

Sept. 23, 1930.

J. A. H. BARKEIJ

1,776,760

INTERNAL COMBUSTION ENGINE

Filed Dec. 4, 1926

2 Sheets-Sheet 1

Fig. 1.

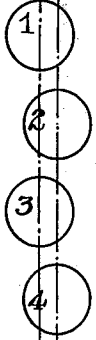


Fig. 2.

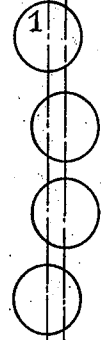


Fig. 3.

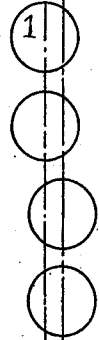


Fig. 4.

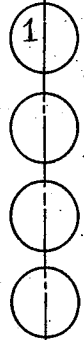


Fig. 5.

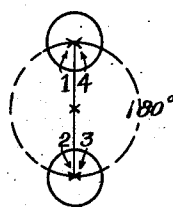


Fig. 6.

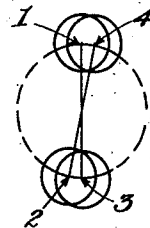


Fig. 9.



Fig. 10.

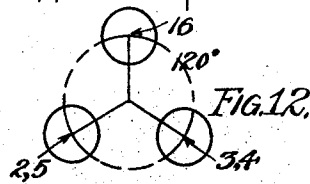
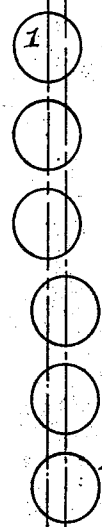


Fig. 7.

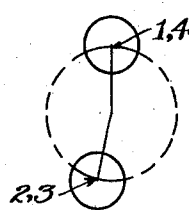


Fig. 8.

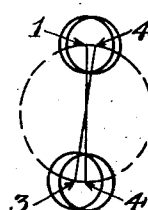


Fig. 16.



Fig. 17.

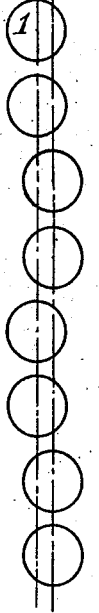


Fig. 18.

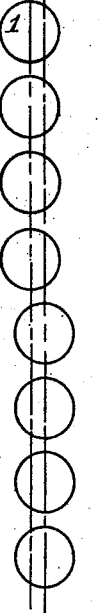


Fig. 19.

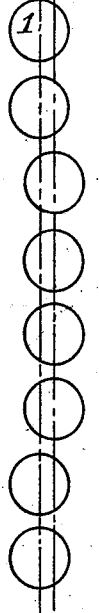


Fig. 20.

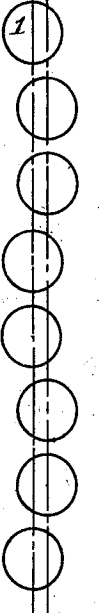


Fig. 21.

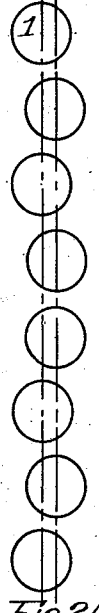


Fig. 22.

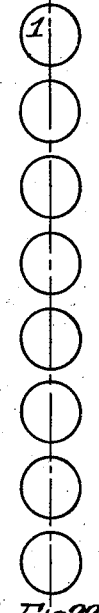


Fig. 11.

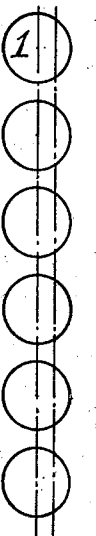


Fig. 13.

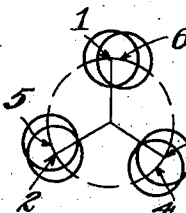
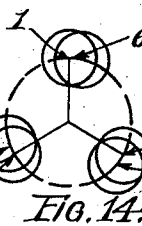
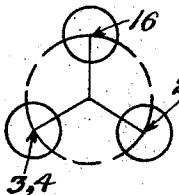


Fig. 15.

Fig. 21, Fig. 22.

Inventor:

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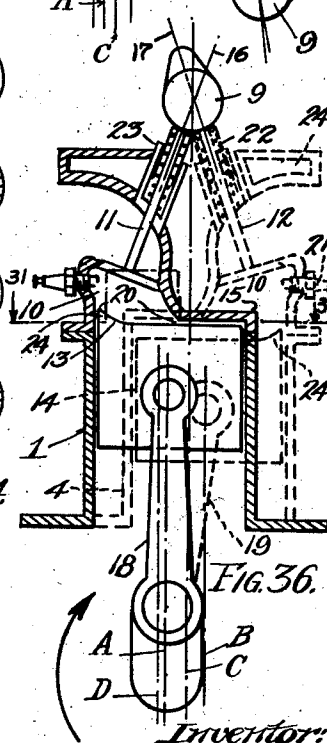
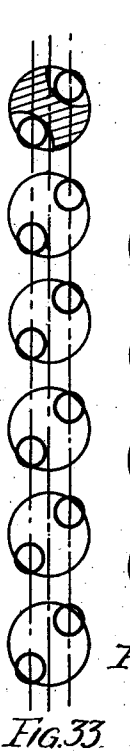
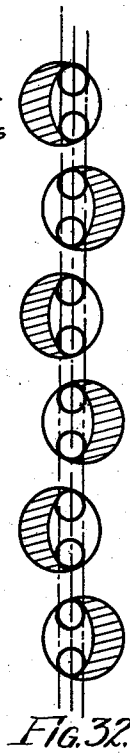
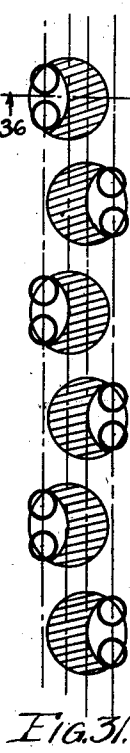
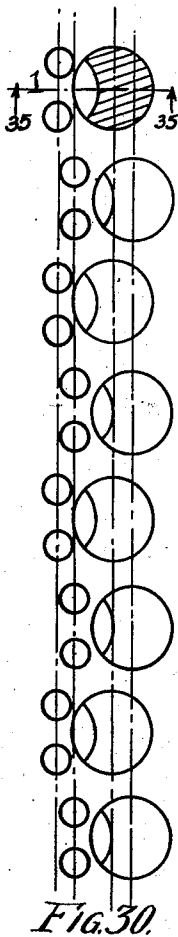
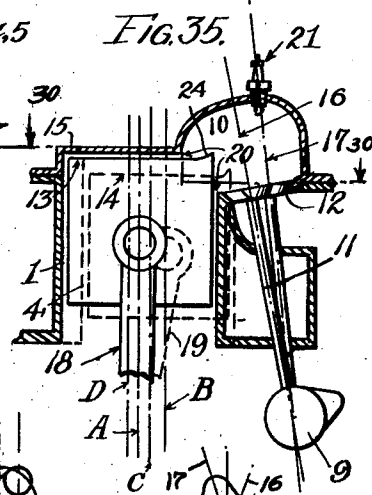
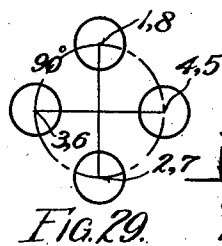
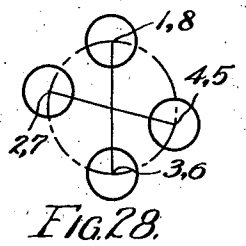
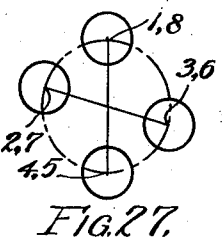
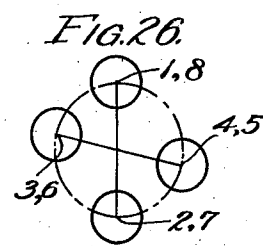
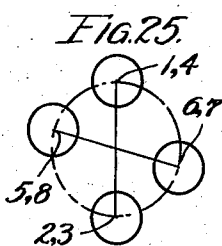
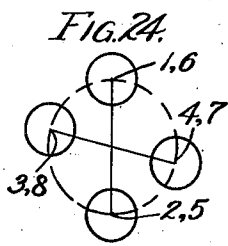
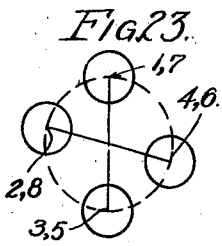
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INTERNAL COMBUSTION ENGINE

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2 Sheets-Sheet 2



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UNITED STATES PATENT OFFICE

JEAN A. H. BARKEIJ, OF ALTADENA, CALIFORNIA

INTERNAL-COMBUSTION ENGINE

Application filed December 4, 1926. Serial No. 152,708.

