where the thrust collar 18 is shown in approximately reasonable proportion to the size of cylinders shown. These thrust collars, if made in halves, also require a considerable space on the shaft or pin on which they are clamped or seated, the length axially being commonly made equal to about one-third of their outside diameter. The bearing shoes and shoe supporting devices also require a space approximately equal in diameter to that of the thrust collar and of considerable length axially.

It can be seen that the proper accommodation of these bulky parts, without encroaching in the space required by the ball sockets 28 and the retaining rings 34 offers considerable difficulty, especially in short stroke engines, in which the ball sockets 28 are proportionately large with reference to their distance from the crank pin axis. It is also an advantage that no projection of large diameter extend inwardly, or toward the cylinders, on the crank pin axis much beyond the plane of the ball sockets 28.

The construction disclosed in Fig. 2 overcomes these difficulties by providing for set-

ting the bearing face of the thrust collar 18 a suitable distance outward, or to a direction away from the cylinders, from the point of intersection 11 of the crank pin axis with the shaft axis, and providing a further suitable distance outwardly on the crank pin for the seating of the collar.

This arrangement of parts as there shown permits the use of thrust collars of large diameters without encroaching on the space required by the ball sockets 28, even in a short stroke engine, and also accommodates the bearing shoes and shoe supporting devices without a projection of their housing, formed by the knuckle 7, inwardly toward the cylinders beyond the plane of the ball sockets 28.

The proper carrying out of this arrangement requires that the crank pin be so placed that the point 11 of intersection of its axis with that of the shaft is closer to its inner end than to its outer end, as shown in Fig. 2.

The design of shaft I provide by which all the conditions and requirements above listed are properly met, results in an unbalanced crank pin, or a considerable revolving mass centering at the outer end of the crank pin, and including a portion of the wabbling knuckle, a portion of the crank pin and a portion of the outer crank arm. This revolving mass can be largely balanced by a counterweight 33, attached to an arm extending diametrically opposite to the outer crank arm.

This manner of applying the counterweight however, results in an unbalanced revolving moment produced at each end of the shaft, as each mass revolves in a plane separated some distance from the plane in which its counterweight revolves, but in as much as these revolving moments of equal force and of opposite direction are produced at each end of the shaft they cancel each other.

In the construction shown in Figs. 1 and 2, which is my preferred construction, particularly for large engines, it is essential that there be very effective lubrication of the thrust bearings. To this end, I form a hollow chamber in the wabbling knuckle (7) between its two bearings on the crank pin, or cranked portion of the shaft, and within this chamber I locate the thrust bearing. Means are then provided to conduct lubricant to this chamber in ample and sufficient quantity. Such means are indicated in Fig. 2, where there is shown by dotted lines, a bored passage (24), entering on the axis of the shaft at its end, and communicating with the chamber within the wabbling knuckle (7). Through this passage lubricant is supplied to this chamber, and to the thrust bearing within it, and at the same time, to the bearings of the wabbling knuckle on the crank pin (6). This hollow construction of the wabbling knuckles (7), with the thrust bearings (18) located within and enclosed by the chamber so formed, is important.

Other means or passages may be employed for getting the lubricating oil into the interior chamber of the wabbling knuckle, if desired. It is essential that lubricating oil be conducted into this chamber in sufficient quantity to not only supply ample lubricant to the thrust, and to the end bearings of the knuckle, but also in sufficient quantity to serve as a cooling medium capable of carrying off the excess heat generated through the friction of the thrust bearing. To this end a continuous circulation of oil should be maintained into and out of the knuckle, the oil being supplied in sufficient quantity and allowed to leak out through the end bearings and through other passages if necessary, in order to maintain such a circulation.

