PATENT SPECIFICATION

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PROVISIONAL SPECIFICATION.

Improvements in Multi-Cylinder Internal-Combustion Engines of the Opposed-Piston Type.

We, HERBERT PENWARDEN, of 52, The Rise, Hillingdon, in the County of Middlesex, a British subject, and JOHN KINGCOME, K.C.B., Engineer Vice Admiral, Engineer-in-Chief of the Fleet, Admiralty, S.W.1, a British subject, do hereby declare the nature of this invention to be as follows:—

This invention relates to a method of obtaining control of the lead of one piston over the other in opposed-piston engines in order to improve the exhausting and scavenging and with special reference to engines of triangular form. It is known that the most economical use of space in opposed-piston engines is achieved by making the complete engine of triangular form, comprising three crankpins, three cylinders and six pistons in each transverse plane, the crankshafts being placed at the apices of the triangle. In order to function correctly one crankshaft must rotate in the opposite direction to the other two crankshafts and the inner dead centre firing position of the third cylinder will be the sum of the sequences of the inner dead centre firing positions of the other two cylinders. From this it will be seen that in a reversible engine the two crankshafts which rotate in the same direction will each rotate through 45° from the dead centre firing position of No. 1 Cylinder to the dead centre firing position of No. 2 Cylinder and through another 45° from the dead centre firing position of No. 2 Cylinder to the dead centre firing position of No. 3 Cylinder during which time the oppositely rotating crankshaft will move through 90° from the dead centre firing position of No. 1 Cylinder to the dead centre firing position of No. 3 Cylinder, in other words the engine will be in the form of a right angle isosceles triangle. There will be no lead or lag of the pistons for port timing when working on the two stroke cycle of operation.

It has been proposed to make engines of equilateral triangle form, thus to comply with the fundamental essential that the sum of the two firing angles of the similarly rotating cranks equal the firing angle of the oppositely rotating crank, it is necessary to have a firing interval between cylinders No. 1 and No. 2 of 40° and between cylinders No. 1 and No. 3 of 80°. This entails a lead of one piston (the exhaust for better timing) over the other piston in each cylinder of 20°. The angles between the cylinders are 60° and for any triangle other than a right angle isosceles triangle the lead of one piston over the other will be the sum of the two angles where the cranks rotate in the same direction, minus the third angle where the crank rotates in the opposite direction and the product divided by three.

In practice it is found desirable with two-stroke cycle operation for the exhaust piston to have a lead over the scavenge piston, but it is undesirable for this lead to be as much as 20° which is necessitated by the equilateral triangle form.

It is therefore proposed in this invention to use lesser leads of the order of 40° to 10° or thereabouts for reversible engines and of the order of 10° to 18° or thereabouts for non-reversible engines. Thus in an engine with an exhaust piston lead of 10° over the scavenge piston, the angles of the triangle will be 52½°, 52½°, and 75°, the equation being $52\tfrac{1}{2}^\circ \times 2 = 105^\circ - 75^\circ = 30^\circ \div 3 = 10^\circ$ lead.

Also for example with 18° lead the angles will be 58½°, 58½° and 63° the equation being $58\tfrac{1}{2}^\circ \times 2 = 117^\circ - 63^\circ = 54^\circ \div 3 = 18^\circ$ lead, and for 4° lead the angles will be 48°, 48° and 84°, the equation being $48^\circ \times 2 = 96^\circ - 84^\circ = 12^\circ \div 3 = 4^\circ$ lead.

In carrying this invention into effect it is proposed to make the engine in the form of an isosceles triangle of any proportion necessary to give the required lead angle for the piston controlling the exhaust ports over that of the piston controlling the scavenge ports, and to accommodate the greater length of one side of the triangle over the other two sides by either using longer connecting rods for these two pistons or by placing the connecting rod gudgeon pin further from the combustion end of the piston in these two pistons than in the other four pistons.

It will be understood that in reversible

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engines the exhaust piston will lead the scavenge piston for ahead running and lag behind the scavenge piston when running in the reverse direction and furthermore that each of the three crankshafts may have any number of crankpins arranged longitudinally, with corresponding numbers of cylinders and pistons.

Dated this 7th day of November, 1945.

W. WESTON.
Chartered Patent Agent
For the Applicants.

COMPLETE SPECIFICATION.

Improvements in Multi-Cylinder Internal-Combustion Engines of the Opposed-Piston Type.

We, HERBERT PENWARDEN, of 52, The Rise, Hillingdon, in the County of Middlesex, a British subject, and JOHN KINGCOME, K.C.B., Engineer Vice Admiral, Engineer-in-Chief of the Fleet, Admiralty, S.W.1, a British subject, do hereby declare the nature of this invention, and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to two-stroke multi-cylinder opposed-piston internal-combustion engines, with compression ignition or petrol injection and spark ignition, for marine vessels, aircraft, or heavy vehicles such as armoured military vehicles.