My first object is to establish a slight irregularity in the firing and balance of a multicylinder engine. This slight irregularity has the tendency to diminish the periodic and torsional vibrations and has other advantages in connection with the radial arrangement of cylinders as will be mentioned later.

My second object is to arrange the cylinders in staggered relation to each other, resulting in a shorter and more rigid engine, and in ample room for valves, valve pockets, valve gear and uniform combustion chambers.

My third object is to combine the first two objects with an overhead single camshaft, lifting the inlet and exhaust valves (all arranged at the same angle) of the cylinders, arranged in two groups, directly. This arrangement can be conveniently combined with a combustion chamber having a restricted passage between the cylinder bore and the combustion chamber in the cylinder head, where the valves are located and the ignition means.

The present invention contains three closely related varieties. Variety A has regular firing, the two other varieties, B and C, irregular firing. In two varieties, A and B, the cylinders are grouped in two planes. The first object is incorporated in varieties B and C. The second object in varieties A and B. The third object in varieties A. and B.

Varieties A and B have to incorporate the third object, variety C may be executed with an L-head or valve-in-head arrangement, combined with combustion chambers partially overlapping the cylinders.

In the L-head type, the valves are at a different angle for the sets of inlet and exhaust valves, in the varieties A and B with two rows of cylinders.

In the overhead type for the varieties A and B the respective sets of two valves per cylinder are arranged alternatively at the same angle to a vertical plane midway the two groups of cylinders.

If the cylinders are arranged in line as in variety C, the valves for the L-head formation may be all at the same slant, and may be also perpendicular, resulting in combustion

chambers absolutely uniform for all the cylinders of the engine. The same condition obtains for the overhead arrangement in variety C.

In the first variety A, the cylinders are built in staggered relation, the crankshaft is placed in the plane of one cylinder group, the crankpins are arranged in n radial planes, " n " being the number of cylinders. In this variety the crankpins are also unaligned in pairs, like the cylinders, except in the case of the four cylinder (Fig. 7) and all the cases of the eight cylinder (Figs. 23-28.)

In the second variety B, the cylinders are unaligned as in variety A, but the crankpins are always aligned in pairs in $n/2$ radial planes, " n " being the number of cylinders, for all types of the four, six and eight cylinder. The shaft axis is placed in the plane of one group.

In the third variety C, the cylinders are aligned, but not the crankpins as in variety A. They are arranged again in n radial planes, except again for one case in the four cylinder (Fig. 7) and all cases of the eight cylinder (Figs. 23-28.)

Realizing that the present invention may be embodied in constructions other than those specifically shown and described, f. i. in engines with more than 8 cylinders in longitudinal direction, or in engines with opposed cylinders, or in engines of which the cylinders are arranged in V, W, Y or X form, I desire that the disclosure shall be considered as illustrative and not in the limiting sense.

Figs. 1-4, 9-11, 16-22 represent the horizontal sections through the cylinders of multicylinder engines of an internal combustion engine.

Figs. 5-8, 12-15, 23-29 are end views of the arrangements of the crankpins of various crankshafts, to be combined with various cylinder arrangements shown.

Fig. 30 shows the horizontal partial section through Fig. 35 as shown, and Fig. 35 shows the vertical section through the cylinder and restricted passage shown in Fig. 30. Both represent an L-head motor.

Fig. 31 shows the partial horizontal sec-

tion S³¹ of Fig. 36 and Fig. 36 shows the vertical section S³⁶ of Fig. 31. Both represent a valve-in-head engine.

In these two Figures 35 and 36 the section lines do not run through the dividing line between cylinderhead and cylinder, but it is of course supposed that the cylinderhead and cylinder can be made in one piece, or the dividing line could have been made higher at the level where the upper surface of the piston and the undersurface of the head come in close approximation, when the piston is in top position. The present dividing line has been made lower for reasons to be explained later, which have nothing to do with the particular form of the combustion chamber, particular situation of the valves, or particular situation of the throat.

Fig. 32 is a horizontal section at the same level as that shown in Fig. 36, but the valves of all the cylinders are placed here in a single row.

Fig. 33 is a horizontal section at the same level as that shown in Fig. 36, but the two valves of each cylinder are placed in two different vertical planes, at a slant towards each other or parallel to each other and the crankshaft axis in two rows. The vertical section of this arrangement however is not shown, but can be easily deduced from said same Figure 36, supposing thereby that the two cylinders shown form in reality only a single cylinder of enlarged diameter.

The right cylinder wall of cyl. 1 and the left cylinder wall of cyl. 4 have to be imagined as being erased. However, this arrangement is of no particular importance except as to the purport and importance of placing the valves above a throat, instead of beside it, as is sufficiently shown already by the Fig. 33 in connection with the following description of Figs. 31 and 36.

Fig. 34 shows a horizontal cross-section of cylinders arranged in line having the same throat at the level shown in Fig. 36. Cyls. 1 and 4, however, show a throat larger than those of cyls. 2 and 3, showing that applicant does not want to be bound by any particular relation between the position of the inverted valves and the size of the throat so long as the valves are in close proximity to said throat and are considerably smaller in effective area than the effective area of said throat. The valves have as a rule to overlap said throat in order to retain the better volumetric efficiency, and to retain the more favorable ratio between the volume and wallsurface of the explosion chambers of Fig. 36 above those of Fig. 35, in which the valves are beside the cylinder, resulting in a chamber which is less compact, unless the throat between cylinder and explosion chamber is placed completely in a vertical position. The chamber shown in Fig. 35 has its throat partly in a horizontal, partly in a vertical plane, and

has therefore already a much more favorable relation between these two quantities in view of thermodynamic efficiency than the regular L-head construction with such a throat only in horizontal position, as in the latter construction the horizontal axes of said chamber will be necessarily larger. The stroke and bore being a given constant, the height in the latter type of combustion chamber has to be necessarily smaller. Moreover, the construction of Fig. 35 places the valves in a more favorable position, eliminating or rather decreasing the resistance for the gases by decreasing the sharpness of the curves followed by the gases if the throat between cylinder and combustion chamber is placed only in a horizontal position.

In this latter respect the constructions of Figs. 35 and 36 both are distinctly more favorable than the well known Ricardo construction in which the throat between combustion chamber and cylinder is in a horizontal position, the gases towards and from the cylinder having to pass two complete curves between the respective inlet and exhaust manifold and the cylinder proper.

In this respect the construction of Fig. 36 is superior than that of Fig. 35, as those curves are here entirely eliminated, besides the more favorable relation between volume and wallsurface of the combustion chamber. If only one of the valves is placed in inverted position above the cylinder and throat, only for one valve will the volumetric efficiency be improved with respect to said curves, and said ratio between volume and wallsurface will also be a little less favorable for the same reasons as explained for Figs. 35 and 36 in relation to each other, as in relation to the present standard construction of the Ricardo head on automobile engines.

Figs. 1-8 refer to the four cylinder.

Figs. 9-15 refer to the six cylinder.

Figs. 16-29 to the eight cylinder.

Figs. 30-35 refer to the L-head type as applied on the first two varieties, A and B, as will be discussed after Figs. 36, 31, 32.

Fig. 36 refers to the valve-in-head valve arrangement applied on the two varieties A and B, as shown, though applicable on the third variety C also with minor changes in the arrangement of the parts, as shown in Fig. 36, as the cylinders in variety C are aligned, in varieties A and B staggered.

Fig. 31 shows the arrangement of Fig. 36 in horizontal section through the top of the cylinder and the undersurface of the cylinderhead, showing the throat or restricted passage 20 of Fig. 36 in horizontal section. The shaded area in this figure shows the extent of the throat and at the same time the extent of the area of near approach, between the top surface of the piston 13, and the undersurface 15 of the head, as shown clearly in Fig. 36. It shows further, that the cylinders 1, 3, 5

are placed in the plane A, visible from Fig. 36, and the cylinders 2, 4, 6 in plane B, also shown and indicated in Fig. 36. The valves, being normally about half the diameter of the cylinderbore or a little less or more, overlap the cylinderbores in horizontal projection as shown.

Fig. 32 shows the cylinders in the same formation as Fig. 31, but the valves are all parallel to each other and perpendicular. The respective throats have to be widened to accommodate said position of the valves, a circumstance, which will be discussed later on at the end of the application. The valves barely overlap the cylinderbore here, as the valves move more to the middle.