Any number of cylinders may be employed in an engine of this design that may be found convenient. Four cylinders have been found to constitute a practical design, and in Fig. 3 I show a cross section showing the arrangement of four cylinders. As here shown, two cylinders are formed in the upper half, and two cylinders in the lower half of the cylinder holding body (2), and bearings for the shaft are formed between the two halves. The lower half of the cylinder holding body rests on the base plate (25); and side plates (26), are provided, which are secured to the cylinder holding body on each side, and which extend to and are attached to the end shaft bearings (27), as shown in Fig. 5.

The side frames 26 together with the base plate 25 to which they are properly secured, form, together with the end bearing supports, a box shaped girder of great stiffness. As shown in the drawings, the end bearing supports are made integrally with the base plate 1, but in practical construction, particularly of large engines, it will be preferable to make the end bearing supports separate from the base plate.

This construction results in a very strong and rigid support for the main shaft bearings, which are so maintained rigidly in line, while at the same time the shaft is readily accessible. Removal of the main shaft is readily accomplished through the loosening and lifting off of the upper half of the cylinder holding body 2 and removal of the caps of the end bearings, when the shaft may be lifted out. This construction also permits the removal of either side frame 26 without disturbing the other main parts, which for purposes of overhauling, is a considerable practical advantage.

As my invention is primarily intended to

be carried out in an engine operating on the two-stroke cycle, an even number of cylinders can be, and preferably should be employed. This permits of placing one-half the cylinders in the upper and one-half in the lower halves of the cylinder holding body or housing 2, symmetrically arranged with reference to the dividing plane. This is for structural reasons important, and would not be possible with an odd number of cylinders, which an engine operating on the four-stroke cycle would require, if regularity of impulses was preserved.

All references to "cylinders" hereinbefore are intended to apply to "working cylinders" or engine cylinders in which the working gases expand and all references to "cylinders" in the claims which follow are to be so understood. It is, of course, possible to add, where space permits, cylinders having other functions, such as for the compression of air or pumping of fluids, which additional cylinders may contain pistons operated from the wabbling knuckles, but cylinders of this nature are not considered herein.

As shown in Fig. 3, the guides 10, for the sliding block (8) are attached to the base plate (25), and are centered on a plane passing between the lower cylinders.

In Fig. 4, I show an end view of the wabbling knuckle (7), used for a four cylinder engine, showing the four sockets (28) for the reception of the ball ends of the connecting rods (16), and also showing the sliding block (8), mounted on the pin (9), at the bottom. As here shown, the wabbling knuckle is made in two halves, united by a flanged joint and bolts.

This construction of the wabbling knuckle 7 in halves is an essential to my design as a whole, as it not only permits the making of the inclined crank pins integral with the crank arms at each end of the crank pins, but also permits of complete access to the thrust bearing located within or embraced by it.

In the practical construction and operation of this type of engine in moderate and large sizes, it is essential that the separate shoe type of thrust bearing, which is the preferred type of thrust bearing to employ for this service, be completely accessible, for assembly in place, or for overhaul, inspection, removal or adjustment, without interference from the part which embraces and encloses it when in operation, and for this alone it is most important that the wabbling knuckle be made in two completely separate halves.

For the operation of the various valves, such as the fuel injection valves, starting air valves, or other devices connected with the working cylinders, which require cyclic operation, I provide the valve gear shafts (29), shown in Fig. 5, which receive motion from the main shaft (3) through the gears (30). These shafts have a bearing in the end bearings (27), and lie parallel to the main shaft (3). They pass through one end of the cylinder holding body (2), as shown in Fig. 5, and also in Fig. 3, and reach to the vicinity of the center of the cylinders. In the case of the four cylinder design, two of such valve gear shafts are provided, one on each side of the engine, each shaft serving to operate the gear connected with the two cylinders on its side of the engine. They are suitably supported in bearings where necessary, as in the bearings (31) in Fig. 5, and can be provided with cams (32), or other devices for operating the valves, etc.

