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On the Balancing of Two-Stroke 12-Cylinder Engines.

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Abstract.

Simultaneous explosions in two cylinders will occur in the two stroke engines of in-line, V or W type, provided the cylinders are arranged in the same way as in the four stroke engines. This paper discusses the arrangements of the cylinders and the forms of the crankshafts necessary in order that the two conditions—explosions at uniform intervals and balancing of inertia forces—may be fulfilled.

These objects can be attained in the 12-cylinder 90°-V and the 12-cylinder 60°-W type engines by using asymmetrical crankshafts.

1. Introduction.

With the recent development of high-speed heavy oil engines, many aeroengines have been made as experiments. At present most of them are of four-stroke cycle, although for heavy oil engines, there is no need of the four stroke. Since there are indications that the two stroke heavy oil engines will come into vogue before very long, it may be worth our while to investigate the methods of balancing two stroke engines.

With radial engines the methods of balancing are the same whether they are of two-stroke or four-stroke cycle. But simultaneous explosions in the two cylinders will occur in two stroke engines of in-line, V or W type, if the arrangement of the cylinders is the same as those of the four-stroke type. What is wanted is more uniform torque, but to arrange things so that the explosions occur at uniform intervals with simultaneous perfect balancing is no easy matter. The 12 cylinder V and W are the only practical types in which the two conditions—explosions at uniform intervals and perfect balance—can be fulfilled simultaneously.

2. Crankshaft of V-Type Engine.

Explosions at uniform intervals in a 12 cylinder engine are those that occur at every 30° of crank angle. For this purpose the explosions is one block of the engine must occur at every 60° of crank angle, so that the angle between the two blocks of V must be 30°, 90°, or 150°. In these engines, the 90°-V type is the only one that can be balanced almost perfectly.

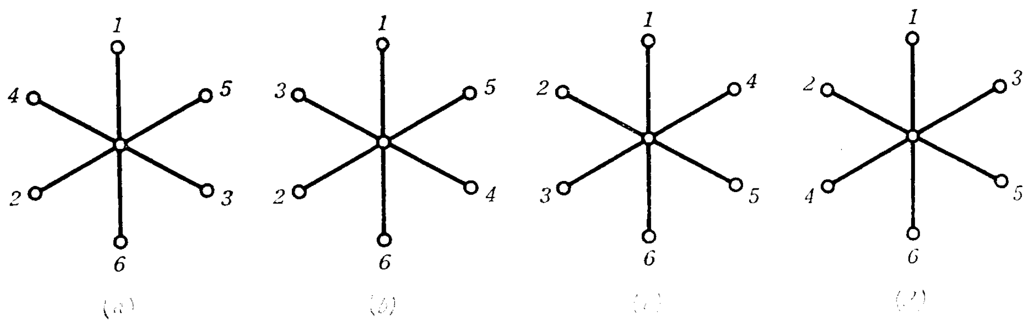

Fig. 1.

To cause the explosions at every 60° in one block, we must adopt a crankshaft in which the angles between the cranks are 60°. Of many such forms, those shown in Fig. 1–(a), (b), (c), and (d) have the characteristic that the couple due to the second harmonics of the inertia forces is zero. This is because cranks 1 and 6, 2 and 5, and 3 and 4 are opposite each other. But there are couples due to the primaries of inertia forces. These couples, however, can be easily balanced by means of suitable counter weights. Preferably, the couple to be balanced should be small, and from this point of view the best form is that shown in Fig. 1-(a). The inertia force and couple which remain unbalanced will now be computed for a crankshaft of this form.

3. Unbalanced Inertia Force of V-Type Engine.

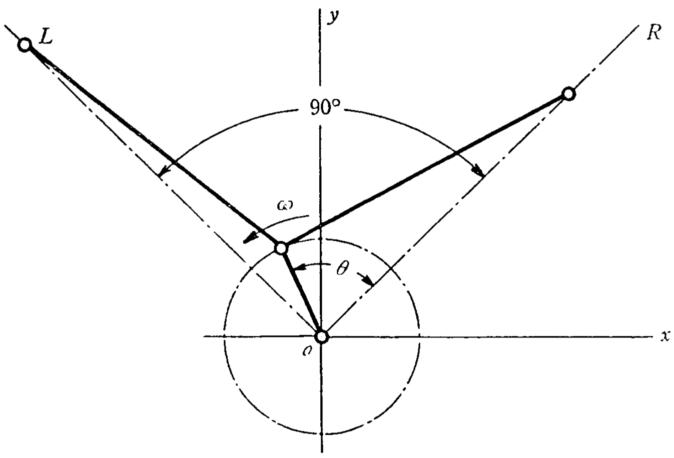

Fig. 2.

