United States Patent

Buske

[15] **3,692,005**

[45] **Sept. 19, 1972**

[54] INTERNAL PRESSURE ENGINE

[72] Inventor: **Norman L. Buske,** 15 Indian Run Trail, Wakefield, R.I. 02879

[22] Filed: **April 19, 1971**

[21] Appl. No.: **134,947**

[52] **U.S. Cl.**.....**123/51 R,** 92/69, 92/75

[51] **Int. Cl.**.....**F02b 25/08**

[58] **Field of Search**.....123/51 R, 51 A, 51 B; 92/69, 92/75

[56] **References Cited**

UNITED STATES PATENTS

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Primary Examiner—Wendell E. Burns

Attorney—Robert E. Burns and Emmanuel J. Lobato

[57] **ABSTRACT**

An internal combustion engine comprises at least three like members, called hedrons, between two parallel end plates. Each of the hedrons has end faces engaging the respective end plates, a concave side face and an adjacent convex side face. When the hedrons are assembled with the concave side face of each hedron slidably engaging the convex side face of an adjacent hedron, the concave side faces of the hedrons define a combustion chamber the volume of which is varied by inward and outward movement of the hedrons. Each of the hedrons is supported by an eccentric or crank on a shaft that extends between the end plates. The shafts are interconnected by a timing plate or by gears so that the rotation of the shafts and corresponding movement of the hedrons is synchronized. The end plates are provided with intake and exhaust ports. A charge is introduced into the combustion chamber, compressed by inward movement of the hedrons and thereupon ignited. The expanding combustion products force the hedrons outwardly and this outward movement is converted into rotary movement of the shafts. Power is taken off any one of the shafts or from a central shaft driven by the individual shafts supporting the respective hedrons.

18 Claims, 52 Drawing Figures

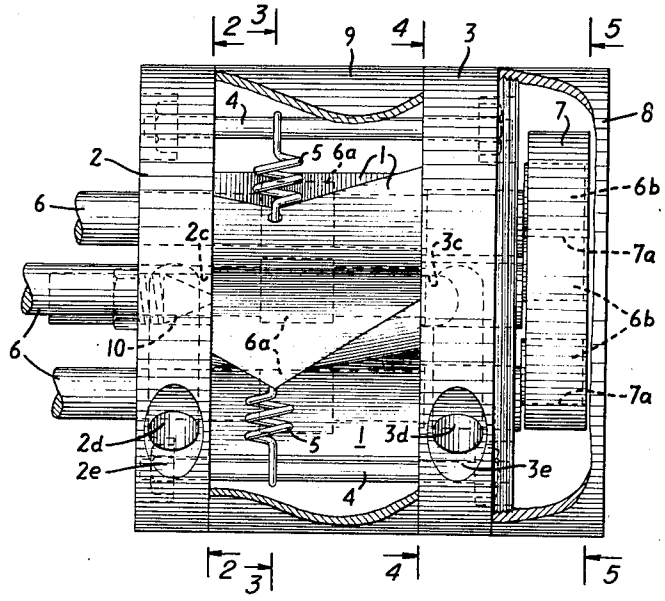


FIG. 1

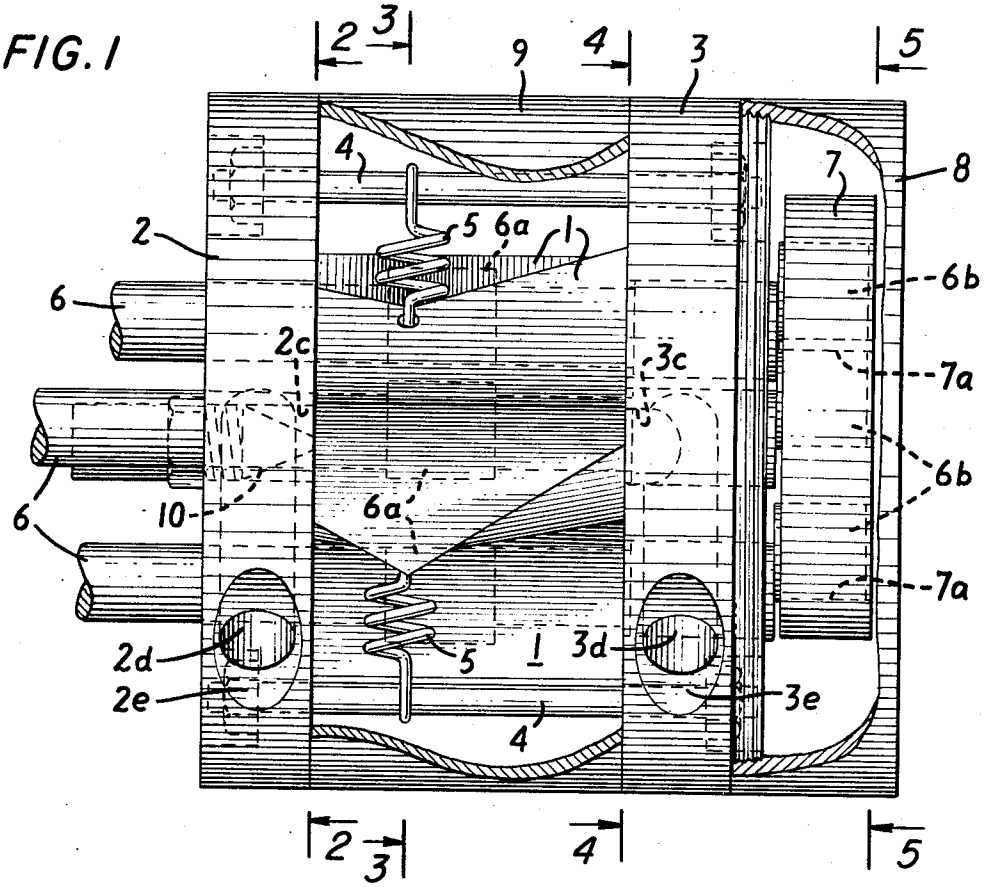
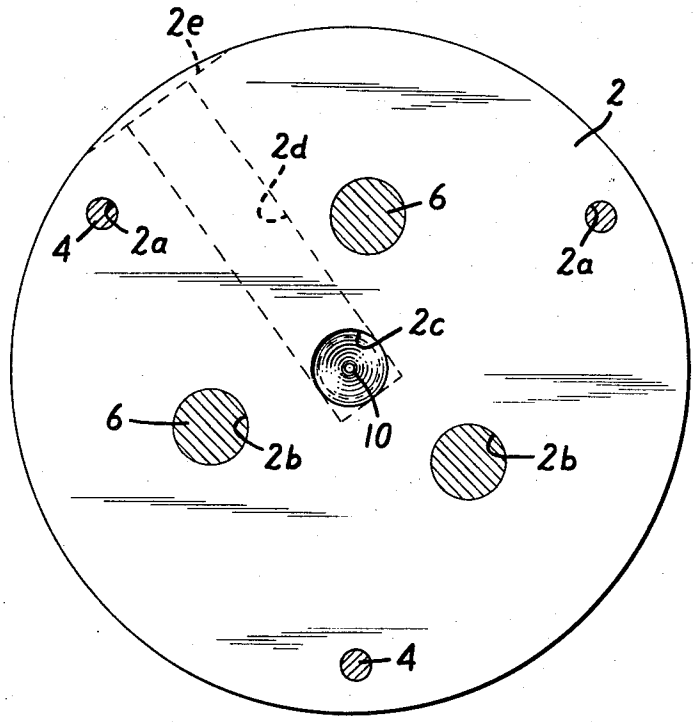

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6a
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2d
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3d
2e
3e
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2 3
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FIG. 2


2e
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2d
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2a
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2b
2b
4

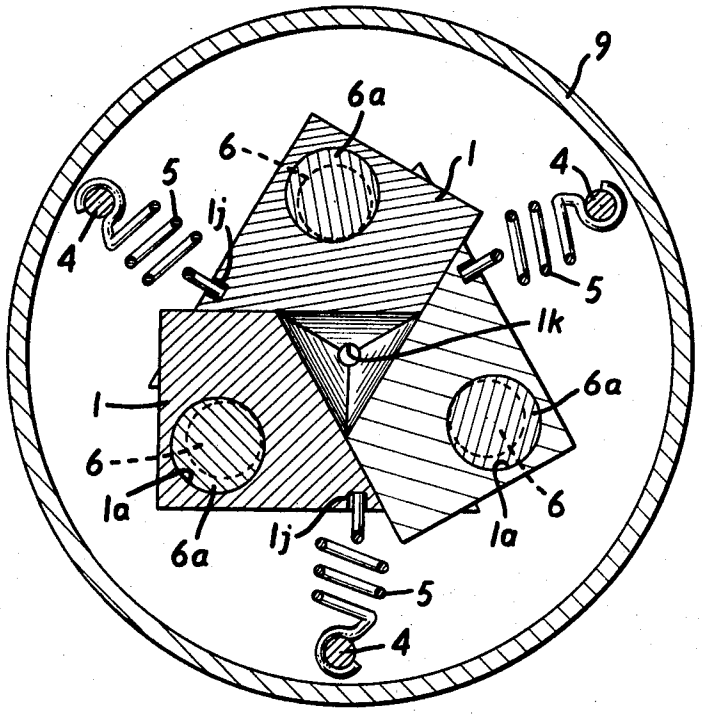


FIG. 3

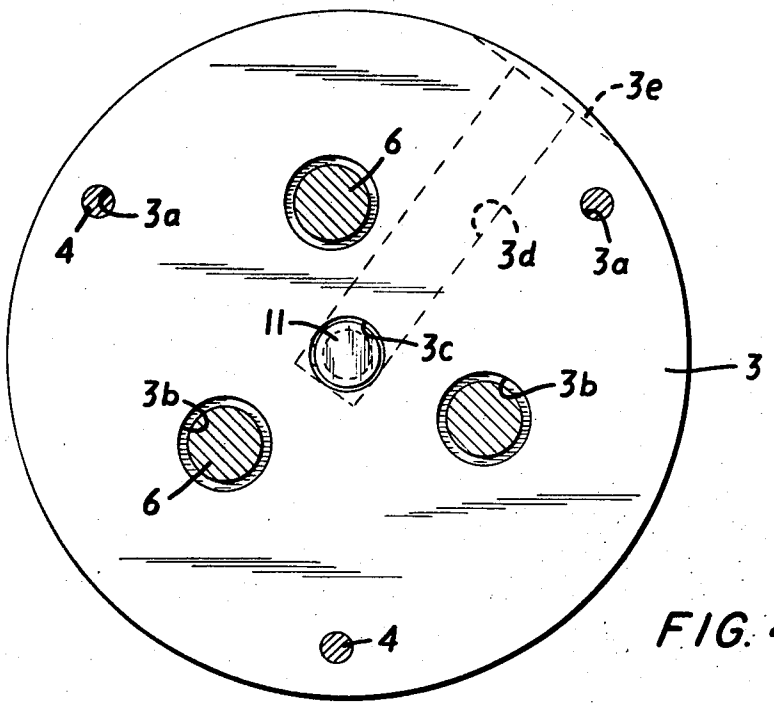


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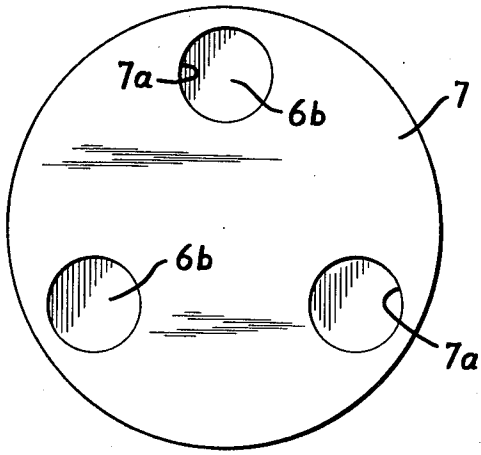