I prefer the construction in which two pistons reciprocate in one straight and continuous cylinder, open at both ends, but it must be recognized that this exact construction is not essential, as instead of one straight and continuous cylinder being employed for the two co-operating pistons, two cylinders, whose axes may not exactly coincide, may be employed, with one of the two co-operating pistons reciprocating in each cylinder, and the two cylinders connected at their inner ends, so as to form one central compression space, common to both cylinders. With this construction, the exhaust ports would be formed in one cylinder, and the inlet ports formed in the other cylinder, and as each pair of cylinders would be connected, their operation would be the same as if one continuous cylinder was used for the two pistons. This construction might be employed if it was desired to modify the relative timing of the opening and closing of the exhaust and inlet ports, by any two co-operating pistons, by setting one cylinder in a slightly angularly advanced position relative to the cylinder with which it is connected.

With such construction, it is not even essential that each cylinder of such a connected pair, have its axis exactly parallel to the axis of the connected cylinder. These latter modifications, while unfavorably affecting the balance of the engine, do not affect the essence of my invention, and it must be recognized, that in these specifications and in the claims which follow, any reference to a cylinder in which two pistons reciprocate, is intended to cover any such equivalent construction in which two separate cylinders, whose axes may even not exactly coincide, but which are connected to a common compression space, are employed.

It must also be recognized that while I prefer the construction in which the axes of the cylinders are parallel to the main axis of the shaft, the cylinders may be set with their axes not exactly parallel to the axis of the shaft, within certain restricted limits, without materially affecting the operation

desired. Any such limited deviation from exact parallelism between the axes of the cylinders and that of the shaft, does not affect the essence of my invention, and is intended to be allowed for and covered in the claims which follow, by the expression "substantially parallel".

Although it is preferable, for the sake of perfect balance of the reciprocating parts, to have the two crank pins, or the two cranked portions of the shaft in the same plane, this exact arrangement is not essential, but, if desired, the two cranked portions of the shaft may lie in different planes, separated by a small and limited angle, so that one of each pair of co-operating pistons may have a lead over the other piston. This arrangement may, if desired, be utilized to modify the relative timing of the opening and closing of the exhaust and inlet ports in any one cylinder.

The term "wabbling knuckle" by which, in these specifications and in the claims which follow, I designate that part mounted on the cranked portion of the shaft and against which the pistons thrust, need not be regarded as an inherently descriptive term, but as an arbitrarily selected term, used to designate the part referred to. The part must necessarily have a wabbling movement, and it resembles to some extent, a knuckle like joint.

I wish to make it distinctly understood that the two cylinder form of engine, I have depicted in Fig. 1, I have shown merely to simplify the explanation of the operation of the essential parts of the engine. The two cylinder form makes it feasible to show a vertical longitudinal section through the center of shaft and axes of cylinders and it is for this reason that it is shown. I do not consider the two cylinder engine forms a desirable embodiment of my invention. On the other hand, the four cylinder engine shown in Figs. 2 and 3 forms a preferred form of engine for the embodiment of my invention.

I claim as follows:

1. In an engine, a revolving shaft, two wabbling knuckles mounted on the said shaft on axes inclined to the main axis of the shaft and means preventing them from revolving with the shaft, a cylinder holding body comprising two parts, the said shaft passing through the said cylinder holding body along the junction of the said two parts, cylinders in the said cylinder holding body arranged with their axes parallel to the axis of the said shaft, two pistons reciprocating in each of the said cylinders, and connections between the said pistons and the said wabbling knuckles.

2. In an internal combustion engine, a revolving main shaft having two inclined crank pins, cylinders held parallel to the axis of the said shaft, two pistons reciprocating in each of the said cylinders, wabbling members mounted on each of the said two inclined crank pins, connections between the said pistons and the said wabbling knuckles, and valve gear shafts held parallel to the said main shaft and being geared to the said main shaft.