Fig. 34 shows the cylinders arranged in line, but the valves are at an angle alternatively, like in the Fig. 32 for the unaligned cylinders in two groups. The valves again overlap the cylinderbore to a greater extent as shown in Fig. 32. The throat has been shown here, not overlapping the cylinderbore for the cylinders 2 and 3, but overlapping said axis for cylinders 1 and 4. Of course such a construction should not be applied on one and the same engine, but serves only to show that when the valves are placed at a slant, that the throat may or may not overlap the cylinder-axis, while in the arrangement of Fig. 32, the restricted passage has to overlap the cylinder-axis, virtually for the reason that otherwise the gases would have to make again certain curves, a circumstance I just try to avoid in the construction Fig. 36, compared with Fig. 35, as we will see and discuss later more extensively.

Fig. 33 shows an arrangement of the inlet and exhaust valve of one cylinder entirely different from that shown in Figs. 35, 36. A side view of this arrangement is not shown, as bearing a certain resemblance to the arrangement of Fig. 36, which can be easily visualized with the help of the following description. Before I do this, I wish to point out, that the arrangement of Fig. 35 has all the inlet and exhaust valves at one side of the two groups of cylinders, and a single inlet and single exhaust manifold will be sufficient for this arrangement. In the arrangement of Fig. 36 however the inlet and exhaust valves, are on either side of the two groups of cylinders, and a single inlet and a single exhaust manifold has to be provided at either side of the two groups of cylinders. To obviate this drawback, and to retain at the same time the advantage of uniform combustion chambers for all cylinders in the varieties A and B, all the inlet valves are placed on one side of the engine, all the exhaust valves at the other side. However, this arrangement would entirely eliminate the important advantage of the restricted passage between explosion chamber and cylinderbore, well known in the art.

To eliminate again this disadvantage, I have shown in Fig. 33 only the horizontal section of the top end of the cylinderbore and the undersurface of the head to produce the required turbulence, due to throats between an explosion chamber and an expansion chamber, and the turbulence due to the squeezing effect between piston and head. These two kinds may be produced entirely independent of each other, but in the present arrangement the shaded area of Fig. 33 shows and represents the throats as well as the shaded area of close approach between piston and cylinderhead. Visualizing now Fig. 33 in Fig. 36 the valves 11 represent only one valve (inlet or exhaust) and valves 12 the other valve (instead of an inlet and exhaust valve behind each other for each of the two cylinders shown, cyl. 1 in the foreground, cylinder 4 in the background,) and visualizing the two overlapped cylinders of Fig. 36 as one cylinder, we see immediately that said single cylinder, has the two throats 20 opposite each other, the two explosion chambers 10 also opposite each other, each provided with a sparkplug.

I am, however, in this application not interested in this type, it serves only to show that the disadvantage of two sets of inlet and exhaust manifolds at either side of the two groups of cylinders, as is demanded for the arrangement of Fig. 36, can be avoided, if required, retaining thereby the other advantages, which said overhead arrangement of the valves has over the L-head arrangement of Fig. 35, of which the most prominent is the uniformity of the combustion chambers.

After having explained the main characteristics and grouping of the various drawings and their interdependency, I will analyze more closely the individual figures. Thereafter we will see how they form the three varieties, what their main characteristics are, and then I will explain the relation of the Figures 30-36 to the three varieties of Figs. 1-29 more closely.

I only have to point out, that in Figure 30, cylinder 1 shows the area of the throat of Fig. 35 only, in horizontal section of the cylinderbore and undersurface of the head, resp. 1 and 15. This throat is much smaller than that of Figs. 31, 32, 33, 34, as the throat 20 of Fig. 35 is partially in vertical position as can be seen from that Fig. 35. At the same time, this shaded area of Fig. 30 shows the area of near-approach between piston top 13 and cylinderhead 15, which area is of course, correspondingly greater than that shown in said Figs. 31-34.

The actual cross section (horizontal) of the combustion chambers in Figs. 30, 31, 32, 33, 34 has been omitted, as being visible from Figs. 35, 36. The size of the two throats being shown, it is evident that this cross section

for the overhead valve type of Fig. 36 can be made smaller than that of Fig. 35, which has the valves beside the cylinder.

Figs. 1-3 show the three different staggered arrangements of the cylinders, and Fig. 4 the lined arrangement of the cylinders for the four cylinder.

Figs. 9, 10 show the two staggered arrangements of cylinders for the six cylinder engine, and in Fig. 11 the lined arrangement of the cylinders.

Figs. 16-21 show the 6 different staggered arrangements of the 8 cylinder engine, and the lined arrangement of cylinders in Fig. 22.

In Fig. 5 the four crankpins of a crankshaft are aligned in pairs, crankpins 1 and 4, and crankpins 2 and 3, as in any standard motor.

Fig. 6 shows the crankpins 1 and 4, not aligned but adjacent to each other, the crankpins 2 and 3 also adjacent to each other and so that crankpins 1 and 3, 2 and 4 are diametrically opposite each other. Fig. 7 shows crankpins 1 and 4 again aligned, and also crankpins 2 and 3, but these two pairs of aligned crankpins are not diametrically opposite each other. In Fig. 8 crankpins 1 and 4 are again adjacent, like crankpins 2 and 3, however with this difference compared with Fig. 6 that here crankpins 1 and 2, and 4 and 3 are diametrically opposite each other.

Fig. 12 shows the six crankpins 1 and 6, 2 and 5, 3 and 4, aligned in said pairs, with 120° between them. In Fig. 13 the same crankpins are arranged in the same pairs with the same angle, but seen from the other end of the shaft. The first shaft is called a left handed, the second shaft a right handed six cylinder shaft, as is well known in the prior art in itself—or in themselves, rather.

Figs. 23-28 incl. show the different arrangements of the crankpins of an 8 cylinder motor. Figs. 23-28 incl. show the two groups of four crankpins not arranged in perpendicular arrangement, but let us suppose for variety B (in order to decrease the number of drawings) they are arranged at right angles as shown for only one variety in Fig. 29, and let us call the same arrangements, in which said two groups of four crankpins are arranged at an angle of 90°, (Figs. 23 and 29, 24 and 29, and 29, 26 and 29, 27 and 29, 28 and 29). Figs. 23^a, 24^a, 25^a, 26^a, 27^a, 28^a, respectively.

Having explained the various cylinder and crankpin-arrangements, it will be clear at once that variety A for the four cylinder is made of the combination of Figs. 1 and 6, Figs. 2 and 7, Figs. 3 and 8, for the six cylinder of the combination of Figs. 9 and 14, Figs. 10 and 15, for the eight cylinder of Figs. 16 and 23, 17 and 24, 18 and 25, 19 and 26, 20 and 27, 21 and 28. That variety B is made for the four cylinder out of the combination of Figs. 1 and 5, 3 and 5, for the six

cylinder of the combination of Figs. 9 and 12, 9 and 13, 10 and 12, 10 and 13, for the eight cylinder of the combination of cylinder-arrangement and crankpin-arrangement of Figs. 16 and 23^a, 17 and 24^a, 18 and 25^a, 19 and 26^a, 20 and 27^a, 21 and 28^a (a means the perpendicular arrangement of the two groups of four crankpins of Fig. 29 combined with the specific crankpin-arrangement in two groups of four crankpins of the Figs. 23-28).

Variety C for the four cylinder is made of the combination of Figs. 4 and 6, 4 and 7, 4 and 8, for the six cylinder of the combination of Figs. 11 and 14, Figs. 11 and 15, for the eight cylinder of the combination of Figs. 22 and 23, 22 and 24, 22 and 25, 22 and 26, 22 and 27, 22 and 28.

The three varieties can be visualized now very clearly and the combination of Figs. 30 and 35 shows clearly the arrangement of the valves and single camshaft, lifting all the valves of all the cylinders directly. If the cylinders are arranged in staggered formation as in the two first varieties, the valves per cylinder are arranged alternatively at a different angle. If the cylinders are aligned as in variety C, the valves of all the cylinders may have the same angle, and may be arranged perpendicularly or at a slant. In the first two varieties the combustion chambers cannot be absolutely uniform, as the angle of the valves in this L-head formation varies alternatively per cylinder. If two camshafts were applied, one at each side of the two groups of cylinders, the valves may be all placed at the same angle, resulting in absolute uniform combustion chambers, even if these chambers lie partially over the cylinder-bore as proposed in this application in Figs. 35 (and 36). In variety C there would not be any reason to use two camshafts, as all the valves may be placed here at the same angle, with a single overhead camshaft. Figs. 31 and 36, show that the valves may be placed at an angle towards each other in the head. In the first two varieties A and B, the valves may be placed alternatively in pairs per cylinder, at an angle towards each other with their valvestems, as shown in Fig. 31 plus 36. However, they may be placed as shown in Fig. 32 in perpendicular position in these two varieties, as shown in Fig. 32, where all the valves of all the cylinders are placed parallel to each other above throats wider than those shown in Fig. 31.