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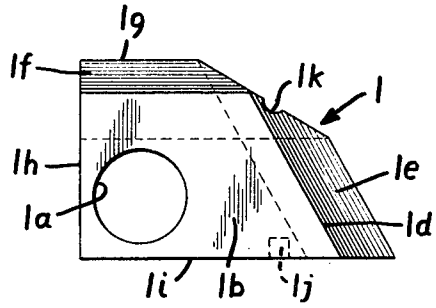


FIG. 6A

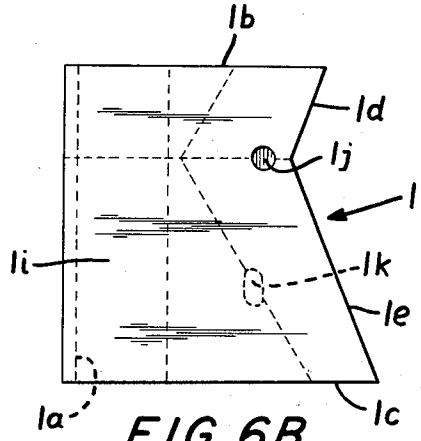


FIG. 6B

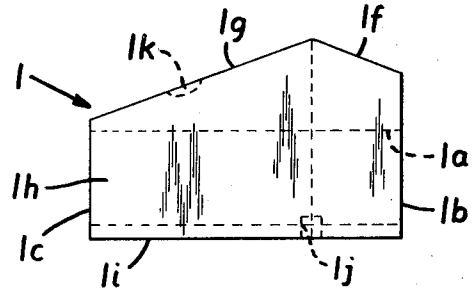


FIG. 6C

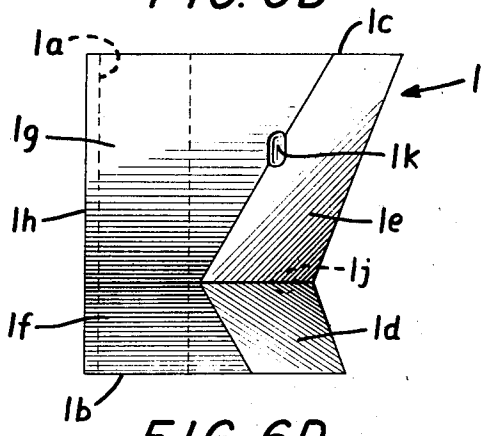


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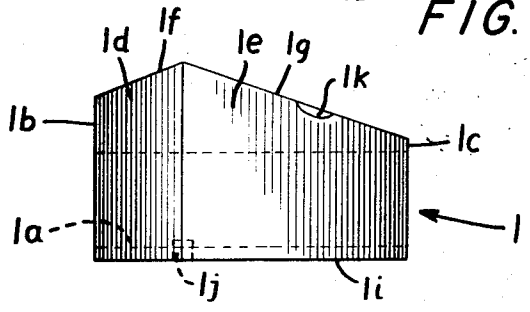


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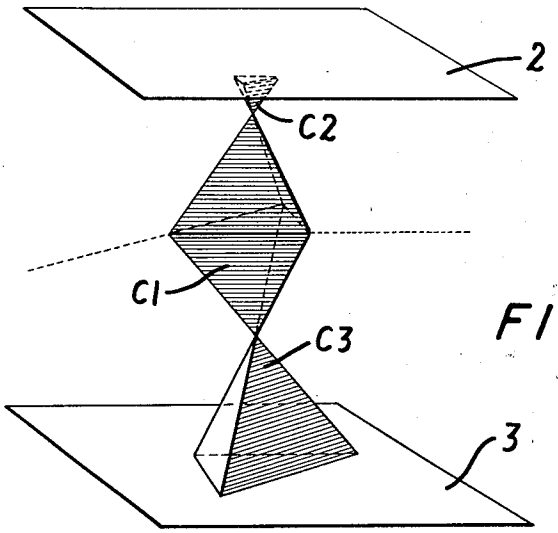


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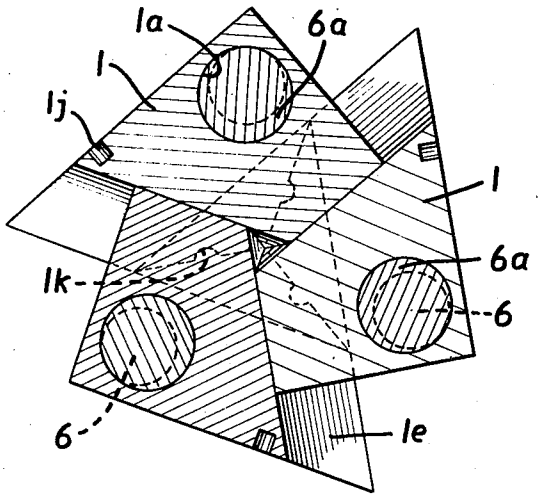


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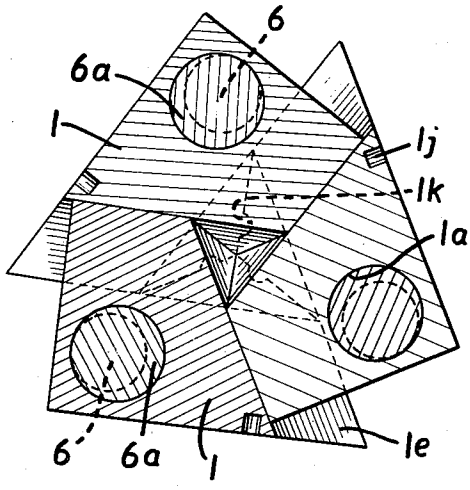


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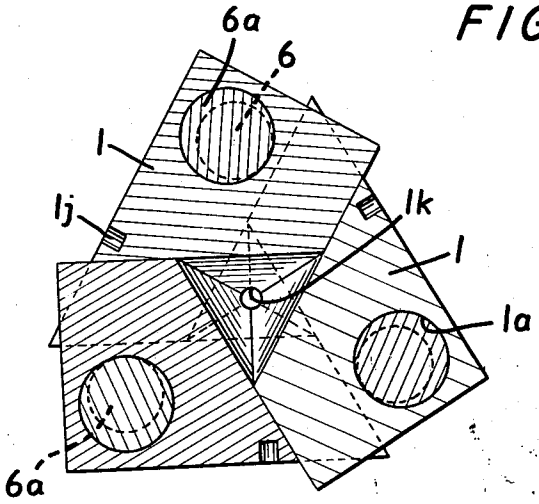


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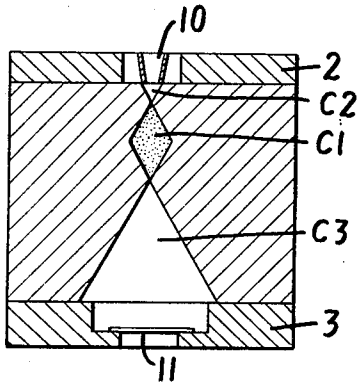


FIG. 11

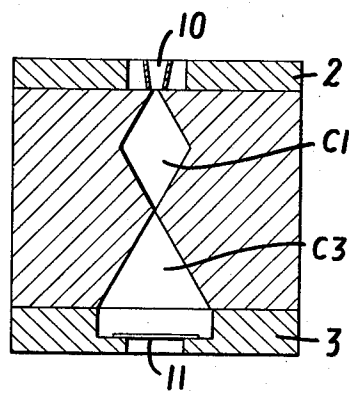


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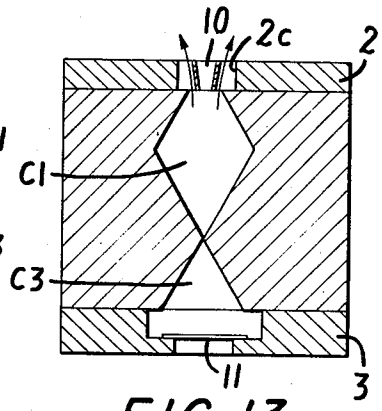


FIG. 13

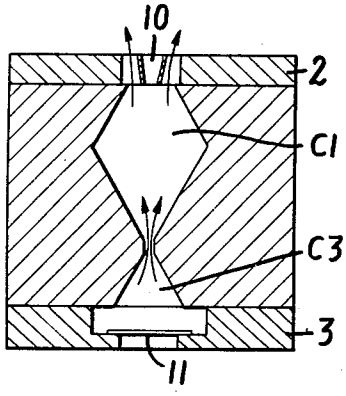


FIG. 14

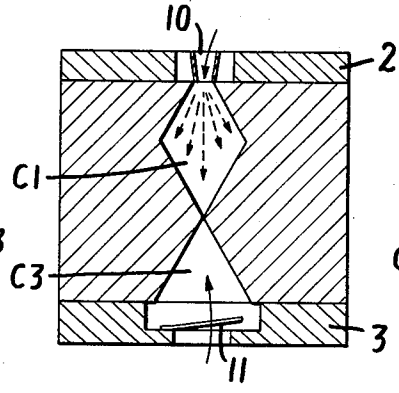


FIG. 15

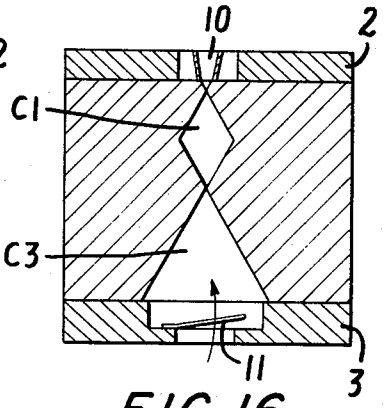


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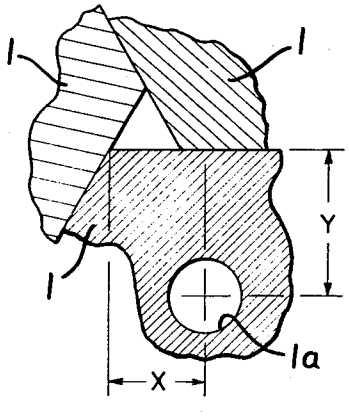