3. In an engine, a main shaft carrying two inclined crank pins, with wabbling members mounted on the said inclined crank pins, cylinders arranged substantially parallel to the said shaft, each of the said cylinders having two pistons reciprocating within it, the said cylinders being associated with a cylinder holding body made in two separable parts, the said main shaft passing through the said cylinder holding body between the two said parts and connections between the said pistons and the said wabbling members.

4. In an engine, a horizontal main shaft carrying two inclined crank pins, with wabbling members mounted on the said inclined crank pins, a cylinder holding body comprising a lower part and an upper part, the said parts being separable from each other, the said main shaft passing through the said cylinder holding body between the said upper and lower parts, cylinders substantially parallel to the said shaft associated with the said cylinder holding body, two pistons reciprocating in each of the said cylinders and connections between the said pistons and the said wabbling members.

5. In an engine, a horizontal main shaft carrying two inclined crank pins, wabbling knuckles or members mounted on the said crank pins, a cylinder holding body comprising a lower part and an upper part, the said upper part being removable from the said lower part, the said main shaft passing through the said cylinder holding body between the said upper and lower parts and being held in bearings supported by the said lower part, cylinders substantially parallel to the said shaft formed in or carried by the said cylinder holding body, two pistons reciprocating in each of the said cylinders and connections between the said pistons and the said wabbling members.

6. In an engine, a horizontal main shaft carrying two inclined crank pins, wabbling knuckles or members mounted on the said crank pins, a cylinder holding body comprising a lower part and an upper part, the said upper part being removable from the said lower part, the said main shaft passing through the said cylinder holding body between the said upper and lower parts, four cylinders substantially parallel to the said shaft formed in or carried by the said cylinder holding body, two of the said cylinders being formed in or carried by the said upper part, and two of the said cyl-

inders being formed in or carried by the said lower part of the said cylinder holding body, two pistons reciprocating in each of the said cylinders and connections between the said pistons and the said wabbling members.

7. In an engine, a main shaft comprising two inclined crank pins and a straight middle portion between the two crank pins, the axes of the said crank pins intersecting the main axis of the shaft, the said crank pins having their outer ends or ends most distant from the said middle portion of the shaft more distant in a radial direction from the shaft axis than their opposite or inner ends, wabbling members carried on the said crank pins, open ended working cylinders surrounding and arranged substantially parallel to the said shaft between the said crank pins, two pistons reciprocating in each of the said cylinders and connections between the said pistons and the said wabbling members.

8. In an engine, a main shaft comprising two inclined crank pins and a straight middle portion between the two crank pins, the axes of the said crank pins intersecting the main axis of the shaft, the two points of intersection of the shaft axis with the axes of the said crank pins being closer to the inner ends of the said crank pins than to their outer ends, or ends most distant from the said middle portion of the shaft, wabbling members carried on the said crank pins, open ended working cylinders surrounding and arranged substantially parallel to the said shaft between the said crank pins, two pistons reciprocating in each of the said cylinders and connections between the said pistons and the said wabbling members.

9. In an engine, a main shaft comprising two inclined crank pins and a straight middle portion between the two crank pins, the axes of the said crank pins intersecting the main axis of the shaft, the two points of intersection of the shaft axis with the axes of the said crank pins being closer to the inner ends of the said crank pins than to their outer ends, or ends most distant from the said middle portion of the shaft, a wabbling member carried by two bearings on each of the said crank pins, a thrust collar on each of the said crank pins located between the said bearings of the said wabbling members, open ended working cylinders surrounding and arranged substantially parallel to the said shaft between the said crank pins, two pistons reciprocating in each of the said cylinders and connections between the said pistons and the said wabbling members.