The valves in the valve-in-head type are here always at the same angle, not in the L-head. In variety C, where the cylinders are aligned, the valves may be at an angle alternatively per cylinder, as shown in Fig. 34. However, in this arrangement they may also be placed perpendicular and parallel to each other as shown in Fig. 32 for the first two varieties, where the cylinders are staggered, but it was considered superfluous to show

this again in a new figure for variety C. It is clear, however, that with a single overhead camshaft the combustion chambers can be made absolutely uniform throughout for all the cylinders in all three varieties, whether the valves are at an angle or perpendicularly arranged.

In the L-head formation however, we have seen, that absolute uniform combustion chambers combined with a single camshaft, lifting all valves directly, can only be effected in the third variety C, but not in the first two varieties A and B, where the cylinders are in staggered relation, unless two camshafts are used. This should be avoided at any price.

In this latter arrangement Fig. 32, however, the throat between the cylinderbore and the combustion chamber has to be enlarged over the cylinderaxis to accommodate the valves, as will be explained more in extenso later on. In Fig. 34 is shown that the arrangement of Fig. 36 can also be combined with the variety C, in which the cylinders are aligned.

Fig. 33 shows that the two valves in one cylinder, the inlet valve and the exhaust valve can be placed at a converging angle with their stems for any of the three varieties. To effect here equally as in Figs. 30, 31, 32, 34, 35, 36 a combustion chamber having a restricted communication between cylinderbore and valve chamber to produce a turbulence in the latter, as is well known in the art, the two chambers had to be separated from each other by the upper surface of the piston in top position and resemble therefore somewhat the end view of the valve arrangement of the four valves of two staggered cylinders of Fig. 36, supposing thereby that the width of the single cylinder would be equal to the combined overlapped width of the two cylinders, shown in Fig. 36 in staggered formation, and provided with two throats 20 as shown in Fig. 36, as represented diagrammatically in Fig. 33 in horizontal section through the lower part of the cylinderhead and the upper part of the cylinder.

Before going into further details referring to the Figures 30-36 it is preferred, to analyze further the three varieties of the combination of cylinders and crankpins with respect to the location of the axis of the crankshaft, carrying these crankpins and driving the pistons in these various cylinders. The three varieties will be discussed in succession for the four, six and eight cylinder-type. First the position of the crankshaft in these various types, with respect to 1° the pressure exerted by the piston during the explosion period on the two groups of cylinders (and the aligned group) will be analyzed, and 2° the influence of the position of the crankshaftaxis with respect to the regularity or irregularity of firing will be analyzed.

First considering the pressure exerted by the piston during the explosion stroke in the different three varieties, when the crankshaft is placed in four different planes with respect to the plane or planes of the cylinders, we refer to the four planes A, B, C, D as shown in Fig. 35 or 36. The number of cylinders is irrelevant.

Variety A

Considering first variety A, in which the cylinders are arranged in two parallel planes A and B. If the shaftaxis is placed in the plane A, the shaft has to rotate clockwise to decrease the pressure of the piston on the cylinderwall, due to the angularity of the connecting rod during the explosion period, for the right group of cylinders placed in the plane B. For the left group of cylinders this pressure will be normal in this position of the shaft, rotating in either direction.

If the shaftaxis is placed in the plane B the shaft has to rotate counter-clockwise to decrease the pressure for the left group of cylinders. Again for the right group this pressure will be normal independent of the rotation of the shaft.

In either case, if the shaft is rotated in the wrong direction, the pressure will be increased above normal for one group of cylinders.

If the shaftaxis is placed in the plane C (see Fig. 35 or 36) midway the two planes of the cylinders, the pressure of the piston on the cylinderwall during the explosion stroke and inlet stroke is greater than normal for one group of cylinders and smaller than normal for the other group of cylinders, depending upon the direction of rotation. If the shaft turns clockwise this pressure (I will call from now on this pressure of the piston on the cylinderwall during the explosion stroke (and inlet stroke) downward, shortly as "this pressure") will be decreased from normal for the right group of cylinders and increased for the left group of cylinders. Reversely, if the shaft rotates counter-clockwise, this pressure will be increased for the right group of cylinders and decreased from normal for the left group of cylinders.

Consequently, which way the shaft turns one group of cylinders, will have increased pressure during the downstroke.

If we place the shaftaxis in plane D to the right of the two groups of cylinders, variety A, this pressure will be decreased for both groups of cylinders in varying degree, more for the right group of cylinders than for the left group. The shaft has to rotate however in clockwise direction, if it rotated in counter-clockwise direction the average pressure would be increased in the different degree as explained for both groups of cylinders. The shaft could be placed, of course, to the right of the two planes A and B, in a fifth plane E,

and the shaft had to rotate counter-clockwise to decrease this average pressure for both groups. Otherwise, it would increase this pressure in the same proportion as explained.

Variety B

The four positions of the crankshaft in this variety B will have the same effect, as in the variety A, as the cylinders are here similarly placed in two planes.

Variety C

If the shaftaxis is placed in plane A—B—C (as all cylinders are aligned in one plane) this average pressure will be normal for all cylinders, independent of the direction of rotation. If the shaftaxis is placed in the plane D, the shaft has to rotate clockwise direction to decrease this average pressure, otherwise it will be increased. The shaft could be placed to the right of the plane A, but the shaft had to rotate in reversed directions to obtain respectively the same effects as to piston pressure.

Now we will consider, before going into detail as to the specific types of the three varieties, the position of this shaft in said four planes, as to the effect thereof on the regularity or irregularity of firing intervals. Here, however, the direction of rotation is of no importance, but the position of the crankshaft is closely related to the position of the crankpins and offset of cylindergroups and the number of cylinders is relevant.

Variety A

In this variety the firing will be regular if the crankshaft is placed in the plane A in the combination of the Figures 1 and 6, 2 and 7, 3 and 8, and the crankpins are placed in accordance therewith to effect equal intervals between the firing. The direction of rotation, however, does not affect this effect at all, different from the effect thereof on this pressure as explained before. If the shaft is placed in the plane B the firing will be equally regular if there is a relation between this position and the relative position of the crankpins.

If the shaft is placed in the planes C and D the firing can also be made equal. In all four positions, if there is no relation between the crankpin-arrangement, the amount of offset of the cylinders, and the position of the shaftaxis the firing will be irregular.

To effect this equal firing the crankpins have to be aligned sometimes in pairs, as shown in Fig. 7 and Figs. 23-28, resp. for the four and eight cylinder.

Variety B

The same things as said under variety A, can be repeated here, but is considered superfluous, except for the following. In this variety the cylinders are supposed to be in two groups as in variety A, but the crankpins

here are in a rigid position and are aligned in pairs, equally for the four, six and eight cylinder, and the firing will be irregular for all types and combinations, even if the shaftaxis is placed in the plane C, midway the two planes of the two groups of cylinders. If the shaft is placed in the planes A, B or D the firing will be irregular anyway, the amount being dependent upon the offset of the cylinders and the length of the connecting rods. If the shaft is placed in the plane C, the cylinders may be offset as little as is possible and the connecting rods may have any length, the firing will be unequal.

Variety C

In this variety the shaft can only have two positions, plane A—B—C or plane D. If placed in the first plane, irregularity of firing will be caused by the unaligned position of the crankpins (except Fig. 7 and Figs. 23-28). If placed in the plane D this irregularity will be affected equally for all the cylinders, being in aligned position.

Now we will consider the individual types of the three varieties for the three individual types of engines, the four-cylinder, six-cylinder and eight-cylinder (or multiplications thereof in longitudinal or radial direction).

FOUR CYLINDER

Variety A

This variety is created by the combinations of Figs. 1 and 6, 2 and 7, 3 and 8. The firing is supposed to be regular. The cylinders are placed in Fig. 1 in staggered relation alternatively. The crankpins 1 and 4 (see Fig. 6) are displaced proportionately to said offset position of the cylinders to effect equal firing, in combination with the position of the shaft in the plane A, B, C or D as explained before.

In Fig. 2 cylinders 1 and 4 are in the left plane A, cylinders 2 and 3 in the plane B. The aligned crankpins 1 and 4 are offset correspondingly with the aligned crankpins 2 and 3 to effect equal firing, and the position of these two pairs of aligned crankpins has to be further according to the shaftaxis-position to effect equal firing intervals (see Figure 7).