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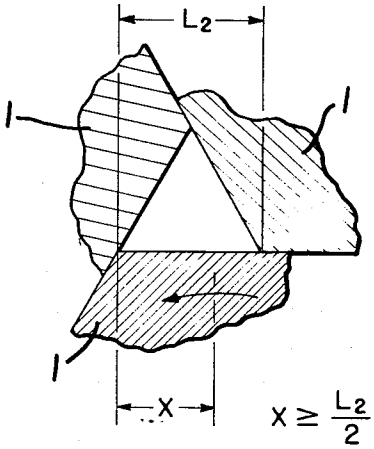
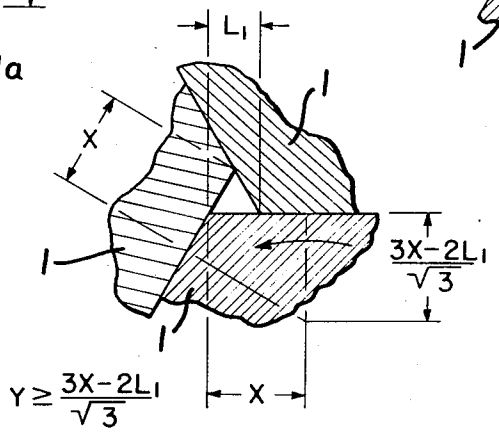


FIG. 18

FIG. 19



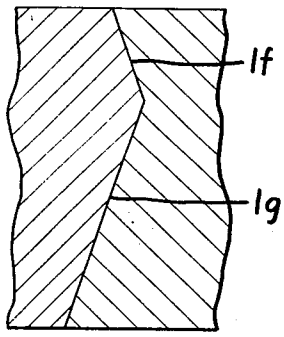


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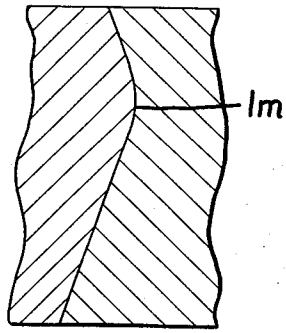


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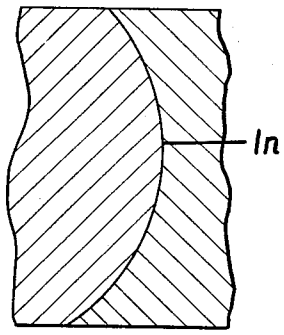


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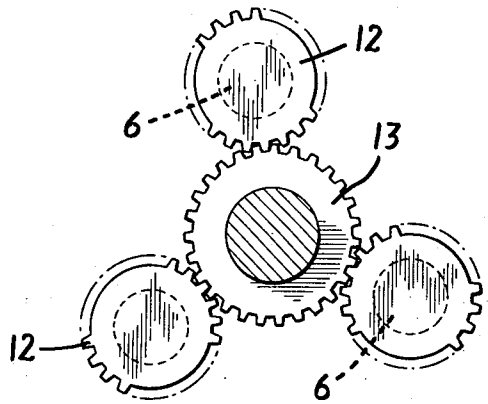


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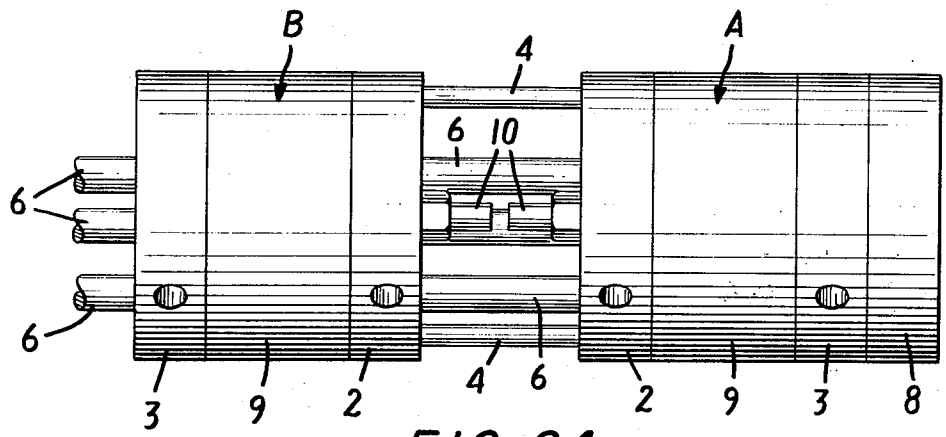


FIG. 24

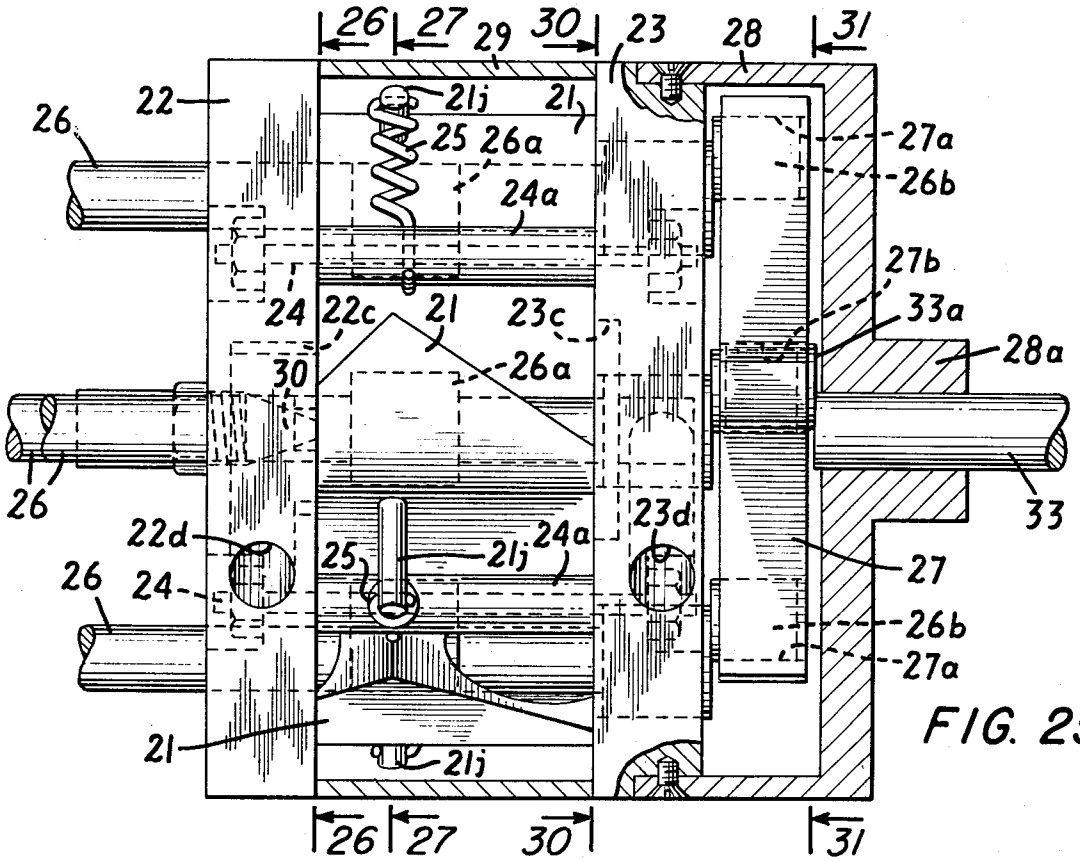

26
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23
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31
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21j
21
25
26a
24a
27a
26b
27b
33a
28a
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22c
23c
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FIG. 25

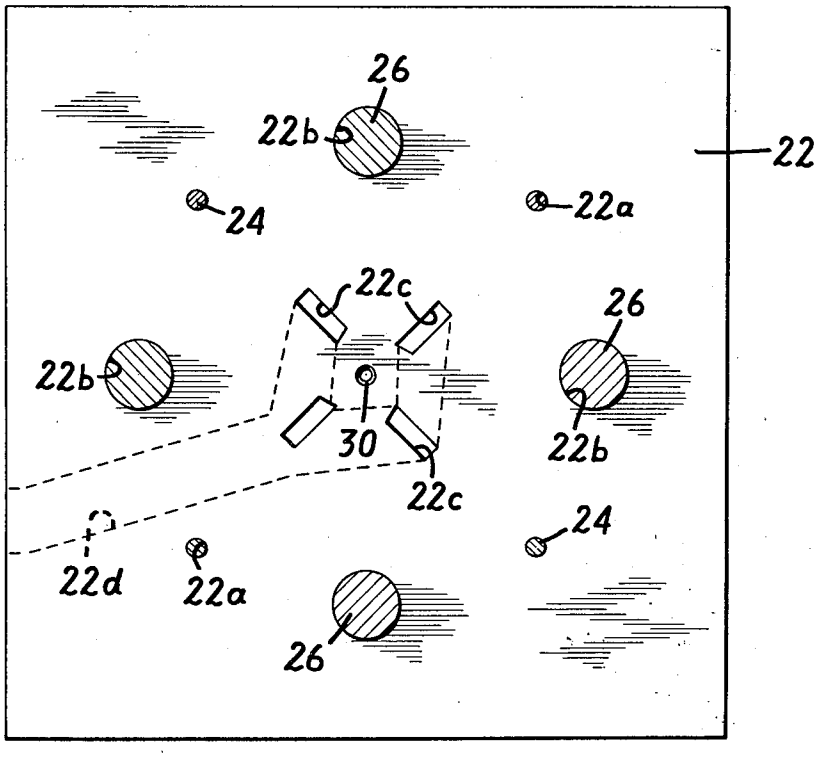

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22b
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22a
22c
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22b
30
22c
22d
22a
24
26

FIG. 26

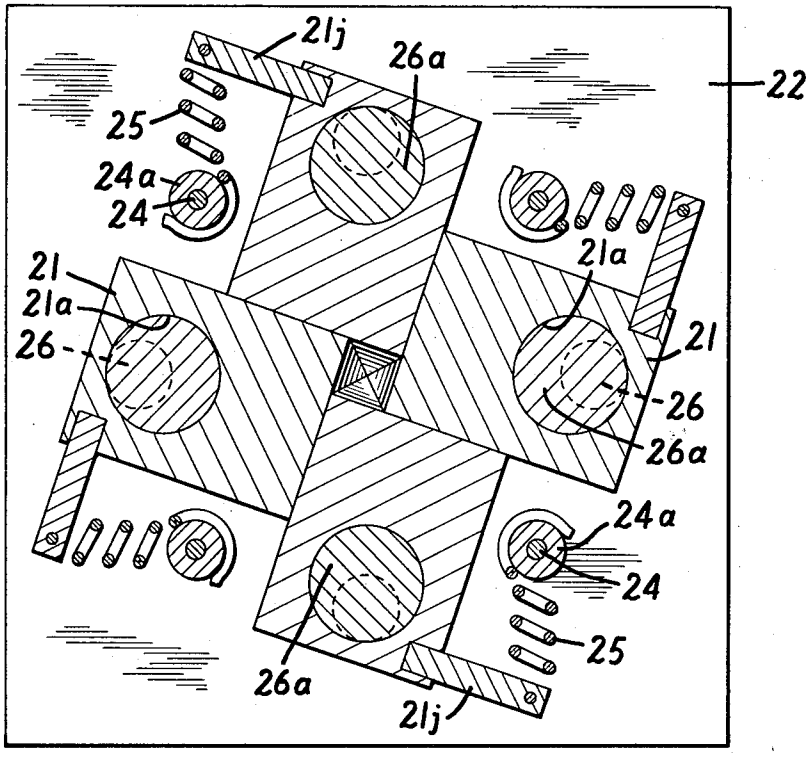

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24a
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26a
21j