It can be shown that the most economical cylinder arrangement for a multi-cylinder opposed-piston engine from the point of view of frontal area and compactness is a transverse triangular arrangement and it has already been proposed to provide such an engine with the cylinders arranged so that their axes formed an equilateral triangle with a crankshaft at each corner.

The present invention arises out of a study of the operating conditions and requirements for engines having a triangular arrangement of cylinders and consists in the provision of a new range of triangular arrangement for the cylinders.

The invention is applied to a triple-crankshaft opposed-piston internal-combustion engine comprising one or more transverse sets of three cylinders, each set arranged so that the extended cylinder axes define a triangle with the corners of the triangle on the axes of the crankshafts which have crankpins each common to the respective two pistons of adjacent cylinder ends, and according to the invention the cylinder axes triangle is an isosceles triangle with a major angle between the equal sides of greater than 60° and not more than 90°.

The invention is illustrated by way of example on the accompanying drawings in which:—

Figure 1 is a transverse section through an engine on the axes of one triangular set of cylinders; and

Figure 2 is a diagram to illustrate the effect on performance of different major angles in the cylinder triangle.

In the engine section shown by Figure 1 are three exactly similar cylinders a^1, a^2 and a^3 arranged axially on an inverted isosceles triangle extending between the axes of three crankshafts b^1, b^1 and b^3. The crankshafts b^1 and b^2 rotate in the same direction which is opposite to that of b^3. The cylinders contain pistons c^1, c^2 and c^3 respectively which control air inlet ports d and pistons e^1, e^2 and e^3 respectively which control exhaust ports f. The pistons at adjacent cylinder ends are connected by connecting rods to crankpins in common and the greater length of the side of the triangle between the crankshafts b^1 and b^2 is accommodated by longer connecting rods. The cylinders each have a fuel injection valve g for two-stroke compression-ignition operation and the general construction of the engine being on well known lines will not be further described. It will, however, be understood that the set of cylinders shown by Figure 1 is only one transverse set of an engine having banks of cylinders on the lines of the triangle and thus comprising several transverse sets in tandem with crankshafts in common.

For an isosceles triangle opposed-piston engine to function properly one crankshaft must rotate in the opposite direction to that of the other two. Also in any set of cylinders the inner dead centre firing positions will all occur within one sector, which may be called the power sector, of a complete crankshaft revolution. In a complete engine the power sectors of the several sets of cylinders will be spaced so as to obtain the most even torque possible through each complete revolution. The firing interval between successive cylinders in each power sector of rotation may be expressed as an angular interval of crankshaft rotation. During a power sector the two crankshafts which rotate in the same direction will first rotate through the firing interval between the firing position of one of the equal side cylinders and the hypotenuse cylinder and then through the firing interval between the firing position of the hypotenuse cylinder and the other equal side cylinder whilst the other crankshaft will rotate through twice the firing interval in the opposite direction.

For example, in a right-angled isosceles set of cylinders the firing interval will be 45° and the power sector will be 90° starting with one equal side cylinder and ending with the other with the hypotenuse cylinder firing at the mid-point of the sector. A right-angled isosceles triangle arrangement of cylinders will function equally well in either direction and for this reason is a useful form, although having a 45° firing interval and triangular sets of cylinders anything less than an 8-set 24-cylinder engine would not give absolutely regular torque in the complete engine.

With a 90° major angle the firing interval angle equals the geometrical angle between successively firing cylinders in the power sector and the opposed pistons in each cylinder move exactly in phase without lead or lag of one piston over the other, each triangular set of cylinders being dynamically balanced. It is known, however, that higher efficiency can be obtained in an opposed piston engine by giving one piston a lead over the other. With any major angle other than 90° the firing interval is different from the angle between successively firing cylinders in the power sector and this entails a phase difference between the opposed pistons in each cylinder. The difference expressed as an angular interval of crankshaft rotation is one third of the difference between the sum of the two angles of the triangle where the crankshafts rotate in the same direction and the remaining angle.

As mentioned above, an equilateral triangular arrangement of cylinders has previously been proposed and this entails a phase difference angle of 20° which is one third of the difference (60°) between the sum of two of the angles and the other. A phase difference angle of 20° we consider to be excessive for efficient operation and the present invention resides in the provision of engines of the kind described with a major angle greater than 60° and not greater than than but including 90°.

The set of cylinders shown by Figure 1 has a major angle of 75° at the crankshaft b^3 which entails a phase difference angle of 10° as will be seen by deducting 75° from the sum (105°) of the angles at b^1 and b^2 and taking one third of the remainder (30°).

