Dec. 13, 1960 R. J. MEIJER 2,963,854

HOT-GAS RECIPROCATING ENGINE

Filed March 9, 1959 2 Sheets-Sheet 1

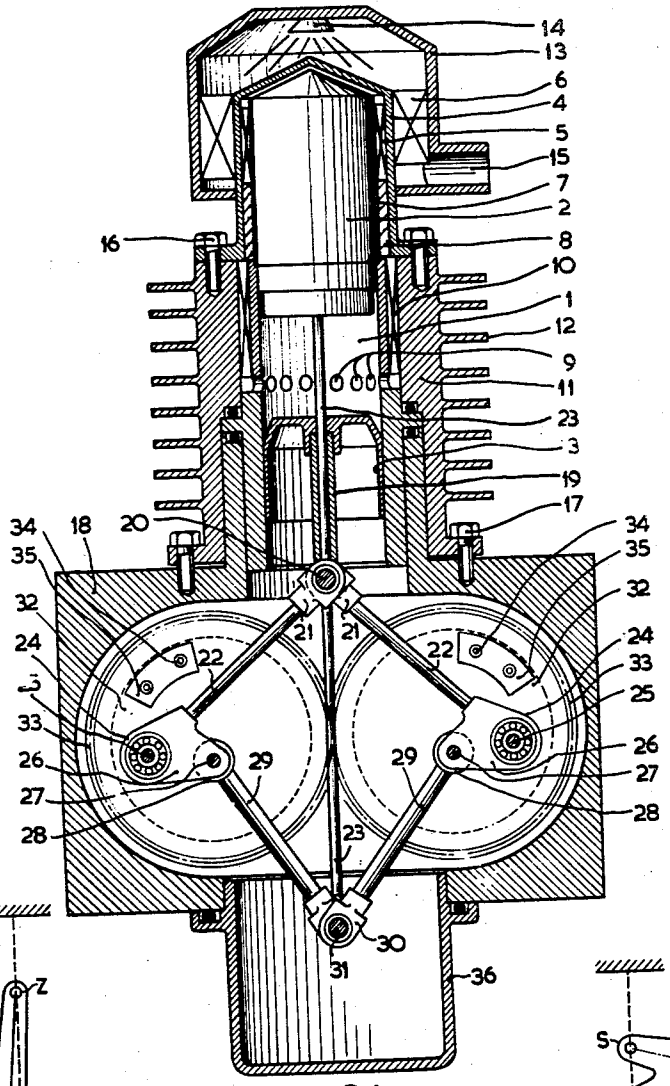


FIG.1

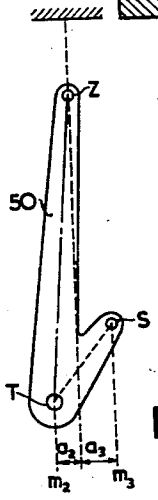


FIG.2

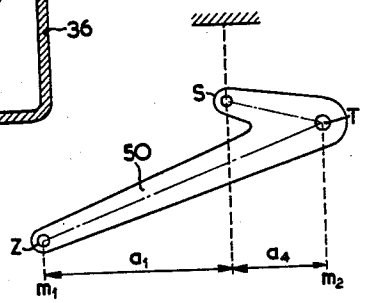


FIG.3

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HOT-GAS RECIPROCATING ENGINE

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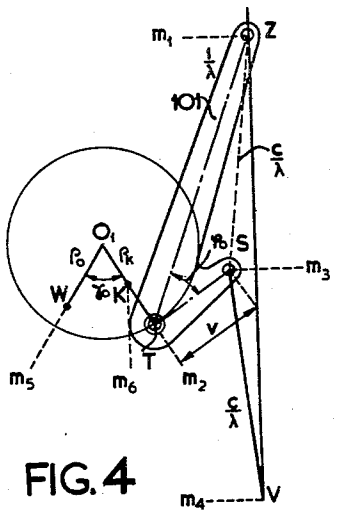