FIG. 27

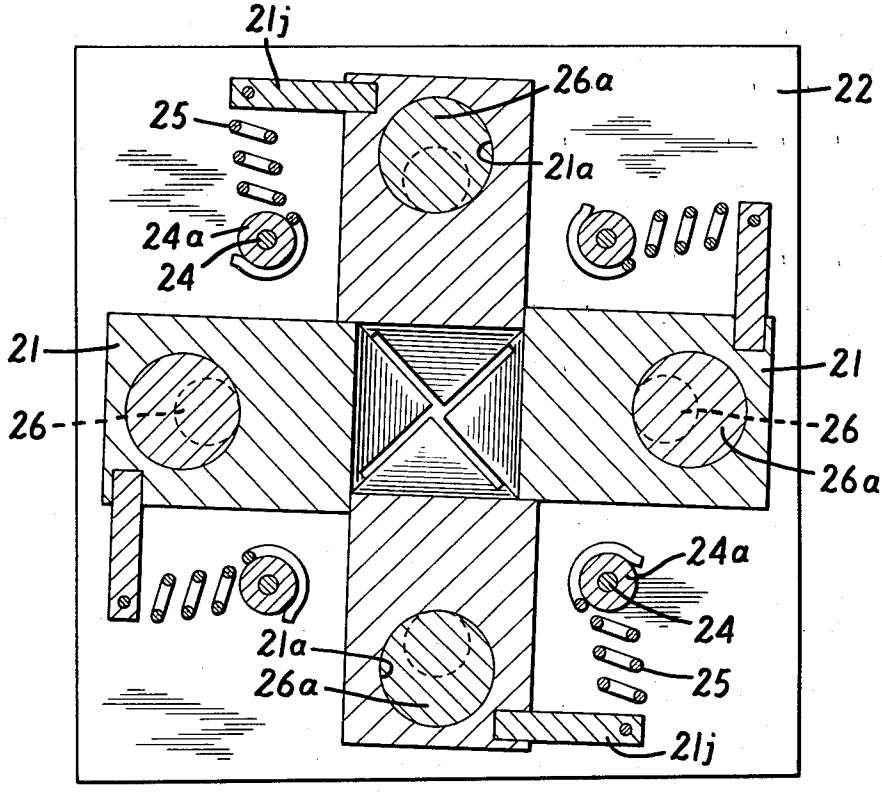

21j
26a
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24a
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21a
26a
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21j

FIG. 28

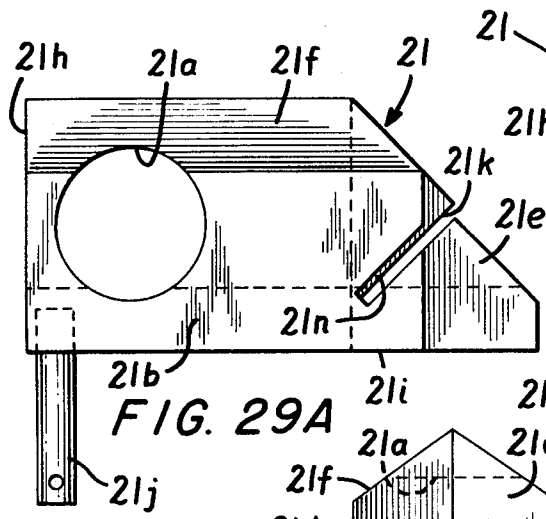


FIG. 29A

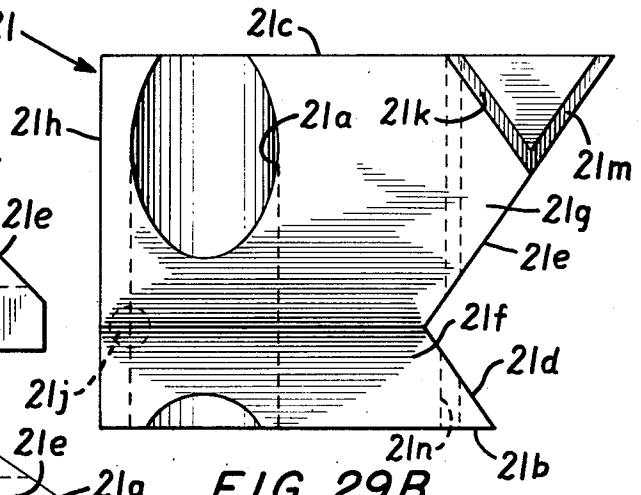


FIG. 29B

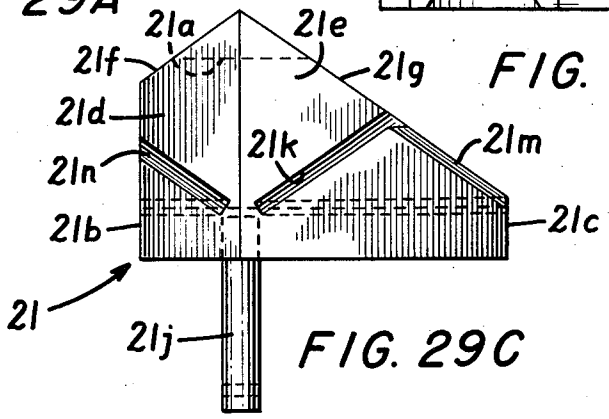


FIG. 29C

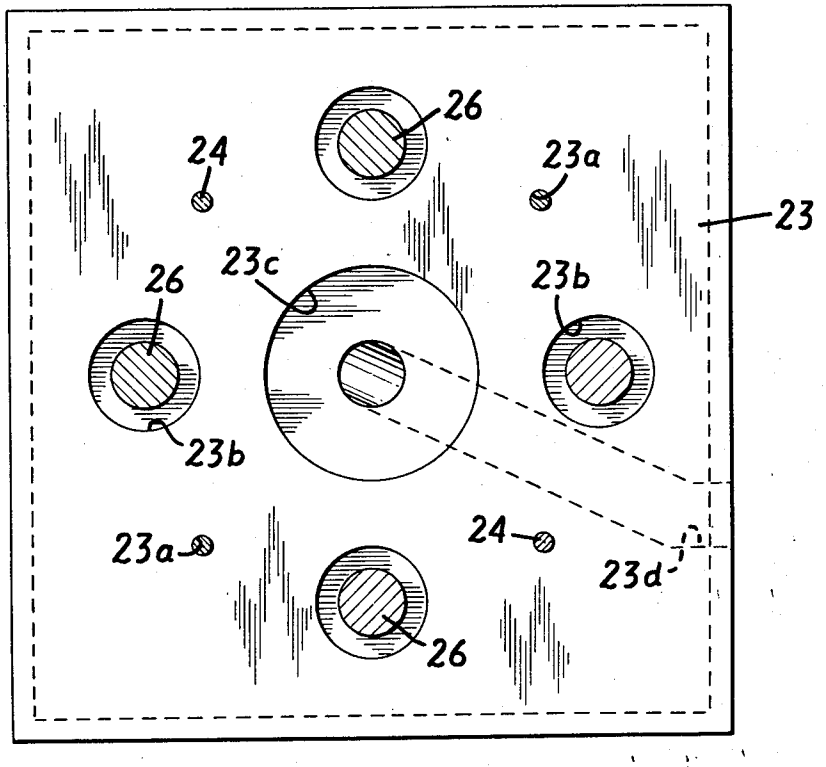


FIG. 30

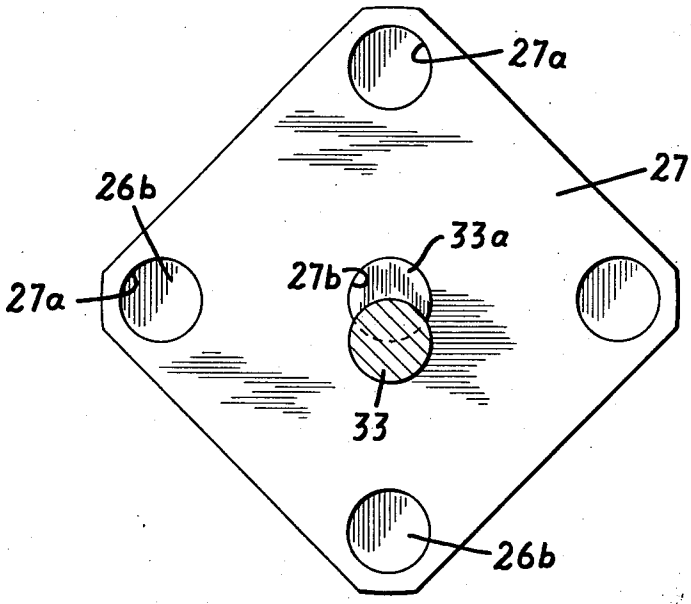


FIG. 31

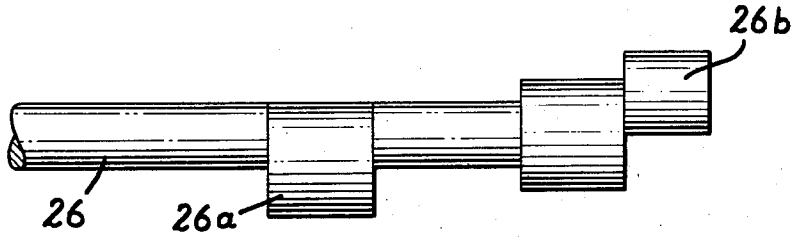
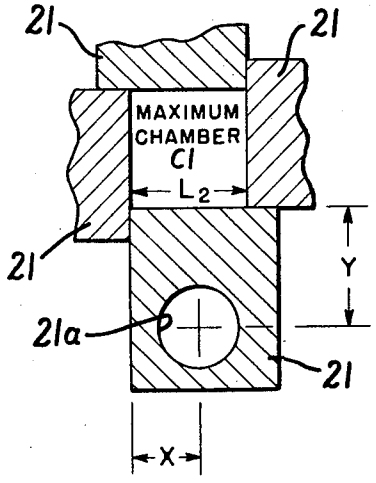