In Fig. 3 the cylinders 1 and 2 are in the plane A, the cylinders 3 and 4 in the plane B. In Fig. 8 the cylinders 1 and 4 are offset with respect to each other and so are crankpins 2 and 3 to effect equal firing. Again, if the shaftaxis is placed in the four mentioned planes, the offset of the crankpins has to be changed accordingly to effect equal firing.

We see finally that for the three types of this variety the firing can be made always equal, how much the cylinders are offset, and independent of the specific form of the staggered arrangement of the cylinders and inde-

pendent of the plane in which the shaft is placed.

It is, however, possible to effect immediately irregular firing by destroying the correspondence between these three constituents, cylinders, crankshaft position, crankpin position. We see consequently that this variety may be with equal firing or unequal firing without falling in the variety B or C.

Resuming the three types of variety A, the firing will be equal, independent of the firing order and independent of rotation. If the cylinders 2 and 4 (see Fig. 1) are placed to the right of the cylinders 1 and 3, the crankpins 2 and 4 have to be rotated a corresponding amount to the right of crankpins 1 and 3 in a clockwise direction, the shaft rotating in a clockwise direction, or counterclockwise direction. In other words, if the shaftaxis is placed in the plane B instead of A, the position of the crankpins has to be changed accordingly to effect equal firing. If the crankpin arrangement of Fig. 6 is placed in the plane B the firing will be irregular.

The positions of the crankpins shown in Figs. 6, 7, 8 are therefore only for the position of the crankshaft axis in plane A and not for the position thereof in the plane B, C or D in which case they have to be changed accordingly to effect equal firing intervals.

Variety B for the four-cylinder

In the combination of Figs. 1 and 5, representing one type of the variety B, the cylinders are arranged in staggered relation alternatively, so that the cylinders 1 and 3, 2 and 4 are aligned. In Fig. 5, the crankpins 1 and 4, 2 and 3 are aligned. The firing will be with unequal intervals depending upon the amount of offset of the cylinders, and the length of the connecting rod. With an offset of about 25% of the stroke of the engine, the difference will amount to about 6°. With equal pistons, connecting rods, the combustion chambers in the left-hand cylinders will be a little higher than in the right-hand cylinders, provided, of course, that the axis of the crankshaft lies in the plane of the left group of cylinders. A change in one of the constituents has to be made to equalize the compression in all the cylinders. The pistons or connecting rods have to be made higher for the right group of cylinders, or the combustion chambers have to be lowered (which causes however complication in the angle and length of the valves and uniform combustion chambers), or the crankshaft should be placed midway the two groups of cylinders, (in which case, however, the irregularity of firing is different from the irregularity resulting from the position in plane A). For that reason, it is supposed for the present time that the crankshaft axis

is in the plane A of the left group of cylinders.

In the following explanation we will suppose that the explosion takes place and is consummated when the piston reaches its top position. The intervals between the explosions, the shaft rotating counterclockwise for this combination, will be for a firing order 1, 2, 4, 3 for the cylinders 1 and 2, $180^\circ - 6^\circ$, (supposing from now on that the degree of offset and the position of the crankshaftaxis results in this difference in the firing intervals for all the following combinations in all three varieties, the position of the crankshaftaxis in variety C, however, being supposed to be in the plane of all the aligned cylinders) for the cylinders 2 and 4, 180° , for the cylinders 4 and 3, $180^\circ - 6^\circ$, for the cylinders 3 and 1 again 180° . The maximum difference between successive intervals is 6° constant. If the direction of rotation is reversed these intervals change respectively. (Clockwise rotation.)

For the other firing order 1, 3, 4, 2 the intervals are identical respectively, for either rotation (cl. w. 180° , $180^\circ + 6^\circ$, 180° , $180^\circ - 6^\circ$).

The second type of variety B is the combination of Figs. 2 and 5, the cylinders of Fig. 2 are aligned in plane A for cylinders 1 and 4, and in plane B for cylinders 2 and 3. The crankpins of Fig. 5 are aligned for crankpins 1 and 4, 2 and 3 in said pairs. The firing intervals in a firing order 1, 2, 4, 3 will be respectively $180^\circ + 6^\circ$, $180^\circ - 6^\circ$, $180^\circ + 6^\circ$, $180^\circ - 6^\circ$ (shaft rotating clockwise).

If the shaft rotates counterclockwise the intervals will be resp. $180^\circ - 6^\circ$, $180^\circ + 6^\circ$, $180^\circ - 6^\circ$, $180^\circ + 6^\circ$. The interval difference being here 12° constant. The same condition obtains for the other firing order in the same sequence of length of interval, but between different cylinders.

The third type of variety B is the combination of Figs. 3 and 5. In Fig. 3 cylinders 1 and 2 are aligned, in plane A, cylinders 3 and 4 in plane B. The crankpins are again in the same position as in the two other types of this variety. The firing intervals are for the firing order 1, 2, 4, 3 respectively 180° , $180^\circ + 6^\circ$, 180° , $180^\circ - 6^\circ$, the shaft rotating clockwise. If the shaft rotates counterclockwise the intervals will be respectively 180° , $180^\circ - 6^\circ$, 180° , $180^\circ + 6^\circ$, the difference being constant 6° for both directions of rotation and both firing orders.

If the shaftaxis is placed in plane B, C, or D the intervals will also be irregular, though in a varying degree, corresponding to offset of cylinders and length of connecting rods.

Variety C

The first type of this variety is made by the combination of Figs. 4 and 6. Fig. 4 shows all

the cylinders aligned and Fig. 6 shows the crankpins 1 and 4 and 3 and 2 adjacent to each other in said order. For the firing order, 1, 2, 4, 3 the intervals will be for a clockwise rotation $180^\circ - 6^\circ, 180^\circ, 180^\circ + 6^\circ, 180^\circ$. For the other firing order 1, 3, 4, 2 the intervals are $180^\circ, 180^\circ - 6^\circ, 180^\circ, 180^\circ + 6^\circ$ also for a clockwise rotation. For a counterclockwise rotation the intervals will be in reverse order.

The same conditions, (*mutatis mutandis*) are obtained, in the two other types of this variety C, the combination of Figs. 4 and 7, and 4 and 8. The only difference being that the shaft of Fig. 7 is more difficult to balance.

In the combination of Figs. 4 and 7, with a firing order of 1, 2, 4, 3 plus clockwise rotation the intervals are resp. $180^\circ - 6^\circ, 180^\circ + 6^\circ, 180^\circ - 6^\circ, 180^\circ + 6^\circ$.

In the combination of Figs. 4 and 8, with a firing order of 1, 2, 4, 3 plus clockwise rotation the intervals are $180^\circ, 180^\circ - 6^\circ, 180^\circ, 180^\circ + 6^\circ$. If the rotation is changed in these types the intervals are the same in reverse order.

If the shaftaxis is placed in plane D, the only other plane possible (including of course the equivalent fifth plane E, not shown, on the other side of plane A—B—C) the irregularity of the intervals changes equally for all cylinders, being aligned in this variety C.

Now we will consider the types of the three varieties of the six-cylinder.

Variety A for the six-cylinder

Before we consider the individual types of the three varieties, we will consider in which respect the six-cylinder differs from the four-cylinder. In the four-cylinder the secondary inertia forces are unbalanced, in the six cylinders however these can be eliminated by a proper arrangement of the crankpins. In Figs. 12 and 13, the standard arrangement is used and in Fig. 14 these two types are changed in so far the six crankpins are there arranged in six radial planes. However, these crankpins are offset for the pairs 1 and 6, 2 and 5, 3 and 4 so much as will not affect the balance of the reciprocating parts seriously. Fig. 15 is similar, more or less, to Fig. 14 only differing in this important practical difference that the latter type is easier to manufacture as the two halves of the shaft are rotated with respect to each other, while in the shaft 14 the crankpins 1, 2, 3 are at a different angle to each other and so are crankpins 4, 5, 6.

In any type of the three varieties, however, the eight following firing orders (-suction orders) are obtainable. They are 1, 3, 5, 6, 4, 2; 1, 3, 2, 6, 4, 5; 1, 4, 5, 6, 3, 2; 1, 4, 2, 6, 3, 5; 1, 5, 3, 6, 2, 4; 1, 5, 4, 6, 2, 3; 1, 2, 3, 6, 5, 4; 1, 2, 4, 6, 5, 3; called respectively *a, b, c, d, e, f, g, h*. These orders *a, b, c, d*, are produced clockwise for the crankpin-arrangement of

Fig. 13 and counterclockwise rotation for the crankpins of Fig. 12. The orders (*e, f, g, h*) are produced by the respective reverse directions.