FIG. 4

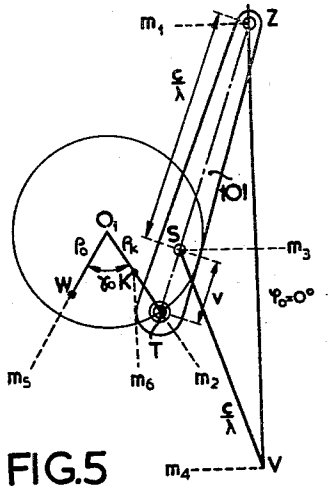


FIG. 5

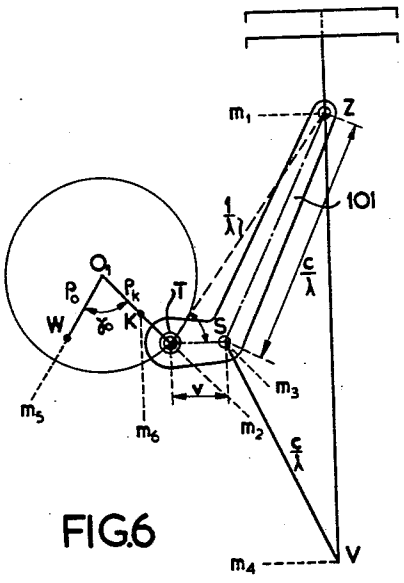


FIG. 6

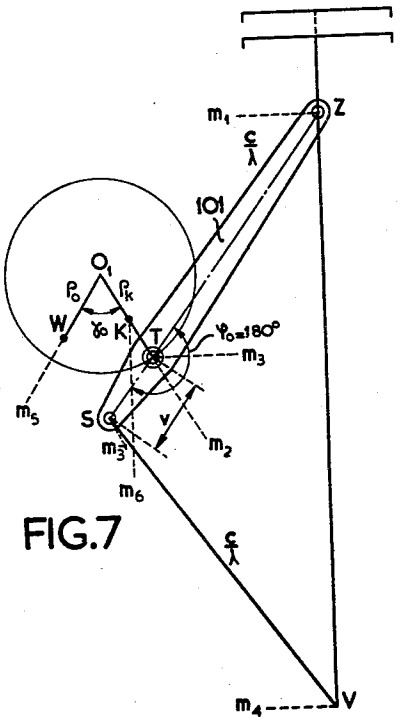


FIG. 7

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United States Patent Office 2,963,854 Patented Dec. 13, 1960

2,963,854

HOT-GAS RECIPROCATING ENGINE

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Filed Mar. 9, 1959, Ser. No. 798,140

Claims priority, application Netherlands Mar. 28, 1958

2 Claims. (Cl. 60—24)

This invention relates to hot-gas reciprocating engines of the displacer type. It is known for such engines, which are to be understood to mean both hot-gas reciprocating motors, cold-gas refrigerators and heat pumps, the last-mentioned two engines operating on the reverse hot-gas motor principle, to be designed so that such an engine comprises two identical cranks located on each side of a plane passing through the centre line of the engine, which cranks form parts of two relatively synchronous crank shafts which rotate with the same phase and in opposite senses and are provided with counterweights, the centre lines of said crank shafts being located parallel and symmetrically on each side of said plane through the centre line of the engine in a plane at right angles to the plane passing through the centre line of the engine, the couplings between the piston and the displacer and the cranks on the crank shafts each including a piston driving rod or a displacer driving rod. The piston driving rods are of equal length and so are the displacer driving rods. The parts of the piston driving rods moving rectilinearly are located on one side of the plane passing through the centre lines of the crank shafts, and the correspondingly moving parts of the displacer driving rods are located on the other side thereof, and in each half of the engine located on one side of a plane passing through the centre line of the cylinder, one of the driving rods present there has two pivots and a centre of rotation, the latter applying to the crank, whereas the other driving rod has only two pivots, the first-mentioned driving rod being coupled at its rectilinearly moving pivot to the piston or the displacer, whereas the second pivot of this driving rod co-acts with one pivot of the driving rods having two pivots, of which the other pivot, likewise moving rectilinearly, is coupled to the displacer or the piston.

In an engine of the kind described above, the required phase difference between the movement of the displacer and the movement of the piston is obtained in a simple manner. Furthermore, the engine may be balanced relatively very well.

In this known engine, it would be necessary for obtaining complete balancing that the two driving rods each have a centre of rotation by means of which they can rotate about the same crank. This embodiment has structural disadvantages, so that in the known engine one driving rod has two pivots and a centre of rotation and the other driving rod has two pivots, the driving rods being coupled together at one pivot and hence only one driving rod applying to the crank of the engine. However, complete balancing cannot be obtained with this structurally attractive embodiment and with the specified dimensions of the driving rods.