FIG. 32



$X \geq L_2/2$

$Y \geq X - L_1$

WITH L_1 = MINIMUM CHAMBER SCALE

FIG. 33

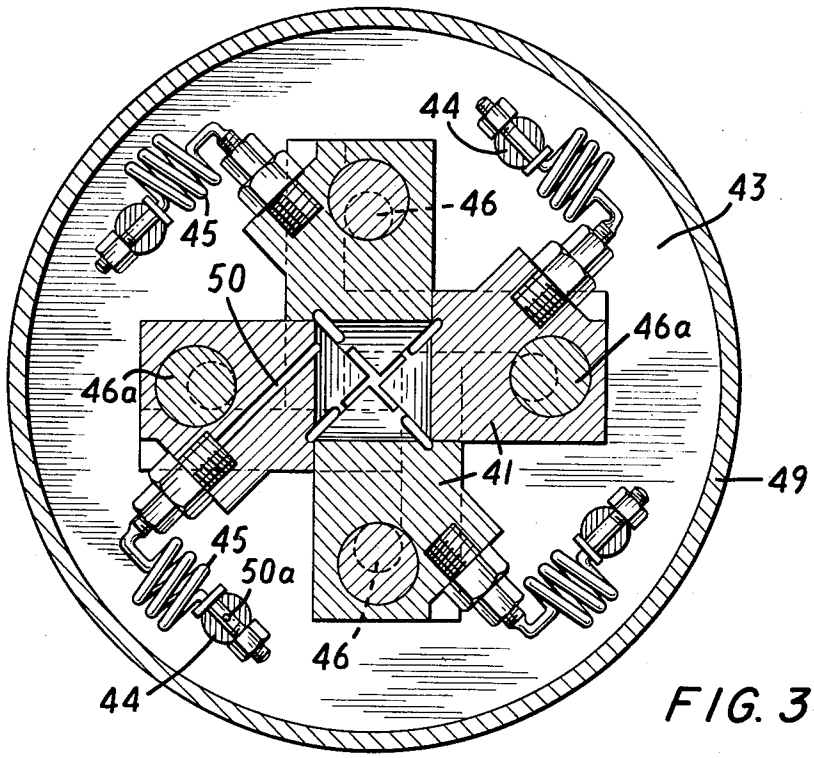


FIG. 34

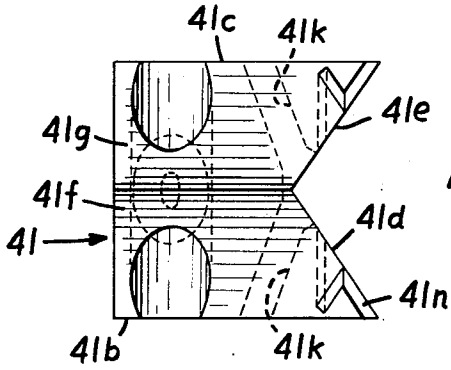


FIG. 35B

FIG. 35A

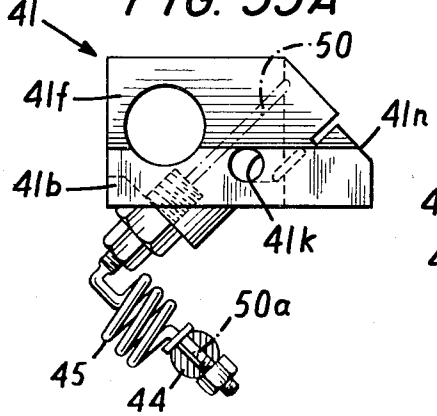
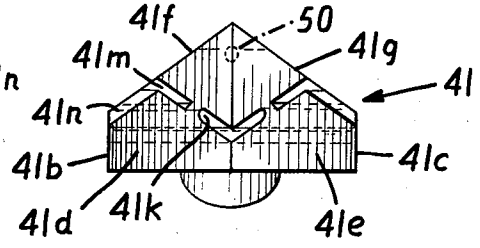


FIG. 35C



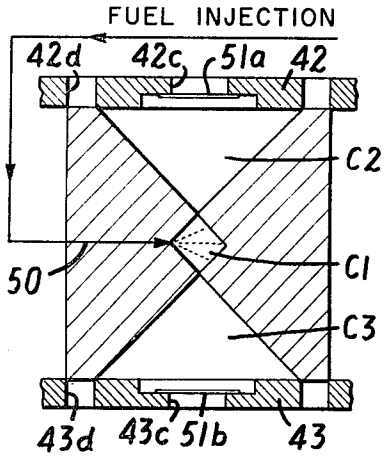


FIG. 36

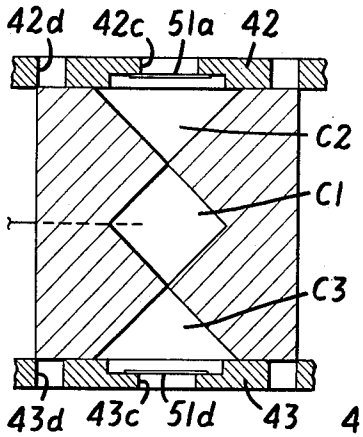


FIG. 37

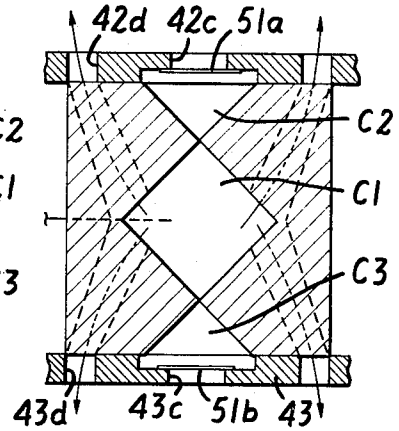


FIG. 38

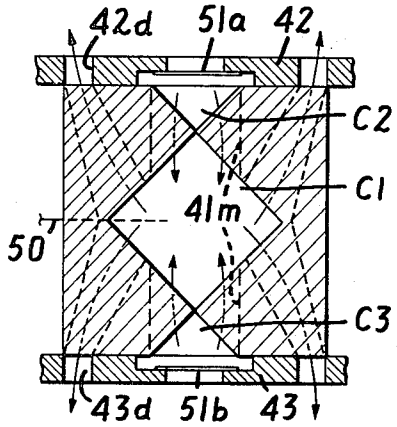


FIG. 39

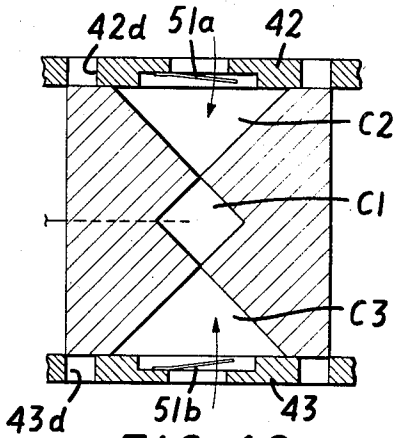


FIG. 40

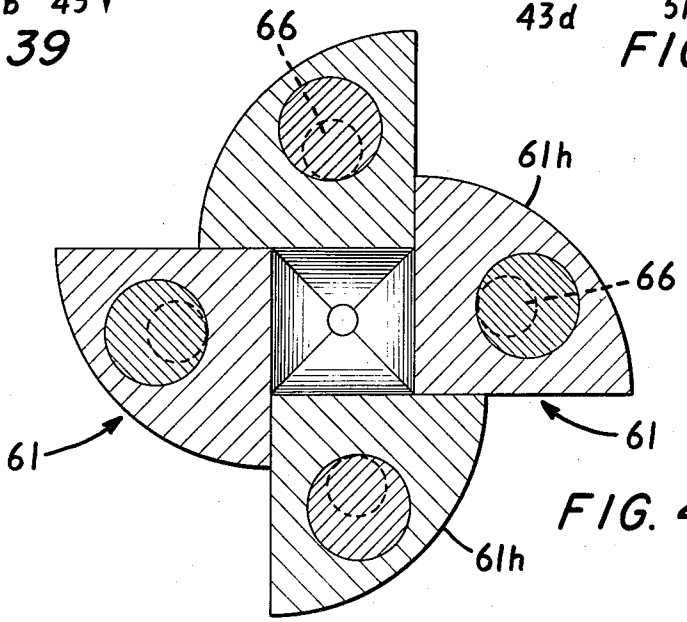


FIG. 41

FIG. 42

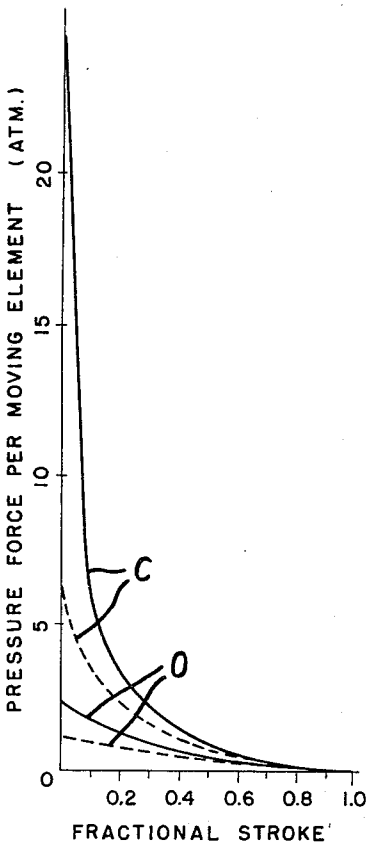


FIG. 43

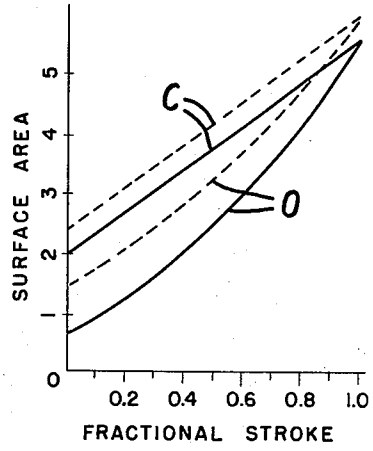
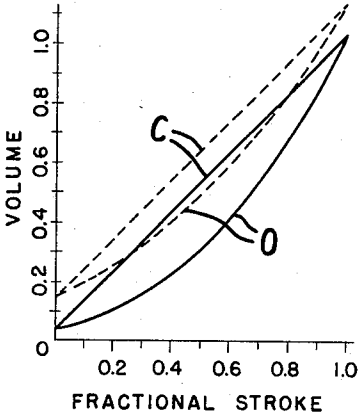


FIG. 44



COMPARISON OF CYLINDRICAL AND OCTAHEDRAL CHAMBERS

INTERNAL PRESSURE ENGINE

The present invention relates to an internal combustion engine having at least one expansible chamber the volume of which is varied periodically by the coordinated movement of at least three containing members by which the chamber is defined.