The phase difference means that in each cylinder one piston will lead the other in its movement toward and away from the inner end of its stroke and to obtain better port timing and thus higher efficiency in normal or ahead running the leading piston is made the exhaust piston. In Figure 1 it can be seen that in the cylinder a^1 the exhaust piston e^1 is nearer the mid-length of the cylinder than is the inlet piston o^1 and similarly in cylinder a^2 the exhaust piston is leading the inlet piston whilst in the cylinder a^3, which is at the firing position, although the pistons are equidistant from the mid-length of the cylinder the exhaust piston has commenced its outward stroke and the inlet piston has not quite completed its inward stroke.

The phase difference of the pistons and thus the efficiency of the engine can be made to meet requirements by selection of a suitable major angle for the triangle. A 90° major angle gives a fully reversible engine without phase difference and dynamically balanced in each triangular set. As the major angle is decreased towards 60° it passes through an optimum efficiency for one direction of rotation with a corresponding loss for the other direction of rotation but regularity of torque between the three crankshafts with fewer than eight transverse sets of cylinders becomes easier to obtain.

Figure 2 is a diagram in which efficiency, with exhaust piston lead, expressed as the percentage volume of air trapped between the opposed pistons after the ports are closed on the compression stroke is plotted against different major angles between 90° and 60°. From Figure 2 it can be seen that a 90° major angle gives a trapped volume greater than that of an equilateral 60° engine and that the highest trapped volume is obtained with a major angle of 75° with an exhaust piston lead of 10°.

Although a 75° major angle gives the highest efficiency in terms of trapped volume the major angle will in practice be selected to suit operating conditions, particularly to reduce to a minimum torsional vibration at given running speeds. In general, the major angle will be selected as large as possible for reversible engines to give as high an efficiency as possible in the reverse direction, whereas for non-reversible engines a smaller major angle will be selected to obtain the smoothest possible output torque.

Having now particularly described and ascertained the nature of our said invention, and in what manner the same is to be performed, we declare that what we claim is:—

1. A triple-crankshaft opposed-piston internal-combustion engine comprising one or more transverse sets of three cylinders, each set arranged so that the extended cylinder axes define a triangle with the corners of the triangle on the axes of the crankshafts which have crankpins each common to the respective two pistons of

adjacent cylinder ends, in which the cylinder axes triangle is an isosceles triangle with a major angle between the equal sides of greater than 60° and not more than 90°.

Dated this 27th day of August, 1947.
W. WESTON,
Chartered Patent Agent
For the Applicants.

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[This Drawing is a reproduction of the Original on a reduced scale.]