The first type of variety A is the combination of Figs. 9 and 14. The cylinders in Fig. 9 are in staggered relation so that cylinders 1, 3, 5 are in plane A and cylinders 2, 4, 6 in plane B. The crankpins 1 and 6, 3 and 4, 5 and 2 are offset in Fig. 14 in the said order, and direction of the order. The firing will be with equal intervals for the firing orders *a, b, c, d, e, f, g, h*, if the shaftaxis is placed in the plane A, and the offset of the crankpins corresponds therewith. Equally for the second type of this variety the combination of Figs. 10 and 15. In Fig. 10 the cylinders 1, 2, 3 are placed in the plane A and the cylinders 4, 5, 6 in the plane B. Correspondingly to effect equal firing intervals the crankpins 1, 2, 3 are arranged at an angle of 120° , and also the crankpins 4, 5, 6 at said angle. The angle between these two sets correspond to the offset position of the cylinders and the length of the connecting rods. Here again the firing will be equal for any of the eight firing orders.

If the shaftaxis is displaced to plane B, the crankpin arrangement of Figs. 14 and 15 has to be changed accordingly, and equally for the position thereof in the plane C and D. The direction of rotation is of no influence on the intervals.

Variety B for the six-cylinder

The first type is represented by the combination of Figs. 9 and 12. The cylinder and crankpin arrangement is already explained thereof in the discussion of variety A. This combination will result in irregular firing intervals. For the firing orders *a, b, d, e, f, h* the intervals are highly irregular, the difference between two successive intervals being α° , for the next two intervals $2\alpha^\circ$. One interval will be 114° , another 126° , the rest 120° . For the firing orders *c* and *g*, however, the intervals differ regularly between $120^\circ, 120^\circ + 6^\circ, 120^\circ, 120^\circ - 6^\circ$.

The same condition obtains for the second combination of Figs. 9 and 13. The same firing orders can be obtained and the intervals will be irregular with a constant difference between two successive intervals for the firing orders *c* and *g*, and with an inconstant difference for the other six firing orders. If the shaftaxis is placed in the other planes B, C, and D the irregularity will be only different. (Supposing no change in crankpin position).

The third type of variety B is the combination of Figs. 10 and 12 and the fourth type the combination of Figs. 10 and 13.

For these two types however, the irregularity with a constant difference exists only for the firing orders *d* and *e*. For the other

firing orders the difference of successive intervals is inconstant. Again difference of position of the shaftaxis results in different constant and inconstant differences between successive intervals. (Supposing no change in crankpin position).

Variety C for the six-cylinder

The first type is a combination of Figs. 11 and 14. The cylinder and crankpin arrangement has been already discussed. For the firing orders *c* and *g*, the difference in the intervals will be constant, for the other six inconstant. The second type is a combination of Figs. 11 and 15. The cylinder and crankpin arrangement has been already discussed. For the firing orders *d* and *e*, the differences will be again constant, for the other six firing orders inconstant. A position of the shaft-axis in plane B, C or D will again only change the constant and inconstant difference.

It is possible in this type to offset the cylinders 1, 2, 4 in plane A, and the cylinders 3, 5, 6 in plane B, or cylinders 1, 2, 5 in plane A, and cylinders 3, 4, 6 in plane B and to change the position of the crankpins in accordance therewith in order to create examples of the same variety C, B, or C, but this is considered superfluous to show.

The eight-cylinder engine

In this type the conditions are again different from the four-cylinder in respect of the secondary inertia forces which are here entirely balanced except for couples in certain types. The difference with the six cylinder lies more in the greater variety in which the cylinders can be placed in staggered arrangement and the greater variety in which the crankpins can be placed, a feature of specific importance in view of the distribution of the fuel.

Variety A

The types of this variety are six, like in the varieties B and C. The combination of Figs. 16 and 23, 17 and 24, 18 and 25, 19 and 26, 20 and 27, 21 and 28 will result in equal firing intervals, if the shaftaxis is placed in the plane A and the offset position of one set of four crankpins, composed of two pairs of aligned crankpins in one plane diametrically opposite each other, is arranged in accordance with the offset position of the cylinders. If the shaft axis is placed in the plane B, C or D the offset position has to be changed accordingly to effect equal firing. The offset shown in Figs. 23-28 is in proportion to the position of the shaft in plane A.

Two types have advantages from a practical standpoint over the other types of crankshaft. The types of Figs. 25 and 26 are easier to forge than the other types 23, 24, and 27, 28. In Fig. 16 the cylinders 1, 3, 5, 7 are arranged in plane A, the cylinders 2, 4,

6, 8 in plane B. The crankpins of Fig. 23 are arranged in accordance therewith so that the crankpins 1, 7 are opposite 3, 5 in one plane and the crankpins 2 and 8 opposite the crankpins 4 and 6 in another plane. Each of these two sets of four cylinders and four crankpins form a regular four-cylinder engine as would produce the combination of Figs. 4 and 5. The crankpins 2 and 8, and 4 and 6 however are placed in a plane at an angle to the plane of the first set of four crankpins 1 and 7, and 3 and 5 to eliminate the irregularity of firing which would otherwise result from the position of the cylinders in two planes.

In Fig. 17, the cylinders 1, 2, 5, 6 are placed in the plane A, and the cylinders 3, 4, 7, 8 in the plane B. Correspondingly the crankpins of Fig. 24 are arranged in two sets of four crankpins in two planes at an angle. Crankpins 1 and 6, are opposite 2 and 5 in one plane and crankpins 3 and 8, opposite 4 and 7 in another plane at an angle corresponding to the offset of the two cylinder-planes.

In Fig. 18 the cylinders 1, 2, 3, 4 are placed in one plane A, cylinders 5, 6, 7, 8 in the plane B. The crankpins corresponding to these cylinders are placed in two planes at an angle, in pairs opposite each other.

In Fig. 19, the cylinders 1, 2, 7, 8 are placed in plane A, and cylinders 3, 4, 5, 6 are placed in plane B. Correspondingly, the crankpins in Fig. 26 are placed at an angle in two planes, corresponding to the degree of offset of the cylinderplanes.

In Fig. 20, the cylinders 1, 4, 5, 8 are placed in plane A, cylinders 2, 3, 6, 7 in plane B. The corresponding crankpins in Fig. 27 are placed in two planes at an angle.

In Fig. 21, the cylinders 1, 3, 6, 8 are placed in the plane A, and cylinders 2, 4, 5, 7 in plane B. The corresponding crankpins in Fig. 28 are so placed at an angle in two planes that the firing will be regular independent of the order of firing, or the direction of rotation.

Variety B for the eight-cylinder

The 6 types are formed by the combination of the Figures 16-21 with the Figures 23-28, in which, however, the crankpins are arranged perpendicularly to each other in two planes in two sets of four crankpins (see Fig. 29).

In Fig. 16 the cylinders 1, 3, 5, 7 are arranged in the plane A and the cylinders 2, 4, 6, 8 in the plane B. The crankpins of Fig. 23 are arranged in accordance therewith in two planes, and further at right angles as shown in Fig. 29 to effect irregular firing.

The cylinders in the following Figures 17-21 are arranged as explained already for Variety A. The corresponding crankpinarrangements of Figs. 24-28 resp. are also ex-

plained under variety A, here however these crankpins are arranged in said two planes at right angles to each other as shown in Fig. 29.

5 The firing intervals in these six types will be irregular but the irregularity between successive intervals will be equal or constant.

The crosswise combinations of Figs. 16-21 with Figs. 23-28 will result in an irregularity much greater than in the first set of six combinations.

Variety C for the eight-cylinder

15 Finally the six types of this variety are a result of the combination of Fig. 22 with the Figures 23-28 successively. The cylinders are arranged in Fig. 22 in a straight line and the crankpins are arranged as already explained for variety A. The firing will be irregular with a constant difference between successive intervals for these six combinations. This irregularity is much smaller than results from the combinations constituting variety B. If the two sets of four crankpins are placed at a smaller angle than shown in Figs. 23-28, the irregularity will increase. Equally, when the shaft is placed in the plane D. For all three varieties it is seen, that the position of the shaft in the other three planes changes the regularity and irregularity equally and must therefore always be considered.