In the type of internal combustion engine which is at present mostly commonly used, one or more combustion chambers are provided by pistons reciprocating in stationary cylinders. The pistons are connected by connecting rods to a rotatable crank shaft. The reciprocation of the pistons, rotation of the crank shaft and complex movement of the connecting rods give rise to vibratory forces which are difficult to counteract. Moreover, it is necessary to provide special sealing means, for example piston rings, between the pistons and the walls of the cylinder in an effort to contain the combustion products of the fuel burned in the cylinder. Imperfect sealing results in "blow-by" which not only decreases the power and efficiency of the engine but also gives rise to serious air pollution.

Various rotary engines have been proposed from time to time but they have been found to involve sealing, lubrication, cooling and other problems which have proved difficult to solve.

It is an object of the present invention to provide a new type of engine having important advantages over those heretofore known. Among these advantages is a very low surface-area-to-volume ratio when the combustion chamber is at or near its minimum value. This feature reduces heat losses to the surrounding surfaces and results in an increased thermal efficiency. It also reduces the emission of unburned hydrocarbons by reducing the "quenching" effect of the chamber walls. Such by reduction of hydrocarbon emission is required by legal limits presently being set for automotive exhausts in an effort to reduce air pollution. Another object of the invention is to provide an engine of simple construction which has a high power-to-weight ratio and can be effectively balanced in a simple manner.

A further object of the invention is to provide an engine having a working chamber which is entirely self-sealing so that piston rings and similar sealing devices are not required.

Still another object of the invention is to provide an engine in which the chamber pressure forces are smaller than the pressure forces on the working members of a conventional piston and cylinder engine. This feature permits the accommodation of higher working pressures than can be accommodated by a conventional engine.

In accordance with the present invention, an engine has a combustion chamber which is entirely enclosed, at least during part of each cycle, by the surfaces of at least three like side members, hereinafter referred to as "hedrons". These hedrons are supported in a manner such that a relative positive pressure from within the combustion chamber acts to seal the interengaging surfaces of the hedrons without the need of gaskets or special sealing devices. The hedrons are slidable upon one another and define at least two expansible chambers of which one is a combustion chamber and the other a precompression chamber. Means are provided for synchronizing the movements of the hedrons so that they remain symmetrical about the axis of the chambers.

The construction, operation and advantages of an engine in accordance with the present invention will be more fully understood from the following description with reference to the accompanying drawings which illustrate, by way of example, preferred embodiments of the invention. For the purpose of simplification, reference is made primarily to engines having a single combustion chamber, it being understood, however, that any desired number of combustion chambers may be provided.

In the drawings:

FIG. **1** is a side view of an internal combustion engine in accordance with the present invention with three hedrons, portions being broken away to show internal construction.

FIGS. **2, 3, 4** and **5** are cross-sections taken approximately on the lines **2—2, 3—3, 4—4** and **5—5**, respectively in FIG. **1**.

FIGS. **6A** to **6E** are five view of one of the hedrons of the engine shown in FIG. **1**.

FIG. **7** is a diagrammatic view of the chambers defined by the hedrons of the engine shown in FIG. **1**.

FIG. **8** is a schematic cross-sectional view of the hedrons in position in which the combustion chamber is of minimum volume.

FIG. **9** is a view similar to FIG. **8** but showing the hedrons in a position in which the combustion chamber is of intermediate volume.

FIG. **10** is a view similar to FIG. **8** but showing the hedrons in a position in which the combustion chamber is of maximum value.

FIGS. **11** to **16** are schematic longitudinal sections illustrating a complete cycle of operation of the engine.

FIGS. **17, 18** and **19** are schematic partial cross-sections illustrating the self-sealing characteristics of the engine.

FIG. **20** is a partial longitudinal section showing the interengaging interfaces of two adjacent hedrons.

FIGS. **21** and **22** are partial cross-sections similar to FIG. **20** but showing different configuration of the interfaces.

FIG. **23** is a schematic view illustrating intermeshing gears for coordinating the movement of the hedrons relative to one another.

FIG. **24** is a side view of a multiple combustion chamber engine.

FIG. **25** is a side view similar to FIG. **1** but showing an engine having four hedrons.

FIG. **26** is a cross section taken approximately on the line **26—26** of FIG. **25** and showing the end plate at the exhaust end of the engine.

FIG. **27** is a cross-section taken approximately on the line **27—27** in FIG. **25**.

FIG. **28** is a cross-section similar to that of FIG. **27** but showing the hedrons in a different position.

FIGS. **29A – 29C** are three views of one of the hedrons of the engine shown in FIG. **25**.

FIG. **30** is a cross-section taken approximately on the line **30—30** of FIG. **25** showing the end plate at the intake end of the engine.

FIG. **31** is a section taken approximately on the line **31—13** in FIG. **25** showing a timing plate.

FIG. **32** is a side view of one of the crank shafts of the engine of FIG. **25**.

FIG. 33 is a partial schematic cross-section illustrating sealing conditions of a combustion chamber defined by four hedrons.

FIG. 34 is a diagrammatic cross-section of an engine with four hedrons and provision for injecting fuel through one of the hedrons into the combustion chamber.

FIGS. 35A to 35C are three views of a hedron provided with means for injecting fuel into the combustion chamber.

FIGS. 36 to 40 are schematic views illustrating an engine cycle with fuel injection through one of the hedrons into the combustion chamber.

FIG. 41 is a partial schematic cross-section illustrating different external configuration of hedrons.

FIGS. 42, 43 and 44 are graphs illustrating a comparison of the characteristics of a combustion chamber defined by a piston in a cylinder and one defined by four hedrons in accordance with the present invention.

The engine shown by way of example in FIGS. 1 and 2 comprises three identical hedrons 1 disposed between two parallel end plates 2 and 3. The end plates are connected with one another, for example by a plurality of through bolts 4, three such bolts being shown in the drawing. Compression springs 5 acting between the bolts 4 and respective hedrons 1 act to bias the hedrons in a direction toward one another. Three shafts 6 extending through the end plates and the hedrons are rotatably supported by bearing in the end plates and have eccentric portions 6*a* received in circular bores 1*a* in the hedrons and serve in effect as cranks to coordinate the movement of the hedrons relative to one another and to convert planar movement of the hedrons into rotary movement of the shafts. Other eccentric portions 6*b* at the right-hand ends of the shafts 6, as viewed in FIG. 1, engage in corresponding openings in a timing plate 7 which is disposed outside the end plate 3 and interconnects the three shafts so that they rotate in synchronism with one another. A cup-shaped cover 8 is removably secured to the end plate 3, for example by being screwed onto a threaded portion thereof, and encloses the timing plate 7 and associated portions of the shafts 6. A cylindrical casing or shell 9 extends between the two end plates 2 and 3 so as to enclose the hedrons and the associated springs. Although the casing 9 is shown in FIG. 3 as being a one-piece cylinder, it can conveniently be made in two or more parts so as to be readily opened or removed to provide access to the hedrons. In the operation of the engine, the casing 9 is not subjected to any working pressure of combustion gases but should preferably be sufficiently tight to exclude dirt and to retain lubricant provided to the hedrons.

Projecting ends of the shafts 6, as shown at the left side of the engine in FIG. 1, may connect to another unit, as illustrated, for example, in FIG. 24, or they may be provided with suitable output drive means, for example a clutch, coupling, gear or pulley. A drive can, if desired, be taken off of one shaft only since the timing plate 7 assures that the shafts rotate in synchronism with one another.

One of the three hedrons is shown in detail in FIGS. 6A to 6E. The other two hedrons are identical but differently oriented, as seen in FIG. 3. Each hedron has opposite parallel end faces 1*b* and 1*c* slidably engaging respectively the inner faces of the end plates 2 and 3. One side face of the hedron is concave and comprises inclined surfaces 1*d* and 1*e* while an adjoining side is convex and comprises inclined surfaces 1f and 1g. When there are three hedrons, as illustrated in FIG. 3, the adjoining side faces 1*d* – *1e* and 1*f* – *1g* intersect at an angle of 120°. The edge defined by the intersection of surface 1*d* with surface 1*f* and the intersection of surface 1*e* with surface 1*g* is herein referred to as the inner edge of the hedron. The corner defined by the intersection of the four surfaces 1*d*, 1*e*, 1*f* and 1*g* with one another is referred to as the inner corner of the hedron. The other side faces 1*h* and 1*i* are not working faces and can be of any desired configuration, either plane or curved. The outer surface 1*i* is shown provided with a recess 1*j* to receive the inner end of the respective spring 5.

When the three hedrons are assembled between the two end plates 2 and 3, as illustrated in FIGS. 1 and 3, with the concave side face of each hedron engaging the convex side face of an adjacent hedron, they define — in at least part of the cycle of operation — three chambers C1, C2 and C3, as illustrated diagrammatically in FIG. 7. The centraL chamber C1 is bounded by concave side surfaces of the three hedrons. The second chamber C2 is bounded by convex side faces of the three hedrons and the inner face of the end plate 2. The third chamber C3 is bounded by convex side faces of the hedrons and by the inner face of the end plate 3. In the configuration illustrated in the drawings, the central chamber C1 is the combustion or working chamber of the engine, the chamber C2 is referred to as an exhaust chamber and the chamber C3 is an intake and pre-compression chamber. It will be seen that the central chamber C1 is a hexahedron while the chambers C2 and C3 are tetrahedrons.

As the hedrons move in a plane parallel to the end plates so that the inner corners defined by the intersections of the concave faces and convex faces move toward a central axis, the central chamber C1 decreases in volume while the chambers C2 and C3 increase in volume. Conversely, movement of the inner corners of the hedrons outwardly away from one another results in an increase of the volume of the central chamber C1 and a decrease in the volume of the other two chambers. Depending on the configuration of the interengaging side faces of the hedrons and the extent of outward movement, one or both of the chambers C2 and C3 may decrease to zero volume and disappear.

The end plate 2 is shown, for convenience, as a circular plate although its outer shape may be varied as desired. It is provided with holes 2*a* to receive the connecting bolts 4 and with bores 2*b* for the shafts 6. Roller or other bearings for the shafts can be provided if desired. An exhaust port 2*c* positioned so as to communicate with the combustion chamber C1 shown in FIG. 13 in the exhaust portion of the cycle is connected by an internal duct or channel 2*d* to an exhaust flange 2*e* adapted to be connected to a suitable exhaust pipe or manifold. A fuel injection nozzle 10 centered in the exhaust port 2*c* is connected through a suitable channel or conduit with a fuel injection system for the engine.

The other end plate 3 which is likewise circular or of other shape, as desired, is similarly provided with holes

3*a* for the bolts **4** and bores or bearings 3*b* for the shafts **6**. A centraL intake port 3*c* positioned so as to communicate with the chamber C3 shown in FIG. **7** is connected by a passage 3*d* with a flange 3*e* for connection to an air filter or other air intake. The air intake port or passage is preferably provided with a one-way valve, for example a reed valve **11**, as illustrated in FIGS. **11** to **16**, so as to permit air to enter the chamber C3 but prevent reverse movement of the air.