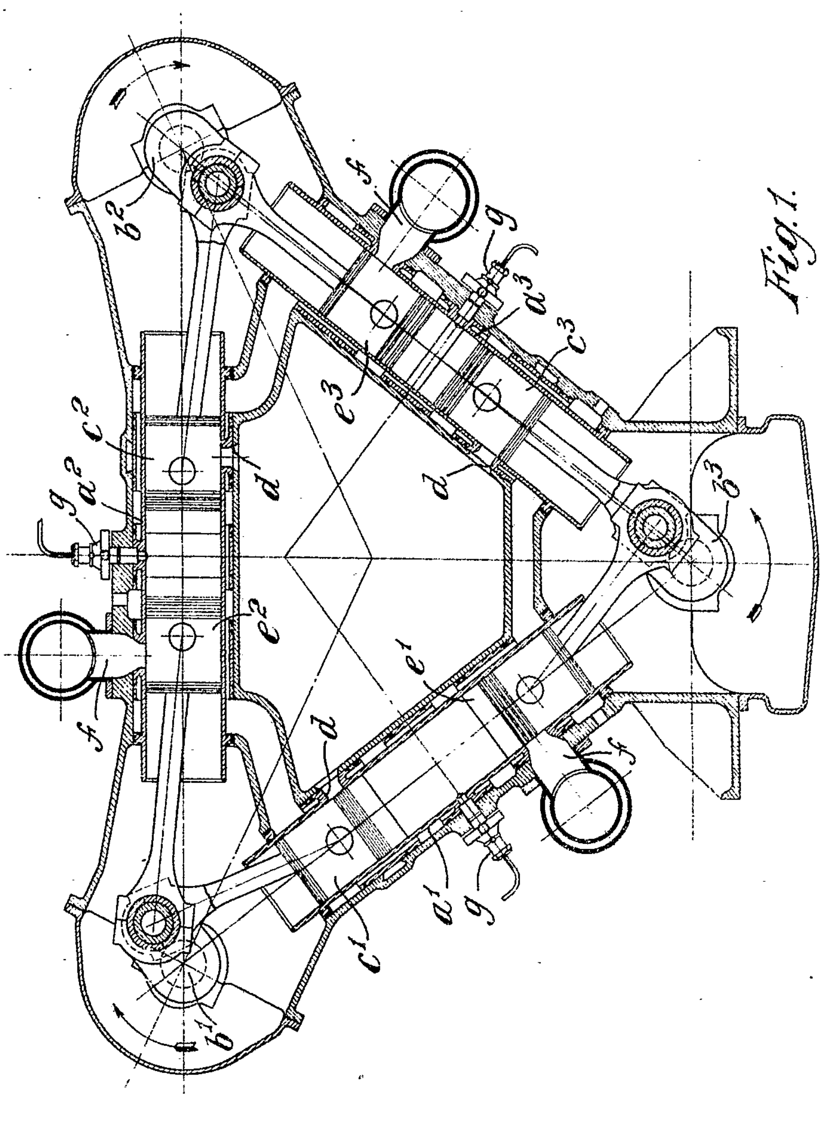

Fig. 1.

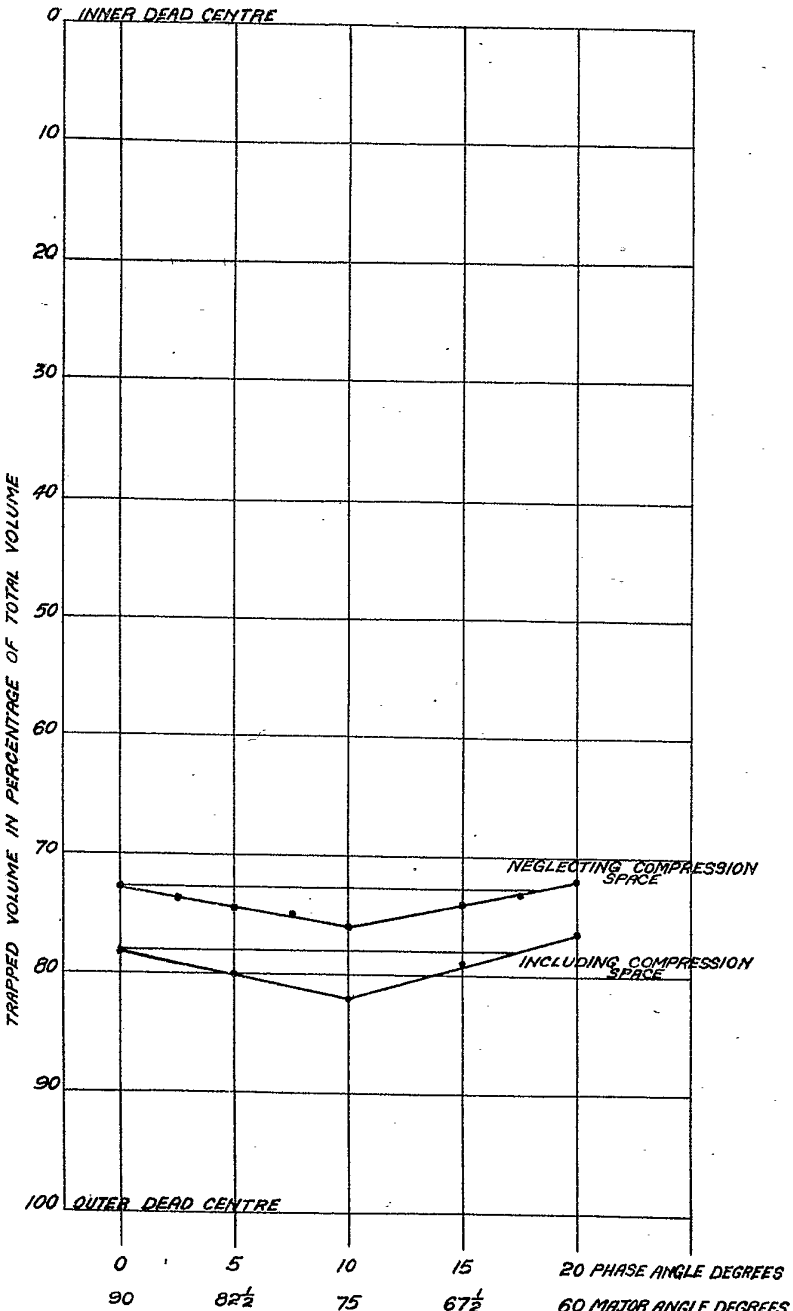
0 INNER DEAD CENTRE
10
20
30
40
50
60
70
80
90
100 OUTER DEAD CENTRE
TRAPPED VOLUME IN PERCENTAGE OF TOTAL VOLUME
NEGLECTING COMPRESSION SPACE
INCLUDING COMPRESSION SPACE
0
5
10
15
20 PHASE ANGLE DEGREES
90
82½
75
67½
60 MAJOR ANGLE DEGREES

Fig.2.