10. In an engine, a main shaft comprising two inclined crank pins and a straight middle portion between the two crank pins, the axes of the said crank pins intersecting the main axis of the shaft, the two points of intersection of the shaft axis with the axes of the said crank pins being closer to the inner ends of the said crank pins than to their outer ends, or ends most distant from the said middle portion of the shaft, a wabbling member carried by two bearings on each of the said crank pins, a thrust collar on each of the said crank pins located between the said bearings of the said wabbling members, each of the said thrust collars being made in two halves and clamped to the said crank pins, open ended working cylinders surrounding and arranged substantially parallel to the said shaft between the said crank pins, two pistons reciprocating in each of the said cylinders and connections between the said pistons and the said wabbling members.

11. In an engine, a main shaft comprising two inclined crank pins and a straight middle portion between the two crank pins, the axes of the said crank pins intersecting the main axis of the shaft, a wabbling member carried by two bearings on each of the said crank pins, a thrust collar on each of the said crank pins located between the said bearings and the said wabbling members, shoulders on the said crank pins, each of the said thrust collars bearing against the said shoulders and being made in halves and clamped to the said crank pins, open ended working cylinders surrounding and arranged substantially parallel to the said shaft between the said crank pins, two pistons reciprocating in each of the said cylinders and connections between the said pistons and the said wabbling members.

12. In an engine, a main shaft comprising a middle portion, a crank pin at each end of the said middle portion and a bearing outside of each of the said crank pins, the said crank pins being inclined at an angle to the axis of the shaft and connected at their inner ends with the said middle portion of the shaft by short connections and with the bearings at their outer ends by suitable crank arms, wabbling members carried on the said crank pins, open ended working cylinders surrounding and arranged substantially parallel to the said shaft between the said crank pins, two pistons reciprocating in each of the said cylinders and connections between the said pistons and the said wabbling members.

13. In an engine, a main shaft comprising two inclined crank pins and a straight middle portion between the two crank pins, the axes of the said crank pins intersecting the main axis of the shaft, open ended working cylinders surrounding and arranged substantially parallel to the said shaft between the said crank pins, two pistons reciprocating in each of the said cylinders, a wabbling

knuckle or member carried on two bearings on each of the said crank pins, a thrust collar carried on each of the said crank pins between the said bearings of the wabbling knuckle, connecting rods connecting the said pistons with the said wabbling knuckles or members, the said connecting rods having ball ends which bear in spherical sockets formed in the wabbling knuckles, each of the said wabbling knuckles having a chambered recess formed in it between its said two bearings on the crank pins, the said chambered recess having a portion of maximum inside diameter which said portion is located back of or beyond the centers of the said spherical sockets, in a direction away from the cylinders.

14. In an engine, a main shaft comprising a middle portion, a crank pin at each end of the said middle portion and a bearing outside of each of the said crank pins, the said crank pins being inclined at an angle to the axis of the shaft and connected at their inner ends with the said middle portion of the shaft by cylindrical parts concentric with the main shaft, the said cylindrical parts joining at their outer ends with the said crank pins in planes oblique to the shaft axis but normal or perpendicular to the axes of the crank pins, wabbling members carried on the said crank pins, open ended working cylinders surrounding and arranged substantially parallel to the said shaft between the said crank pins, two pistons reciprocating in each of the said cylinders and connections between the said pistons and the said wabbling members.

15. In an engine, a main shaft comprising a straight cylindrical center portion, having ends of enlarged diameter, the outer faces of which are formed by planes oblique to the main shaft axis, two crank pins having their axes perpendicular to the said oblique planes and joining the said center portions on the said oblique planes, two crank arms at the outer ends of the said crank pins and two end journals connected to and outside of the said crank arms, wabbling members carried on the said crank pins, open ended working cylinders surrounding and arranged substantially parallel to the said shaft between the said crank pins, two pistons reciprocating in each of the said cylinders and connections between the said pistons and the said wabbling members.

16. In an engine, a main shaft comprising two inclined crank pins and a straight middle portion between the two crank pins, the axes of the said crank pins intersecting the main axis of the shaft, a wabbling member carried on two bearings on each of the said crank pins, a thrust collar carried on each of the said crank pins between the said bearings of the wabbling member, each of the said wabbling members being made in two separable parts, each part forming an approximate half and being recessed for the accommodation of the said thrust collars within it and connections between the said pistons and the said wabbling members.