It has been found that the possibility of complete balancing can nevertheless be obtained also in the structurally simple embodiment of known type, if, according to the invention, certain proportioning descriptions are followed.

The engine according to the invention is characterized

in that the distances between the pivots present on each driving rod are equal and that furthermore there applies the relationship:

$$m_1-m_4+\lambda v(m_3+2m_4)\cos\varphi_0=0$$

in which

m_1 is the mass concentrated at the point where the pivot of the driving rod having two pivots and one centre of rotation is coupled to the piston or the displacer and consisting of half the mass of the piston, the displacer and respectively of the piston rod or displacer rod when present, with the associated coupling mechanism, together with that portion of the mass of the driving rod which is obtained if this mass is divided over the centre of rotation and the pivots in accordance with the lever rule;

m_4=the mass concentrated at the point where the pivot of the driving rod having only two pivots is coupled to the displacer or the piston and consisting of half the mass of the displacer or the piston and of the displacer rod or piston rod when present with the associated coupling mechanism, together with that portion of the mass of the driving rod which is obtained if this mass is divided over the pivots in accordance with the lever rule;

m_3=the mass concentrated at the common pivot of the two driving rods and consisting of the portion of the mass of the driving rod having two pivots and a centre of rotation and the portion of the mass of the driving rod having only two pivots, both portions obtained in accordance with the rule given with m_1 and m_4;

λ=the radius of the crank, divided by the distance between the centre of rotation and the pivot associated with the same driving rod, which pivot is coupled to the piston or the displacer, the radius of the crank being assumed to be equal to unity;

v=the distance between the centre of rotation and the pivot associated with the same driving rod, to which the pivot of the second driving rod is coupled, divided by the radius of the crank, the latter assumed to be equal to unity, and

ρ_0=the angle which in the case of the driving rod having two pivots and a centre of rotation, is enclosed between the lines connecting each pivot and the centre of rotation.

In one embodiment of the invention, the angle γ_0 satisfies the equation:

$$\gamma_0=\pi-\arctan\frac{\lambda v(m_3+2m_4)\sin\varphi_1}{m_1+m_2+m_3+m_4+\rho_k m_6}$$

in which the mass m_5 of this counterweight which is concentrated at the centre of gravity of the counter weight is equal to

$$\frac{1}{\rho_0}\sqrt{(m_1+m_2+m_3+m_4+\rho_k m_6)^2+(\lambda v(m_3+2m_6)\sin\varphi_1)^2}$$

In the above equations γ_0=the angle which, if the centre of rotation lies on that side of the plane through the crank shafts which is opposite to the side where the pivot of the driving rod having two pivots and a centre of rotation coupled to the piston or the displacer is present and the radius of the crank is at right angles to said plane, is enclosed between this radius of the crank and the line connecting the centre of gravity of the counter-weight and the centre line of the crank shaft, as measured from the radius of the crank in a direction which, at least initially, extends from the centre line of the engine;

m_2=the mass concentrated at the centre of rotation and consisting of the portion of the mass of the driving-rod part of the driving rod having two pivots and a centre of rotation, obtained in accordance with the lever rule;

m_6=is the mass of the crank concentrated at the centre of gravity thereof;

ρ_0=the relative distance between the centre of the crank shaft and the centre of gravity of the counterweight

$$\frac{r_0}{r}$$

or the distance between the centre of the crankshaft and the centre of gravity of the counterweight divided by the distance between the centre of the crankshaft and the centre of the crank.

ρ_k=the distance between the centre of the crank shaft and the centre of gravity of the crank

$$\frac{r_k}{r}$$

or the distance between the centre of the crankshaft and the center of gravity of the counterweight divided by the distance between the centre of the crankshaft and the centre of the crank.

The term "lever rule" is to be understood, as usually, to mean the rule according to which the algebraic sum of the masses concentrated in the said points and multiplied by their lever arms, that is to say, in this case the distances between the points and two arbitrary lines passing through the centre of gravity and located in the same plane as the points projected in this plane, is zero with respect to said lines.