In Fig. 2, let

r = crank radius,

θ = angle of crank measured from right block,

ω = angular velocity of crank,

m_p = mass of piston,

m_c = mass of connecting rod,

m_k = equivalent mass of crank,

λ = ratio of length of connecting rod to the crank radius,

a = ratio of distance between the centre of gravity and the small end of connecting rod to the whole length,

b = ratio of distance between the centre of gravity and the big end of connecting rod to the whole length,

$X =$ inertia force in the direction of x,

$Y =$ inertia force in the direction of y,

whence

$$\left\{\begin{array}{l} \sum X = 6\sqrt{2}\,A_6(m_p + bm_c)\omega^2 r \cos 6\theta\,, \\ \sum Y = 0\,, \end{array}\right. \tag{1}$$

where $$A_6 = \frac{9}{128}\frac{1}{\lambda^5} + \frac{45}{512}\frac{1}{\lambda^7} + \cdots\cdots$$

As the value of λ for ordinary aeroengines is about 3.5, the value of A_6 is very small. The balance is usually considered perfect when the sums of the primaries and the second harmonics of the inertia forces are both zero. Since the only remaining unbalanced force here is the sixth harmonic, the balance may be considered perfect.

4. Inertia Couple of V-Type Engine.

As has already been explained, the crankshaft shown in Fig. 1 – (a) has the characteristic that the couple due to the second harmonics of the inertia forces is zero. As the couple due to the fourth and the sixth harmonics also become zero, the only couple to be balanced is that due to the primaries of the inertia forces.

Let x', y' be the axis of the crankshaft rotating with it as shown in Figs. 3 and 4, and M_x', M_y' the moments respectively about x' and y'. Assuming that the distances between the cylinders are equal, and denoting them by d, we have

$$\left\{\begin{array}{l} M_x' = 2\sqrt{3}\,d\left\{m_p + (2a+b)m_c + m_k\right\}\omega^2 r\,, \\ M_y' = 0\,. \end{array}\right. \tag{2}$$

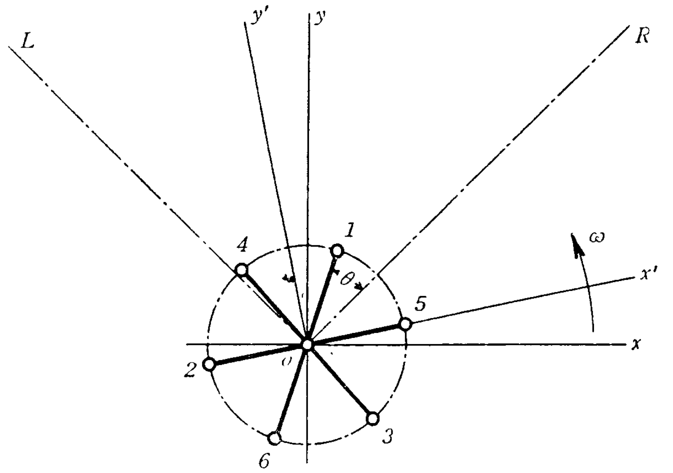

Fig. 3.

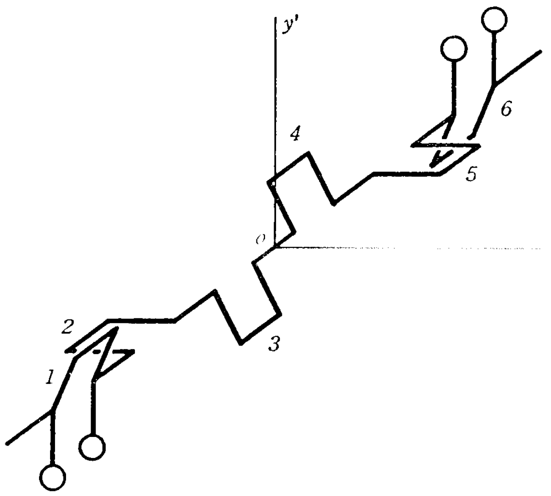

Fig. 4.

The magnitude of the moment M_x' is proportional to ω^2, and does not depend on the position of the crank. Such a moment can be balanced by fixing counter weights in the plane perpendicular to x'.