Coordinated movement of the hedrons with corresponding expansion and contraction of the chambers defined by the hedrons and the end plates is illustrated in FIGS. **8**, **9** and **10** which show, respectively, three different positions of the hedrons and by FIGS. **11** to **16** which illustrate one cycle of operation of the engine. In order to simplify the drawings, the chambers C1, C2 and C3 are shown in only two dimensions in FIGS. **11** to **16** instead of in three dimensions as in FIG. **7**. In the position of the hedrons shown in FIGS. **8** and **11**, the combustion chamber C1 is of minimum volume while chambers C2 and C3 are of maximum volume. A charge of combustible mixture contained in chamber C1 is hence compressed to a selected minimum volume. In the engine herein illustrated, ignition is produced by compression as in the Diesel cycle and may occur somewhat ahead of or slightly later than maximum compression depending on the mode of operation of the engine. Expansion of the combustion gases in the combustion chamber C1 causes the inner corners of the hedrons to move outwardly from a central point, thereby increasing the volume of the central chamber C1, as illustrated in FIG. **12** and also in FIG. **9**. Chamber C2 decreases to zero volume and disappears. At the same time, the volume of intake chamber C3 is decreasing so as to compress air that has been drawn in through the intake valve **11**. With continued movement of the hedrons, the combustion chamber C1 opens into the exhaust port 2*c* of the end plate **2** so that exhaust of the combustion gases begins, as shown in FIG. **13**. Upon further movement of the hedrons, as illustrated in FIG. **14**, exhaust of the combustion products is completed and air which has been compressed in the chamber C3 is admitted to the combustion chamber C1, thereby purging the chamber and introducing a fresh charge of air. Flow of the compressed air from the chamber C3 to the chamber C1 is permitted by a port formed by notches 1*k* formed in the inner edges of the hedrons defined by the intersection of surfaces 1e and 1*g*, as seen in FIGS. 6A – 6E. The position of maximum volume of the chamber C1 is illustrated in FIG. **10**.

The direction of movement of the hedrons is thereupon reversed so that the volume of the combustion chamber C1 decreases and the volume of the intake chamber C3 increases so as to drawn air in through the intake port 3*c*. At a selected time, as illustrated in FIG. **15**, a fuel charge is injected through the nozzle **10** into the combustion chamber. Continued movement of the hedrons is illustrated in FIG. **16** to compress the charge of combustible mixture in the chamber C1 and to draw further air into the chamber C3. This continues until the point of maximum compression of the combustible mixture is reached, as illustrated in FIG. **11**. The parameters of the engine are selected so that compression is sufficient to cause ignition of the charge at the proper point near the point at which the chamber C1 is of minimum volume.

The stroke of the engine, i.e. the distance the hedrons move in varying the volume of the combustion chamber C1 between maximum and minimum values, is determined by the eccentricity of the eccentric portions 6*a* of the shafts **6** and by the location of the bores 1*a* in the hedrons. Since all three hedrons are moving simultaneously, sufficient engine displacement can be obtained with a relatively short stroke. The short stroke permits high engine speed with corresponding high specific power output.

An advantageous characteristic of the engine in accordance with the present invention is that positive pressure forces inside the combustion chamber C1 act on the hedrons in such manner as to provide automatic sealing of the combustion chamber, provided that the support of each hedron by the respective shaft **6** is properly located. In FIG. **17**, the center of the opening 1*a* which receives the eccentric 6*a* on the support shaft **6** is located with respect to the inner corner of the hedron by the coordinates X and Y. The distance Y is measured from the intersection of the surfaces 1*d* and 1*e* of the concave face of the hedron. The distance *X* is measured from the inner corner of the hedron. The interengagement of the hedrons with one another provides self-sealing if two conditions are met. Firstly, when the combustion chamber C1 is at maximum volume, as shown in FIG. **18**, the pressure force must act so as to rotate the hedron **1** toward its corner, as indicated by the arrow. This requires that

$$X \geqq L_2/2.$$

The second condition is that, when the combustion chamber C1 is at minimum value, as shown in FIG. **19**, the hedrons block one another from rotation in the direction indicated by the arrow. This condition translates geometrically to

$$Y \geqq \frac{3X - 2L_1}{3^{1/2}}$$

As seen in FIGS. **18** and **19**, L_1 and L_2 represent one side of the combustion chamber at minimum volume and maximum volume respectively. The degree of these inequalities, together with other parameters, such as engine stroke, angular displacement of the hedrons and bearing loads, determines the sealing forces with which the hedrons bear against one another.

Since the forces of inertia, friction and gravity are not negligible for all operating conditions and since the combustion chamber may at times be under sub-atmospheric pressure, the three compression springs **5** are provided to act inwardly on the hedrons and thereby maintain sealing of the combustion chamber in the possible absence of sufficient internal pressure to provide a seal.

The angle between the plane surfaces 1*f* and 1*g* of the convex side of the hedron (and the like angle of the concave side) should be between 30° and 170° and preferably within the range of 75° to 145° to provide suitable chamber proportions and operating characteristics. Instead of the two plane surfaces 1f and 1g in-

tersecting in a line, as illustrated in FIG. 20, they may be joined by a curved cylindrical surface 1*m*, as illustrated in FIG. 21, so as to avoid an abrupt corner. Moreover, if desired, the concave and convex sides of the hedron may be defined by complementary cylindrical surfaces 1*n*, as illustrated in FIG. 22.

Instead of the shafts 6 being interconnected by a timing plate 7, as illustrated in FIG. 5, they may be connected with one another by means of gears, as illustrated in FIG. 23. In this event, gears 12 fixed on the ends of the shafts 6, respectively, all mesh with a central gear 13 so that all three shafts rotate in synchronism in the same direction. In this event, the power output may be taken from any of the shafts 6 or from the central gear 13.

Any desired number of units such as that shown in FIG. 1 can be combined to provide an engine having a plurality of combustion chambers. By way of example, two units A and B are shown assembled end-to-end in FIG. 24. Connecting bolts 4 and shafts 6 extend between the two units. While a separate timing disc or gears may be provided in each unit, if desired, it is sufficient to provide a single timing disc or set of gears interconnecting the shafts 6. In FIG. 24, only unit A is shown provided with a timing disc. The eccentrics 6*a* on the shafts 6 are arranged at different angles in the several units so as to provide the desired timing between the units, for example so that the compression stroke in one unit coincides with the power stroke in another unit. The two units shown in FIG. 24 are reversed end-for-end so as to simplify connections to the fuel injection nozzles 10.

In FIGS. 25 to 32, there is shown an internal combustion engine which is similar to that of FIGS. 1 to 20 except that it has four hedrons defining the working chambers of the engine, Accordingly, the engine is shown as comprising four hedrons 21 disposed between two end plates 22 and 23 connect by bolts 24. The hedrons are similar to those of FIGS. 1 to 20 except that the angle between the concave face and the convex face of the hedron is 90°. Moreover, to provide for the use of tension springs rather than compression springs for biasing the hedrons toward one another, each hedron is provided with a laterally projecting arm 21*j*. Tension springs 25 accordingly act between the arms 21*j* of the hedrons and spacers 24*a* on the bolts 24 between the end plates. As seen in FIG. 28, there are four connecting bolts and also four shafts 26 having eccentric portions 26*a* received in corresponding bores of the respective hedrons and eccentrics 26b received in bores 27*a* of a timing plate 27. A central bore 27*b* in the timing plate receives an eccentric 33*a* of a power output shaft 33 which extends out through a bearing portion 28*a* of an end cover 28. A casing 29 extends between the end plates 22 and 23 to enclose the hedron assembly.

As seen in FIGS. 29A – 29C, each of the hedrons is provided with grooves 21*k* and 21*m* to form exhaust and air inlet passage ports respectively. A small reduction 21*n* is also necessary so that the intake passage formed by alignment of the grooves 21*k* is exposed. The grooves 21*k* and 21*m* can conveniently be made by saw cuts in the hedron.

The end plate 22 at the exhaust end of the engine has holes 22*a* for the bolts 24, bores 22*b* for the shafts 26 and four exhaust ports 22c communicating with an internal duct or channel 22*d* connected to a suitable exhaust pipe or manifold. An injection nozzle 30 is disposed centrally of the exhaust ports.

The end plate 23 (FIG. 30) at the intake end of the engine is provided with holes 23*a* for the bolts 24, bores 23*b* for the shafts 26 and with a central air intake opening 23*c* communicating with an intake passage 23*d*. A suitable reed or other check valve (not shown) is provided in the intake passage spaced from the intake opening 23*c* so as to provide a ballast for intake air.

The four hedrons assembled between the end plates in the manner previously described provide a central chamber defined by the concave surfaces of the hedrons and two chambers defined between the convex surfaces of the hedrons and the respective end plates. The central chamber which constitutes the combustion chamber of the engine is of octahedron form while the other two chambers comprising respectively an exhaust chamber and an intake and precompression chamber are of pentahedron form.

The operation of the engine is as described above with respect to the embodiment illustrated in FIGS. 1 and 20. It will be noted, however, that the combustion chamber is defined by four hedrons moving inwardly and outwardly simultaneously instead of three hedrons as in the previously described embodiment.

When the engine comprises four hedrons, the angle between the surfaces which define the convex and concave interfaces of the hedrons should be between 30° and 170° and preferably between 75° and 145°. The preferred angle to obtain maximum volume to surface ratio is approximately 110°.

The conditions for self-sealing when there are four hedrons are illustrated in FIG. 33 where the center of the opening 21a of the hedron which receives the eccentric 26*a* of the support shaft 26 is located with respect to the inner corner of the hedron by the coordinates *X* and *Y*. The values of X and Y to obtain self-sealing are:

$$X \geq L_2/2$$
$$Y \geq X - L_1 .$$

As in FIGS. 18 and 19, L_1 and L_2 represent one side of the combustion chamber at minimum volume and maximum volume respectively.

In order to introduce fuel into the combustion chamber after the chamber has closed and a charge of air in the chamber has been compressed a desired amount, the fuel can be injected into the chamber through a duct formed in one of the hedrons, as illustrated by way of example in FIGS. 34 to 40. The engine is of the same general configuration as described in conjunction with FIGS. 25 to 33 and comprises four hedrons 41 assembled between two end plates 42 and 43 and enclosed in a casing 49. The hedrons are biased into a sealing relation with one another by springs 45 acting between the hedrons and stationary studs 44. At least one of the springs 45 is hollow and is connected at its inner end to a fuel-injector duct 50 which is formed in the respective hedron and leads to the combustion chamber. The injector duct may, if desired, be formed with a restricted orifice or nozzle at its inner end to provide suitable injection characteristics. A suitable connector 50*a* is provided at the outer end of the spring 45 for connection to a fuel injection supply line. With this

construction, fuel can be injected into the combustion chamber at any desired point in the engine cycle. The other springs do not need to be hollow but are conveniently of the same construction to provide symmetry of the engine and to facilitate manufacture and stocking of the parts.