In order that the invention may be readily carried into effect, several embodiments will now be explained in detail, by way of example, with reference to the accompanying drawings, in which:

Fig. 1 is a cross-sectional view of a hot-gas reciprocating engine of the displacer type;

Fig. 2 shows a driving rod having two pivots and a centre of rotation, with masses concentrated at these points and suspended in a pivot, which figure serves to explain the term "lever rule";

Fig. 3 shows the driving rod of Fig. 2, but now suspended in another pivot;

Figs. 4, 5, 6 and 7 show diagrammatically four different embodiments of the driving mechanism.

Referring now to Fig. 1, reference numeral **1** indicates a cylinder of a hot-gas reciprocating engine in which a displacer **2** and a piston **3** are adapted to reciprocate. The upper end of the cylinder is constituted by a cylinder head **4** which has internal fins **5** and external fins **6**. A lining **7** separates the fins **5** and a regenerator **8** from the interior of the cylinder. The cylinder also has bores **9** which communicate with a space containing fins **10** secured to a body **11** which has external ribs **12**, the fins and the ribs constituting the cooling system. The cylinder head **4** is surrounded by a body **13** containing a burner **14** (shown diagrammatically). The combustion gases pass along the fins **6**, leaving the body **13**, after having dissipated their heat, through an outlet channel **15**. The cylinder head **4** is secured by means of bolts **16** to the body **11**, which is secured likewise by means of bolts **17** to a crank case **18**. By means of said bolts, the cylinder **1** is also rigidly joined to the crank case **18**. The piston **3** has a hollow piston rod **19**. Two heads **21** of two driving rods **22** can swing about a shaft **20**, which is rigidly secured to the piston rod **19**, a displacer rod **23** which is rigidly secured to the displacer being led through the piston rod **19** and the shaft **20**. The driving rods **22** also have two centres of rotation **24**, which can rotate about crank pins **25**. Ball bearings are provided between the centres of rotation **24** and the crank pins **25**. Rigidly secured to the centres of rotation **24** are plates **26**, provided with pins **27** about which two heads **28** of displacer driving rods can swing. At the other ends of the displacer driving rods **29** there are provided heads **30** which each can swing about a shaft **31** which is rigidly secured to displacer rod **23**. The crank pins **25** are provided eccentrically on shafts **32**, which are coupled together by means of gear wheels **33** and on which counter-weights **35** are arranged by means of screws **34**. The crank case **18** is closed by means of a cover **36** so that the whole crank case may be filled with oil, if desired.

The distance between the pivot **20** and the pivot **27** is exactly the same for the two piston driving rods and also exactly equal to the distance between the pivots **31** and **27** of the displacer driving rods; the angle φ_0 enclosed between the lines **27—25** and **25—20**, the weight of the counter-weight **35** and the angle γ_0 enclosed between the connecting line **27—25** and the line connecting the centre of gravity of the counter-weight **35** and the centre of the crank shaft **25** are determined in accordance with the equations specified hereinafter.

Figs. 2 and 3 show a driving rod **50** having a centre of rotation at T and pivots at points Z and S. The centre of rotation T is connected to the crank; the pivots Z and S are imagined to be connected to the piston and to the displacer respectively. It will be evident that the three masses m_a, m_b and m_c, which are imagined to be concentrated at the points Z, T and S, may readily be determined since the rod, if suspended at Z, is at rest, if the algebraic sum of the moments $m_b \times a_2$ and $m_c \times a_3$ with respect to the perpendicular through Z is zero and such is the case in Fig. 3, if $m_a \times a_1 = m_b \times a_4$, in which the rod is suspended at S. Furthermore, $m_a + m_b + m_c$ must be equal to the whole mass of the rod **50**.

Figs. 4, 5, 6 and 7 show diagrammatically four different embodiments of driving rods, it being assumed that the piston rod is connected to point Z and the displacer rod is connected to point V. The centre line of the crank shaft is indicated by O_1 and the crank pin bears the character T. Connected to the crank pin T is a driving rod **101**, of which the second pivot, to which the displacer driving rod is coupled, is indicated by S. The distance between the centre of rotation T and the pivot S is v, and the angle enclosed between ZT and TS is φ_0. The centre of gravity of the counter-weight bears the character W and the relative distance between W and O_1 is indicated by ρ_0. Similarly, K is the centre of gravity of the crank and ρ_k is the relative distance between K and O_1. The angle enclosed between WO_1 and KO_1 is γ_0. The masses m_1, m_2, m_3, m_4, m_5 and m_6 are imagined to be concentrated at the points Z, T, S, V, W and K. The length of the portion TZ of the driving rod is assumed to be equal to