There are however several ways of attaching the counter weights. From considerations of lightness they should be placed as far as possible from the axis of rotation, while the distanee separating the counter weights should be as great as possible. We shall assume that counter weights have been affixed to the first and the sixth cranks as shown in Fig. 4. Let their masses be m_w, and their distances from the axis of rotation r_w, then

$$m_w = \frac{2\sqrt{3}}{5}\frac{r}{r_w}\left\{ m_p + (2a+b)m_c + m_k \right\}.$$

Mass m_w is not very great.

Thus the masses of the counter weights are easily calculated from (2), and a perfect balance obtained by attaching these counter weights to the crankshaft. After the crankshaft is made, however, it is well to test whether they have been made accurately or not. For the purpose of this test, six weights are first made, the masses of which are exactly equal to $m_p+(2a+b)m_c$. One of these weights is affixed to each crank pin. If the counter weights are correct, the crank shaft, with masses of $m_p+(2a+b)m_c$ at each crank pin, will then balance perfectly. Therefore by testing its balance with a balancing machine it is possible to ascertain the remaining unbalanced couple, if any, and correct it until the balance becomes perfect.

5. Crankshaft of W-Type Engine.

To cause explosions at every 30° of crank angle in a 12-cylinder W type engine, the explosions in one block should occur at every 90°, and the angles between the blocks must be 30° or 60°. Between these two angles a 60°–W type engine can be balanced almost perfectly.

The explosions in one block should occur at every 90°, and for this purpose is used a crankshaft in which the angles between the cranks are 90°. There are several forms of these. A good form of crankshaft is that shown in Fig. 5. Its characteristic is that the couple due to the second harmonics of the inertia forces is zero.

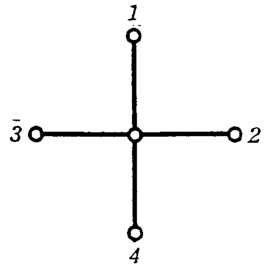

Fig. 5.

6. Unbalanced Inertia Force of W-Type Engine.

Assuming for the sake of brevity that three connecting rods of the same form are assembled on one crank pin; then, referring to Fig. 6, we have

$$\left\{\begin{aligned}\sum X &= 6A_4(m_p+bm_c)\omega^2 r\sin 4\theta\ ,\\ \sum Y &= 2A_4(m_p+bm_c)\omega^2 r\cos 4\theta\ ,\end{aligned}\right. \tag{3}$$

where $$A_4=-\frac{1}{4}\frac{1}{\lambda^3}-\frac{3}{16}\frac{1}{\lambda_5}-\frac{35}{256}\frac{1}{\lambda^7}\cdots\cdots\cdots$$

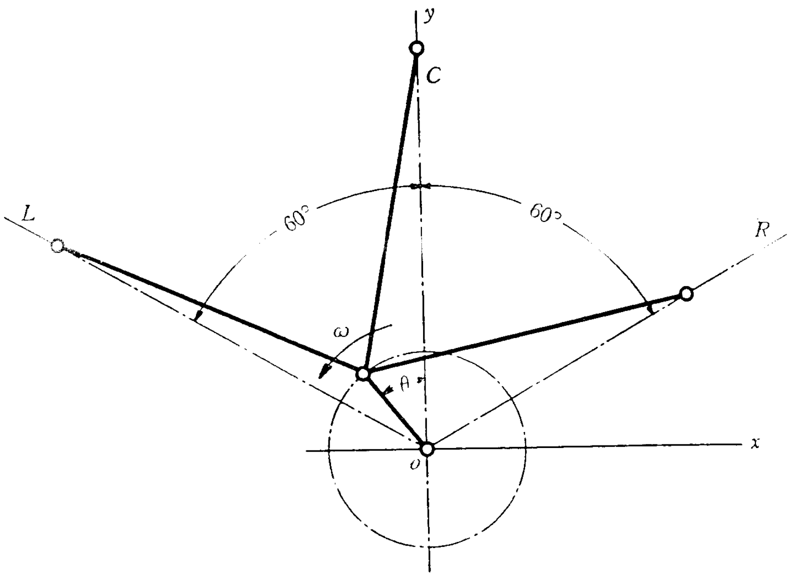

Fig. 6.

Thus the only remaining unbalanced force is the fourth harmonic, which is very small.