Finally, we will consider the relation of the first two objects in relation with the third object. The first object may be considered totally irrelevant to the second object and third object, and the second object totally irrelevant to the first and third object, and the third object totally irrelevant to the first and second object. In fact, either one of these objects could be incorporated in any engine without the other two objects, and either two of these three objects could be incorporated in an engine without the third. I wish, however, to point out how the three objects, each of which has certain advantages as explained, can be combined in an economical compact, efficient form, and how they are mechanically and physically and practically closely related. For that reason, I will analyze the two forms of the third object, the valves, valvelifting mechanism and form of combustion chamber, as shown in Figs. 35 and 36.

Fig. 35 represents the cylinders 1 and 4 of the combination of Figs. 1 and 5.

In Fig. 35, the cylinder 1 is on the foreground in plane A, the cylinder 4 on the background, shown in broken lines in plane B. 11 are the valves belonging to cylinder 1, 12 the inlet and exhaust valves belonging to cylinder 4. 16 are the axes of the valves 11 of cylinder 1, 17 the axes of the valves 12 of cylinder 4. 9 is the camshaft operating

said four valves. 13 and 14 are the pistons or rather piston tops, approaching closely the cylinderheads 15, but so that the top part of the pistons may protrude into the cylinderheads. 10 are the combustion spaces into which the valves, 2 per cylinder, open upwardly. This space 10 is communicating with the space swept by the piston through the restricted passage 20. The piston is provided with a curved up portion 24 at the side where the sparkplug 21 is located. The piston 13 in cylinder 1 is connected with the connecting rod 18, having a length smaller than the connecting rod 19 connected with the piston 14 in cylinder 4. Having enumerated the important parts of this arrangement, I will consider their relation towards each other and towards the three objects enumerated in the beginning of this description, after having explained the parts of the other arrangement shown in Fig. 36.

Fig. 36 represents cylinder 1 and 4 of the combination of Figs. 1 and 5.

In Fig. 36, cylinder 1 is again shown in full lines on the foreground in plane A, and the staggered cylinder 4 on the background in broken lines in plane B. Connecting rod 18 reciprocates piston 13 in cylinder 1 and connecting rod 19 the piston 14 in cylinder 4 (see Fig. 1 combined with Fig. 5). The pistons 13 and 14 are provided at opposite points with curved up portions 24 according to the position of the respective combustion chambers 10 in cylinders 1 and 4 and the respective location of the sparkplugs 21 therein, located in horizontal position in the respective cylinders, pointing with their spark-point-sides towards each other. These pistons may protrude here again, as in Fig. 35, into the combustion chamber for reasons to be explained later. The inlet and exhaust valve for cylinder 1 are represented by 11, for cylinder 4 by 12. Their respective valve-stems axes 16 and 17 point towards each other towards the axis of the camshaft 9. These valves are located in valvecages and plungers for direct operation by the camshaft 9, as is well known in the art, 23 for cylinder 1, 22 for cylinder 4. The combustion chambers 10 are again shown exactly on the same level, as in Fig. 35, but the throats between the space swept by the pistons 13 and 14 are fundamentally different from those shown in Fig. 35, in so far these restricted passages in Fig. 36 are entirely in an horizontal plane, while those, in Fig. 35, are formed partially in a horizontal plane, partially in a vertical plane, to enlarge this restricted passage in view of volumetric efficiency, diminishing thereby the turbulence due to the size of the throat, and increasing thereby the turbulence due to the squeezing effect between piston and cylinderhead, depending upon their area of close approach. The area in horizontal cross section of the throats in Fig. 36 of

cylinders 1 and 4 can be seen from the horizontal cross sections of the cylinders 1 and 4 in Figs. 34 and 37, when the valves are placed at a slant, and from Fig. 32 when the valves are placed perpendicular. The throat in Fig. 36 does not pass the center of the cylinder, as shown in Fig. 31 for all cylinders, and for cylinders 2, 3 in Fig. 34. It passes the axis of the cylinder in cylinders 1 and 4 of Fig. 34 and in all the cylinders of Fig. 32 where the valves are placed perpendicular.

It can be seen further in the horizontal sections of Figs. 34 and 31 that the valves, if placed at a slant, may overlap the cylinderbore in perpendicular direction even if the valves are made smaller than half the cylinderbore. If the valves are placed perpendicular as shown in Fig. 32 they still may overlap the cylinderbore, though in a less degree. The surface of near approach therefore in this construction decreases materially, and therefore also the turbulence, created by a passage of greater diameter than that shown in Figs. 34 and 31. Fig. 33 represents the horizontal position through a cylinder and modified cylinderhead.

In Fig. 33, two throats are shown, one for the inlet valve, one for the outlet valve. The horizontal section of the top of the cylinderhead and upper surface of piston shows that the area of close approach has an entirely different form. There are consequently two combustion chambers opposite each other in every single cylinder, and the inlet valve and exhaust valve of every single cylinder have a slant towards each other, equal to that of the two sets of two valves for two cylinders, in staggered relation, as shown in Fig. 36. The single piston will have two curved-up portions at opposite points of the single piston in the single cylinder, and the spark-plugs, one for each chamber will have a position opposite each other. All these different parts of a single cylinder will resemble in vertical section very much the phantom section of two cylinders shown in Fig. 36. The two throats 20 in the single cylinder, which can be supposed to have a diameter as the overlapped diameter of the two pistons of Fig. 36, will be located in the same relative position. The function however of these two throats will be also turbulence-creating, but their relation to the respective valves are fundamentally different, a subject matter into which we will not delve further in this application.

Finally, I wish to point out that the plane A of the cylinder 1, and the plane B for cylinder 4 are here similarly located as in Fig. 35, and also the plane C midway therebetween, and plane D to the left of these three planes, as explained before.

Finally, I will consider the mechanical contrast of the Figures 35 and 36, (after having them considered in relation to the other

figures with respect to the planes A, B, C, and D), with respect to uniform combustion chambers and the way the valves should be lifted and should be located.

Fig. 35 shows the application of the L-head construction on the varieties A and B, and Fig. 36 shows the valve-in-head construction applied on the same two varieties. Their difference is of no importance with respect to variety C. It is well known in the prior art, that in an aligned arrangement of cylinders either construction will result in uniform combustion chambers for all the cylinders.

In Fig. 35, the left cylinder is in the plane A, the right cylinder 4 (we take the four cylinder of Figs. 1 and 5 as an example) in dotted lines represented in plane B. The valves, inlet and exhaust valves, (as can be seen from Fig. 30, of which the first cylinder 1 shows the upper end of the cylinder and the undersurface of the cylinderhead in shaded cross section, showing in horizontal section at the same time the area of the restricted passage 20 of Fig. 35, but not in vertical section) (resp. 11 for cylinder 1, 12 for cylinder 4), are so arranged that their axes coincide in the axis of the camshaft 9. These axes are respectively for cylinders 1, 16, for cylinders 4, 17. It can be clearly seen in said Figure 35 that the cylinder axes are parallel to each other, but that the axes of the valves have a different slant towards the axes of the cylinders resulting in combustion chambers of varying form, and inlet passages offering varying resistance to the fresh gases and exhaust gases, which will result in uneven operation of the respective cylinders. It is here supposed and shown that the respective combustion chambers are exactly on the same level, resulting in valvestems of two varying lengths for the two sets of cylinders, resulting in more costly construction. The connecting rods of these two sets of cylinders are equally of varying length and increase the cost of construction but this feature is also common to Fig. 36, discussed later on. Although this construction for the two varieties A and B is not advisable and should be replaced by the construction of Fig. 36 with an overhead camshaft, I will point out a few details, which may be applied on this L-head construction for the variety C, in which they will be very useful.

It is well known in the art, as is explained f. i. in the Patent 1,474,003 to H. R. Ricardo, that a convenient way to effect a turbulence in the fresh gases at the end of the compression period is to have the piston top approach the cylinderhead very close. In said patent this has been effected by making a depression in the cylinderhead thereby producing a throat or restricted passage between the cylinderbore and the combustion chamber in the head, which throat produces in itself already a turbulence during the entire com-

pression period, apart from the squeezing effect between piston and cylinderhead. In the present arrangement of Fig. 35, however, the cylinderhead is not depressed, but the piston protrudes into the cylinderhead and approaches the under-surface of said head very close. An advantage of this construction is that the area of near approach between piston and cylinderhead can be maintained much greater in relation to the cylinderbore than in the arrangement of said patent. However, the throat is here located at a slant midway horizontal position, (as shown in said patent) and vertical position. The explosion force, however, exerts a certain pressure on the piston, which may be used advantageously with respect to piston slap, but this would lead us too far. What I want to point out is that this construction has certain advantages with respect to the staggered arrangement of the cylinders, as the piston protruding into the cylinderhead can have the upcurved portion 24, in order to eject the fresh gases in the direction of the spark plug 21 and the upper surface of the cylinderblock can be at the same level for all the staggered cylinders, the valves being with their upper surface at a slant below the upper surface of the cylinderblock, even if the combustion chambers were here somewhat on a different level. This combustion chamber approaches more the spherical form than the standard Ricardo head, which feature affects the ratio between wall surface and volume of explosion chamber, affecting directly the thermal efficiency of the engine. In said patent, it is also emphasized to increase that ratio in favor of the volume.