17. In an engine, a main shaft comprising two inclined crank pins and a straight middle portion between the two crank pins, the axes of the said crank pins intersecting the main axis of the shaft, open ended working cylinders surrounding and arranged substantially parallel to the said shaft between the said crank pins, two pistons reciprocating in each of the said cylinders, a wabbling member carried on two bearings on each of the said crank pins, a thrust collar carried on each of the said crank pins between the said bearings of the wabbling member, each of the said wabbling members being made in two halves united by a flanged joint and being recessed for the accommodation of the said thrust collars within it, and connections between the said pistons and the said wabbling members.

18. In an engine, a main shaft comprising two inclined crank pins and a straight middle portion between the two crank pins, the axes of the said crank pins intersecting the main axis of the shaft, open ended working cylinders surrounding and arranged substantially parallel to the said shaft between the said crank pins, two pistons reciprocating in each of the said cylinders, a wabbling knuckle carried on two bearings on each of the said crank pins, a thrust collar carried on each of the said crank pins between the said bearings of the wabbling knuckle, connecting rods engaging with the said pistons at their inner ends and having ball shaped outer ends, the said wabbling knuckles being recessed for the accommodation of the said thrust collars and being made in two separable parts, each part forming an approximate half and each of the two parts carrying an equal number of spherical sockets in which the ball ends of the said connecting rods bear.

19. In an engine, a main shaft comprising two inclined crank pins and a straight middle portion between the two crank pins, the axes of the said crank pins intersecting the main axis of the shaft, open ended working cylinders, two pistons reciprocating in each of the said cylinders, a wabbling knuckle carried on two bearings on each of the said crank pins, a thrust collar carried on each of the said crank pins between the said bearings of the wabbling knuckle, each of the said wabbling knuckles being made in two separable parts, each part forming an approximate half and being recessed for the accommodation of the said thrust collars within it, each half of each of the said wabbling knuckles having connection with an equal number of connecting rods, each of

said rods connecting in turn with one of the said pistons in one of the said working cylinders.

20. In an engine, a main shaft comprising two inclined crank pins and a straight middle portion between the two crank pins, the axes of the said crank pins intersecting the main axis of the shaft, open ended working cylinders surrounding and arranged substantially parallel to the said shaft between the said crank pins, two pistons reciprocating in each of the said cylinders, a wabbling knuckle carried on two bearings on each of the said crank pins, a thrust collar carried on each of the said crank pins between the said bearings of the wabbling knuckle, each of the said wabbling knuckles being made in two entirely separable parts, each part forming an approximate half, the said two parts of each knuckle being united by a joint lying in a plane passing through the axis of the crank pins and connections between the said pistons and the said wabbling members.

21. In an engine, a main shaft comprising two inclined crank pins and a straight middle portion between the two crank pins, the axes of the said crank pins intersecting the main axis of the shaft, open ended working cylinders surrounding and arranged substantially parallel to the said shaft between the said crank pins, two pistons reciprocating in each of the said cylinders, a wabbling knuckle or member carried on two bearings on each of the said crank pins, a thrust collar carried on each of the said crank pins between the said bearings of the wabbling knuckle, each of the said wabbling knuckles being made in two separable parts, each part forming an approximate half and being recessed for the accommodation of the said thrust collars within it, a number of separate bearing shoes carried by each of the said wabbling knuckles, the said shoes bearing against the said thrust collars and connections between the said pistons and the said wabbling members.