7. Inertia Couple of W-Type Engine.

All the couples due to the harmonics of inertia forces become zero except that due to the primaries. Let x', y' be the axis of the crank-shaft as shown in Figs. 7 and 8. Assuming that the distances between the cylinders are equal, we have

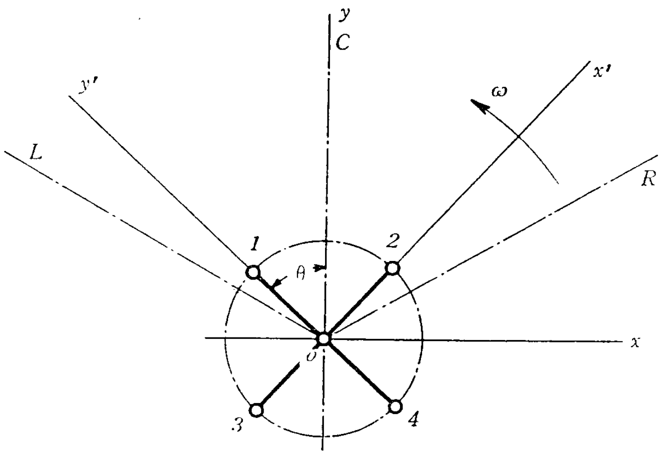

Fig. 7.

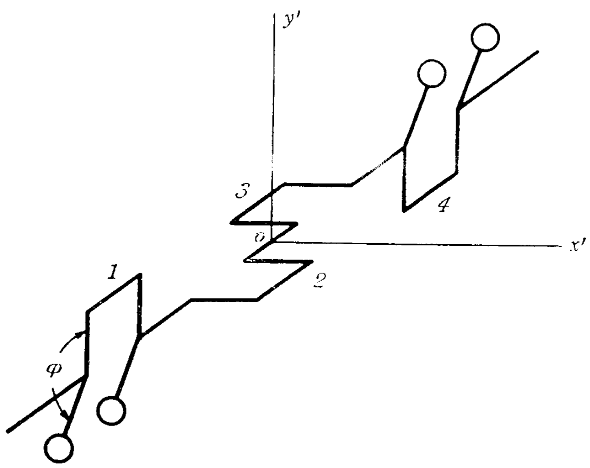

Fig. 8.

$$\left\{\begin{aligned} M_x' &= -3d\left\{\frac{3}{2}m_p + 3\left(a+\frac{1}{2}b\right)m_c + m_k\right\}\omega^2 r\,, \\ M_y' &= d\left\{\frac{3}{2}m_p + 3\left(a+\frac{1}{2}b\right)m_c + m_k\right\}\omega^2 r\,. \end{aligned}\right. \tag{4}$$

The moments are proportional to ω^2 and do not depend on the position of the crank, hence they can be easily balanced by attaching counter weights. Referring to Fig. 9, the magnitude of the resultant moment and its direction are

$$\begin{aligned} M &= \sqrt{10}\,d\left\{\frac{3}{2}m_p + 3\left(a+\frac{1}{2}b\right)m_c + m_k\right\}\omega^2 r\,, \\ \varphi &= \tan^{-1}\left(-\frac{1}{3}\right). \end{aligned} \tag{5}$$

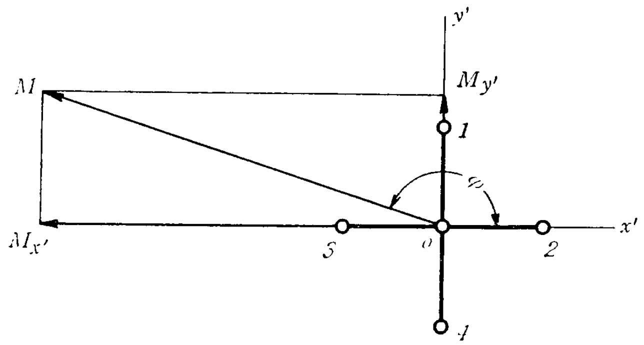

Fig. 9.

A perfect balance is obtained by the use of counter weights which balance the moment expressed by (5). There are several ways in which the counter weights may be attached. Fig. 8 shows them affixed on the first and the fourth cranks.

To test the balance of the crankshaft with a balancing machine, it is necessary, as can be easily seen from (4), to place on each crank pin a mass of $\frac{3}{2}m_p + 3\left(a+\frac{1}{2}b\right)m_c$.

Tôkyô, July, 1932.