That means the wall surface should be as little as possible in relation to the volume. In this respect, it can be seen very clearly that the present chamber of Fig. 35 has very distinct advantages. The inlet and exhaust gases have further an easier entrance and exit, as the valves are located below the restricted passage 20. In this respect Fig. 36 is even more superior, as will be seen from the following explanation.

Considering now Fig. 36, it is seen that the combustion chambers for the two varieties A and B can be made uniform, in contrast with those of Fig. 35. The slant of the axes of the valves 11, 12, resp. 16, 17 towards the axis of the camshaft 9 is identical, the length of the valves will be identical. The ratio between wall surface and volume of explosion chambers will be the same, (being more favorable than that of Fig. 35), the fluid resistance of the angle of the valves of all the cylinders will be the same, which identity favors highly the regular and efficient operation of the highly sensitive gasoline engine (and also Diesel engine). The length of the connecting rods 18 and 19, only will be different as the combustion chambers are here,

as in Fig. 35 placed by preference on exactly the same level. Figs. 35 and 36 both representing the cylinders 1 and 4 of the combination of cylinders, crankpin arrangement, and crankshaft position, of Figs. 1 and 5.

Here again the combustion chamber has been constructed for turbulence. Here, however, the throat is located in a horizontal position as in said Ricardo patent, but the location of the valves are fundamentally different from those of Fig. 35 in said Ricardo patent. The valves are placed above the throats of said respective cylinders, thereby eliminating two curves, which the gases have to make in their way out and in the cylinder as shown in Fig. 35 in said Ricardo patent. Apart from the ratio between the cross section of the valves and the cross section of the throats, this feature in itself will greatly decrease the skin-friction of the gases and increase therefore in itself the volumetric efficiency of said valves irrespective of their area-ratio. In addition thereto, however, this ratio has been made such that the throat 20 of Fig. 36 approaches the axis of the cylinder as shown in Fig. 31, and even may pass it as shown in Fig. 32.

In said patent lines 88-93, page 1, and lines 30-34, page 2, state definitely in accordance with the drawings thereof that the throat is about equal to the passage of the inlet port. It is well known in the art, that it is much easier under any circumstance to get rid of the exhaust gases than to get the gas in the cylinders. I have found, however, that this ratio is wrong and that the second throat located between the explosion space and cylinderspace should be at least 20° greater than the effective passage of the inlet valve. For that reason the throat in Fig. 35 was increased by increasing the horizontal cross section, which, as can be seen in cyl. 1 of Fig. 30, is very small, about equal to that shown in said Ricardo patent, by an additional vertical area as can be seen from Fig. 35, which combined area is greatly in excess of the areas of the inlet valve, even not considering the resistance of the valve itself in said inlet passage. In Fig. 36, the horizontal section of said throat 20 is greater than that shown in said patent, but nevertheless, the area may be smaller or greater than that shown in Fig. 35. This difference (if smaller), however, is easily compensated for by the specific position of both valves, the inlet and the exhaust valve, above said throat diminishing thereby, as already, said, greatly the friction of the entering gases especially. The exhaust valve will benefit also thereby, but, as explained, this is of less importance in view of exhaust-volumetric-efficiency of the fourcycle operation of the engine, but is of extreme importance in view of the tempera-

ture of said valve, which temperature affects again to a great extent the permissible compression ratio without serious tendency to detonation.

6 The piston can be provided also in this arrangement with the curved up portion 24, which directs the gases, squeezed, between the top 13 of the piston in top position, and the undersurface 15 of the head, towards the
10 sparkplug 21 in horizontal position. The pistons 13 and 14 can again protrude in to the cylinder heads 15 (this number indicates the head as such, as well as its specific undersurface as indicated by the lead) which construction simplifies greatly the castings and
15 their assembly and facilitates the cleaning of carbon from the piston heads. The heat of the explosion is extreme only during the first part of the expansion after the beginning of the explosion and continues for some time
20 while the shaft rotates 6-30 degrees depending upon the richness of the mixture. Extreme rich and extreme poor mixtures burn slowly, especially the latter. This part of the combustion chamber absorbs considerably
25 more heat than the barrel of the cylinder, and for this reason expands more than said barrel. The upper part of the cylinder remains now cooler and the lubrication of the top part thereof is improved, even if the piston goes only as far as the top of the barrel, without protruding in the head. This recess
30 in the head however should not exceed $\frac{1}{8}$ of an inch and should not be less than $\frac{1}{16}$, as carbon accumulates, and this space should not be filled up by carbon. Resuming the relation between valve arrangement and cylinder arrangement of only variety A and B (C is irrelevant here only) it is seen that
35 the arrangement of Fig. 36 has all advantages over Fig. 35, and the other advantages resulting from said position in connection with the form of combustion chambers, and other thermodynamical points, worth serious
40 consideration, are also in favor of the latter construction.

It is further supposed for the varieties A and B, in which the cylinders are arranged in two planes, that said cylinders
50 may be also arranged at a small angle, as proposed in my two previous applications Nos. 753,609 and 753,608. The former representing the same type as variety A here with parallel cylinders, the latter representing
55 here with parallel cylinders the variety B. In variety C the cylinders cannot be at an angle. The position of the crankshaft in the plane of only one cylinder group above the line of intersection of the planes of the
60 two groups, can be here applied in the same way, though the intersection of the planes, of course, falls here away.

Claims:

65 1. In a six-cylinder internal combustion engine, having a crankshaft with six crank-

pins with such firing orders as are compatible with an engine with a standard arrangement of aligned cylinders and a crankpin-arrangement whereby the crankpins are symmetrically arranged with respect to a single
70 vertical plane through the approximate center thereof perpendicular thereto, said firing orders having unequal intervals, one interval being greater than 720° divided by six, the next interval being smaller than 720° divided
75 by six, and so alternately, said crankpins so arranged that the crankpins 1 and 6, 2 and 5, 3 and 4 are aligned in pairs at 120° and adjacent to each other in pairs as seen in end view, said irregularity smaller than 720°
80 divided by twice the number of crankpins, said engine having cylinders 1, 3, 5 in one plane, cylinders 2, 4, 6 in another plane.

2. In a six-cylinder internal combustion engine having a firing order equal to that
85 of the standard engine, of six aligned cylinders and a crankshaft having its crankpins 1 and 6, 2 and 5, 3 and 4 aligned in said pairs at 120° as seen in end view, said first engine however having irregular firing intervals, one
90 interval being greater than 720° divided by six, the other following interval smaller than 720° divided by six, said irregularity not smaller than 720° divided by twelve, said engine having resp. cylinders 1, 3, 5 and 2, 4, 6 in two planes.

3. In a six-cylinder engine, having irregular firing orders, having firing intervals greater and smaller than 720° divided by the number of crankpins, said firing orders being, however, equal to those of a standard
100 six cylinders, having its cylinders arranged in line and having a crankshaft of which the crankpins 1 and 6, 2 and 5, 3 and 4 are aligned in pairs at 120° , as seen in end view, said first engine having however its cylinders
105 arranged in two planes and its crankpins arranged in the same way as said second engine, said arrangement resulting in irregular firing intervals, said irregularity not
110 exceeding the cycle of operation of said engine, expressed in degrees, divided by the number of crankpins.

4. A six-cylinder engine, having a crankshaft of which the crankpins are arranged in
115 $n/2$ radial planes through the axis of said shaft n being the number of crankpins, having cylinders arranged in two planes, said first arrangement of crankpins and said second arrangement of cylinders, resulting in
120 irregular firing intervals, said irregularity smaller than the cycle of operation of said engine, expressed in degrees of rotation, divided by twice the number of crankpins
125 of said engine, said crankshaft axis placed in the left plane, if said shaft rotates clockwise.

5. In a six-cylinder engine, a crankshaft of which the crankpins 1 and 6, 2 and 5, 3 126

and 4 are adjacent to each other at an angle of 120° in aligned pairs as said, said crankpins numbered successively from one end of the shaft to the other end thereof, said engine
5 having its cylinders arranged in two planes, said crankshaft axis placed in the left plane, if said crankshaft rotates clockwise.

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