The hedrons of the engine illustrated in FIGS. 34 – 40 further differ from those of the engine illustrated in FIGS. 25 to 33 in that the surfaces 41*d* and 41*e* which constitute the concave side face of the hedron are of equal width as are also the surfaces 41*f* and 41*g* which constitute the convex side face. The angle between the surfaces 41*d* and 41*e* and between the surfaces 41*f* and 41*g* is preferably 110°, as shown. Moreover, as seen in FIGS. 35A – 35C, each hedron is provided with two exhaust passages 41k leading from the concave side face to end faces 41*b* and 41*c*, respectively, and with two grooves 41*m* and reductions 41*n* providing intake passages. Accordingly, the end plates 42 and 43 are provided, respectively, with central intake openings 42*c* and 43*c* controlled by intake valves 51*a* and 51*b*, which may be reed valves as shown schematically in FIGS. 44 to 48. Each of the end plates 42 and 43 is also provided with a plurality of exhaust ports 42*d* and 43*d*, respectively, arranged around the central intake port in position to register with the exhaust passages 41*k* of the hedrons during exhaust phases of the cycle.

As the engine illustrated in FIGS. 34 to 40 is otherwise like that described with reference to the preceding figures, further details of the engine will be readily understood and are accordingly not shown.

A cycle of operation of the engine illustrated in FIGS. 34 to 40 is shown diagrammatically in FIGS. 36 to 40. FIG. 36 illustrates the compression-ignition phase in which a charge of air has been compressed in the combustion chamber C1 — which is shown as being of minimum volume — and fuel is injected into the chamber through the injector duct 50 provided in one of the hedrons. As compression of the air has raised it to ignition temperature, the injected fuel will ignite and burn, whereupon expansion of the combustion products forces the chamber C1 to expand, as illustrated in FIG. 37. Increase in the volume of the combustion chamber C1 results in decrease of the volume of the chambers C2 and C3 so that air which has been drawn into these chambers through the intake ports 42*c* and 43*c* is compressed. In FIG. 38, the hedrons have moved to the point where the exhaust passages 41*k* of each hedron are uncovered by the adjacent hedron, whereupon combustion products are exhausted through the exhaust ports 42*d* and 43*d* formed in the end plates. Air in the chambers C2 and C3 is further compressed. When the hedrons have moved further to the position shown in FIG. 39, the passages formed by grooves 41m are opened so as to connect chambers C2 and C3 with the combustion chamber C1. Air which has been compressed in chambers C2 and C3 thereupon flows into the combustion chamber C1 so as to purge the combustion chamber and fill it with a fresh charge of air. The direction of movement of the hedrons is thereupon reversed so that the combustion chamber C1 decreases in volume to compress the air which has been received from the chambers C2 and C3 and the volume of the chambers C2 and C3 is increased so that air is drawn into them through the intake valves 51*a* and 51*b*, as illustrated in FIG. 40. Upon further compression of the air in chamber C1, fuel is injected, as illustrated in FIG. 36, to repeat the cycle. It will be seen that, as in the case of the embodiment previously described, the engine operates on a two-stroke cycle.

As indicated above, the outer non-working faces of the hedrons can be of any desired shaped as the surfaces are not functional. For example, in FIG. 41, there are shown diagrammatically four hedrons 61 having arcuate outer faces 61*h*. As previously described, the hedrons cooperate with synchronously rotating shafts 66. Other portions of the engine are not shown as they may be the same as those illustrated in FIGS. 25 to 33.

The operating characteristics of an engine according to the present invention, in comparison with those of a piston and cylinder engine, are illustrated in FIGS. 42 to 44. The engines compared are an engine in accordance with the present invention having an octahedral combustion chamber, as illustrated for example in FIGS. 34 to 40, and a piston and cylinder engine. Each comparison shows a stated quantity for an octahedron and the same quantity for a right circular cylinder chamber, for two chambers of unit displacement and of identical compression ratio *r*. The bore to stroke ratio *b* for the piston chamber is set equal to 1. The fractional stroke S represents the relative part of movement of the hedron or displacement of the piston from top dead-center. Hence, top dead-center = 0 and bottom center= 1. Values have been plotted for a compression ratio of 8 to 1 (dotted line curves) and for a compression ratio of 27 to 1 (solid line curves).

The pressure forces on a single moving element (piston or hedron), assuming equal initial chamber pressures, is plotted in FIG. 42 in which the pressure forces for a hedron are represented by the curves O and the pressure forces for a piston are represented by the curves C. The ratio of the pressure force on a single hedron to the like force on a piston is given by the following equation, assuming isothermal expansion to one atmosphere.

$$\text{Pressure force ratio}=\frac{3^{2/3}}{2^{1/6}\pi^{1/3}}\cdot\frac{(r^{1/3}S-S+1)^2}{(6br-6b)^{2/3}}$$

Since the maximum pressures occur near S = 0, the maximum pressure forces on the hedrons are much less than the pressures on equivalent pistons. The low ratios imply that engines constructed in accordance with the present invention may have components which are much lighter than corresponding components in conventional reciprocating engines.

The surface areas are plotted in FIG. 43 in which the curves O are for an octahedral combustion chamber and the curves C are for a cylinder-piston combustion chamber. The ratio of the octahedral chamber surface area to the cylinder-piston surface area is given by the following equation:

$$\text{Surface area ratio}=\frac{3^{7/6}}{2^{2/3}}\cdot\left(\frac{6b}{\pi}\right)^{1/3}\cdot\frac{(r^{1/3}S-S+1)^2}{(r-1)2/3\cdot\left(S+\frac{1}{r-1}+\frac{6b}{2}\right)}$$

It will be seen that the equilateral octahedral chamber has a very low surface area during the critical stage of minimum chamber volume. This reduces quench and heat losses.

The chamber volumes are plotted in FIG. 44 in which the curves O are for an octahedral chamber and the curves C are for a cylinder-piston chamber. The ratio of the octahedral chamber volume to the cylinder-piston surface area is given by the equation:

$$\text{Volume ratio} = \frac{(r^{1/3}S - S + 1)^3}{(r-1)S+1}$$

The number of cooperating hedrons used in one unit of an engine must be at least three and should not be more than six. While theoretically more than six hedrons can be used, this leads to a larger number of parts without compensating advantages. In order to keep the engine of simple construction, it is preferable to use either three or four hedrons.

Although the embodiments herein illustrated utilize a two-stroke compression ignition cycle, it will be understood that the cycle can be changed as desired, for example to a two-stroke or four-stroke spark ignition cycle. If spark ignition is desired, the sparking device may be provided on one of the hedrons and connected electrically to an ignition system through a hollow spring, as illustrated for fuel injection in the embodiment illustrated in FIGS. 34 to 40.

It will be appreciated that features of the several embodiments illustrated in the drawings, by way of example, are interchangeable with one another insofar as they are compatible and that various modifications may be made according to the requirements of particular applications of the invention. The exact geometry chosen depends on the operating conditions to which an engine is to be applied.

What I claim and desire to secure by Letters Patent is

1. In an internal pressure engine, the combination of two parallel end plates spaced from one another and a plurality of like hedrons disposed between said end plates, the number of said hedrons being not less than three and not more than six, each of said hedrons having opposite end faces engaging said end plates respectively, a concave rectilinear side face and an adjoining convex rectilinear side face, said concave side face and said convex side face intersecting one another at an angle equal to 360° divided by the number of said hedrons, said intersection of said concave face and said convex face defining an inner corner of said hedron, said hedrons being disposed with said concave side face of each hedron slidably engaging and mating with said convex side face of an adjacent hedron to define a first chamber bounded by said concave side faces of said hedrons, a second chamber bounded by said convex side faces of said hedrons and one of said end plates, and a third chamber bounded by said convex side faces of said hedrons and the other of said end plates, said hedrons being movable in a plane parallel to said end plates to move said inner corners toward a central point to decrease the volume of said first chamber and increase the volume of said second and third chambers and away from said central point to increase the volume of said first chamber and decrease the volume of said second and third chambers, means for synchronizing said movement of said hedrons with one another and port means for admitting fluid to and exhausting fluid from said chambers.

2. An engine according to claim 1, in which said concave face of each said hedron is defined by two plane surfaces disposed at an angle to one another.

3. An engine according to claim 2, in which the angle defined by said plane surfaces is of the order of 75° to 145°.

4. An engine according to claim 2, in which one said plane surface is wider than the other.

5. An engine according to claim 1, in which recesses in said hedrons at said inner corners define communicating ports connecting said first chamber with at least one of said second chamber and said third chamber when said hedrons are in selected position relative to one another.

6. An engine according to claim 5, in which said second chamber comprises an intake and precompression chamber into which air is admitted through said port means in the respective end plate, compressed in said second chamber and then passes through a said communicating port into said first chamber.

7. An engine according to claim 6, in which said port means in said respective end plate is controlled by one-way valve means admitting air to said second chamber but preventing flow of air from said second chamber.

8. An engine according to claim 1, in which a fuel injection nozzle associated with one said port means injects fuel into said first chamber when said first chamber is in communication with said port means.

9. An engine according to claim 1, in which said means for synchronizing the movement of said hedrons comprises a shaft extending through a circular opening in each said hedron and through corresponding holes in said end plates, each said shaft having an eccentric portion engaging in said opening to rotate said shaft upon inward and outward movement of said hedron.

10. An engine according to claim 9, in which said means for synchronizing the movement of said hedrons comprises eccentrics on said shafts outside one said end plate and an oscillatable timing plate having circular openings receiving all of said last-mentioned eccentrics.

11. An engine according to claim 9, in which said means for synchronizing the movement of said hedrons comprises intermeshing gears connecting said shafts with one another.

12. An engine according to claim 9, in which there are three said hedrons and the location of the center of said circular opening of each hedron is defined by the inequalities.

$$X \geqq L_2/2 \text{ and}$$

$$Y \geqq \frac{3X - 2L_1}{3^{1/2}}$$

where L_1 and L_2 represent the length of one side of said first chamber when at minimum volume and maximum

volume respectively, X is the distance from the inner corner of the hedron parallel to the concave side thereof and Y is the distance from the closest portion of the concave side face of the hedron.

13. An engine according to claim 9, in which there are four said hedrons and the location of the center of said circular opening of each hedron is defined by the following inequalities:

$$X \geq , L_2/2$$

and

$$y \geq X - L_1$$

where L_1 and L_2 represent the length of one side of said first chamber when at minimum volume and maximum volume respectively, X is the distance from the inner corner of the hedron parallel to the concave side thereof and Y is the distance from the closest portion of the concave side face of the hedron.

14. An engine according to claim 9, comprising spring means acting inwardly on said hedrons to keep them in contact with one another under conditions of no pressure and negative pressure in said first chamber.

15. An engine according to claim 14, in which outward projections are provided on said hedrons and said spring means comprises tension springs acting on said projections.

16. An engine according to claim 14, in which said spring means comprises at least one hollow spring connecting with a fuel injection passage in a hedron to provide means for injection of fuel into said first chamber.

17. An engine according to claim 2, in which said plane surfaces are joined by a curved cylindrical surface.

18. An engine according to claim 1, in which said concave face of each hedron is defined by a curved cylindrical surface.

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