22. In an engine, a main shaft comprising two inclined crank pins and a straight middle portion between the two crank pins, the axes of the said crank pins intersecting the main axis of the shaft, open ended working cylinders surrounding and arranged substantially parallel to the said shaft between the said crank pins, two pistons reciprocating in each of the said cylinders, a wabbling knuckle or member carried on two bearings on each of the said crank pins, a thrust collar carried on each of the said crank pins between the said bearings of the wabbling knuckle, each of the said thrust collars being made in two halves and clamped to the said crank pins, and each of the said wabbling knuckles being made in two separable parts, each part forming an approximate half and being recessed for the accommodation of the said thrust collar within it, a number of separate bearing shoes carried by each of the said wabbling knuckles, the said shoes bearing against the said thrust collar, and connections between the said pistons and the said wabbling members.

23. In an engine, a main shaft comprising two inclined crank pins and a straight middle portion between the two crank pins, the axes of the said crank pins intersecting the main axis of the shaft, open ended working cylinders surrounding and arranged substantially parallel to the said shaft between the said crank pins, two pistons reciprocating in each of the said cylinders, a wabbling knuckle or member carried on two bearings on each of the said crank pins, a thrust collar carried on each of the said crank pins between the said bearings of the wabbling knuckle, the said thrust collars being so placed on the crank pins that their bearing faces are a definite distance outward from the points of intersection of the axes of the crank pins with the axis of the shaft, measured axially along the pin in the direction away from the cylinders, and connections between the said pistons and the said wabbling members.

24. In an engine, a main shaft comprising two inclined crank pins and a straight middle portion between the two crank pins, the axes of the said crank pins intersecting the main axis of the shaft, open ended working cylinders surrounding and arranged substantially parallel to the said shaft between the said crank pins, two pistons reciprocating in each of the said cylinders, a wabbling knuckle or member carried on two bearings on each of the said crank pins, a thrust collar carried on each of the said crank pins between the said bearings of the wabbling knuckle, each of the said wabbling knuckles or members having a chambered recess formed in it between its said two bearings on the crank pins, the said chambered recess having a portion of maximum inside diameter which said portion is located beyond the point of intersection of the crank pin axis with the axis of the shaft, measured axially along the pin in the direction away from the cylinders and connections between the said pistons and the said wabbling members.

25. In an engine, a main shaft comprising a straight cylindrical center portion, having ends of enlarged diameter, the outer faces of which are formed by planes oblique to the main shaft axis, two crank pins having their axes perpendicular to the said oblique planes and joining the said center portions on the said oblique planes, two crank arms at the outer ends of the said crank pins and two end journals connected to and outside of the said crank arms.

26. In an engine, the combination of a shaft carrying two crank axes inclined to the axis of the shaft, a cylinder holding body, the said shaft passing through the said cylinder holding body, cylinders substantially parallel to the said shaft formed or held in the said cylinder holding body, wabbling members or knuckles mounted on the said inclined crank axes, two side frames attached to and extending beyond the ends of the said cylinder holding body, a base plate attached to and connecting the two said side frames, guides attached to the said base plate, a guiding means attached to each of the said wabbling members or knuckles, the said guiding means engaging with the said guides attached to the base plate, pistons in the said cylinders connecting with the said wabbling members.

27. In an engine, the combination of a horizontal shaft carrying two inclined crank axes intersecting the axis of the shaft, wabbling members or knuckles mounted on the said inclined crank axes, a cylinder holding body comprising an upper and a lower part, the said shaft passing through the said cylinder holding body between the said upper and lower parts, two cylinders formed in the said lower part of the said cylinder holding body, pistons in the said cylinders connecting with the said wabbling members, two side frames attached to and extending beyond the ends of the said cylinder holding body, a base plate attached to and connecting the two said side frames, guides attached to the said base plate and below the said shaft, the said guides being located centrally, relative to an extension of the axes of the said two cylinders, and a guiding means attached to each of the said wabbling members or knuckles, the said guiding means engaging with said guides attached to the base plate.

In witness whereof, I hereunto subscribe my name this 20th day of December, 1924.

GEORGE K. DAVOL.