$$\frac{1}{\lambda}$$

being the ratio between the distance O_1T divided by the distance TZ. The radius O_1T of the crank is regarded as a unit and assumed to be equal to unity. It can then readily be recognized that, according to the cosine rule,

$$ZS \times \lambda = \sqrt{1 - 2\lambda\nu \cos \varphi_0 + {}^2\nu^2}$$

ZS is indicated as c, so that:

$$c = \sqrt{1 - 2\lambda\nu \cos \varphi_0 \nu^2\lambda^2}$$

According to the invention, the distance SV is equal to the distance ZS. The masses m_1 and m_4 of the masses m_1, m_2, m_3, m_4, m_5 and m_6 consist of half the masses of the piston and the displacer and possibly of the piston rod and the displacer rod with the associated coupling mechanism, together with the weight of the driving-rod portion determined in accordance with the lever rule; m_3 is the sum of the weights of the driving rods after the allocation in m_1, m_4 and m_2; m_2 is the mass of the rod **101** concentrated at the centre of rotation in accordance with the lever rule; m_5 is the mass of the counter-weight concentrated at the centre of gravity W, and m_6 is the mass of the crank concentrated at the centre of gravity K thereof. The mass m_5 is determined by the equation

$$m_5 = \frac{1}{\rho_0} \sqrt{(m_1 + m_2 + m_3 + m_4 + \rho_k m_6)^2 + (\lambda\nu(m_3 + 2m_6) \sin \varphi_0)^2}$$

wherein ρ_0 is the relative distance from O_1 to W and ρ_k is the distance from O_1 to K.

Lastly, the angle between O_1W and O_1K, as indicated by γ_0, is determined by

$$\gamma_0=\pi-\arctan\frac{\lambda v(m_3+2m_4)\sin\varphi_0}{m_1+m_2+m_3+m_4+\rho_k m_6}$$

The driving rod ZST, indicated by **101**, has different shapes in Figs. 4, 5, 6 and 7. In Figs. 4 and 6, the rod is bent and in Figs. 5 and 7 it is rectilinear. Furthermore, in Figs. 4 and 7, the centre of rotation lies between two pivots, but in the case of the rod shown in Figs. 5 and 6, the centre of rotation lies at the end of the rod. Correspondingly, the angle φ_0 also has a different shape, φ_0 being acute in Fig. 4, but 0° in Fig. 5. In Fig. 7, φ_0 has a value of 180°. However, in Fig. 6, φ_0 is again an acute angle $=\angle ZTS$.

What is claimed is:

1. In a hot-gas reciprocating engine comprising a cylinder, a displacer within said cylinder, a piston within said cylinder and provided with a bore extending axially of the cylinder, means connecting said piston and displacer in an out-of-phase relationship, said means including counterweights comprising two members rotatably mounted on axes located one on each side of the axis of the cylinder, a pivot located eccentrically on each of said members, two piston connecting rods of equal length each having one end pivotally connected to said piston, two elongated crank members each rotatably mounted on one of said pivots, the free end of each of said piston connecting rods being pivotally secured to each adjacent crank member, a displacer rod having one end operatively connected to said displacer and extending through the bore of said piston, two displacer connecting rods of equal length, each having one end rotatably secured to the free end of said displacer rod and means pivotally securing the other end of each of said displacer connecting rods to one of said crank members at a point spaced from the adjacent pivot, each of the piston connecting rods having substantially the same length as each displacer connecting rod; the combination in which one of said connecting rods has two articulated pivots and a center of rotation about one of said crank members and another of said connecting rods has two articulated pivots only, said one connecting rod being coupled with its linearly moving pivot to said piston or said displacer while said other connecting rod coacts at one end with the second pivot of said one connecting rod, and a linearly moving pivot at the other end of said other connecting rod being connected to said displacer or said piston, the distance between the two pivots on each of said piston and displacer connecting rods being equal and for each half of said engine lying on one side of the said longitudinal plane of symmetry the following relationship applies:

$$m_1-m_4+\lambda v(m_3+2m_4)\cos\varphi_0=0$$

and that the angle γ_0 is equal to

$$\pi-\arctan\frac{v(m_3+2m_4)\sin\varphi_0}{m_1+m_2+m_3+m_4+\rho_k m_6}$$

whereas the mass m_5 of the counter-weight, concentrated in the center of gravity of the counter-weight, is equal to:

$$\frac{1}{\rho_0}\sqrt{(m_1+m_2+m_3+m_4+\rho_k m_6)^2+(\lambda v(m_3+2m_4)\sin\varphi_0)^2}$$

in which relations:

m_1=the portion of the mass of the connecting rod having two pivots and one centre of rotation, that is obtained, when the mass of this connecting rod is divided between the center of rotation and the two pivots in accordance with the lever rule and which is imagined to be concentrated in that pivot of this connecting rod, which is coupled, possibly by means of a coupling mechanism and/or a rod, to the piston or the displacer increased by half the mass of this piston or this displacer; and this coupling mechanism and/or rod;

m_2=the portion of the mass of the connecting rod having two pivots and a center of rotation, obtained in accordance with the lever rule, which is imagined to be concentrated in the center of rotation;

m_3=the portion of the mass of the connecting rod having two pivots and one center of rotation, increased by the portion of the mass of the connecting rod having only two pivots, both portions obtained by the lever rule and imagined to be concentrated in the common pivot of the two connecting rods;

m_4=the portion of the mass of the connecting rod having two pivots that is obtained, when the mass of this connecting rod is divided between the two pivots in accordance with the lever rule and which is imagined to be concentrated in that pivot of this connecting rod, which is coupled, possibly by means of a coupling mechanism and/or a rod, to the displacer or the piston, increased by half the mass of this displacer or this piston and of the coupling mechanism and/or the rod when present;

m_6=the mass of the crank, which is imagined to be concentrated at the center of gravity thereof;

ρ_0=the relative distance between the center of the crank shaft and the center of gravity of the counter-weight with respect to the radius of the crank $=r_0/r$;

ρ_k=the relative distance between the center of the crank shaft and the center of gravity of the crank pin with respect to the radius of the crank $=r_k/r$;

λ=the radius of the crank divided by the distance between the center of rotation of the connecting rod having a center of rotation and two pivots and the pivot of this connecting rod, which pivot is coupled to the piston or the displacer;

v=the distance between the center of rotation of the connecting rod having a center of rotation and two pivots and the pivot of this connecting rod, to which the pivot of the second connecting rod is connected, divided by the radius of the crank;

φ_0=the angle which, in the case of the connecting rod having two pivots and a center of rotation, is included between the lines connecting each pivot with the center of rotation;

γ_0=the angle which, if the center of rotation and measured from the line which connects the center of rotation with the pivot, is connected to the piston or displacer towards the longitudinal plane of symmetry of the engine lies on that side of the plane through the axis of rotation of the crank shafts which is opposite to the side where the pivot of the driving rod having two pivots and a center of rotation connected to the piston or displacer is present and the radius of the crank is at right angles to this plane, is enclosed between this radius of the crank and the line connecting the center of gravity of the counter-weight and the axis of rotation of the crank shaft, as measured from the radius of the crank in a direction which, at least intially, extends from the longitudinal plane of symmetry of the engine.

2. In a hot-gas reciprocating engine of the displacer type comprising a cylinder, a displacer within said cylinder, a piston within said cylinder and provided with a bore extending axially of the cylinder, means connecting said piston and displacer in an out-of-phase relationship and having two identical cranks located on each side of a plane of symmetry passing through the longitudinal center line of the engine, two crankshafts, said cranks being part of said two crank shafts and adapted to rotate synchronously with equal phases and in opposite directions, said cranks being provided with counterweights, the axes of rotation of said crankshafts being located parallel and symmetrically on each side of said plane of symmetry of the engine, said means including piston connecting rods and displacer connecting rods, the piston connecting rods being of equal length while the displacer connecting rods are also of equal length, and the recti-

linearly moving parts of the piston connecting rods being situated on one side of the plane in which the axes of rotation of said crankshafts are located and the correspondingly moving parts of the displacer connecting rods being located on the other side of said plane; the combination in each half of the engine located on one side of said plane of symmetry in which combination one of said connecting rods has two articulated pivots and a center of rotation about one of said cranks and another of said connecting rods has two articulated pivots only, said one connecting rod being coupled with its linearly moving pivot to said piston or said displacer while said other connecting rod coacts at one end with the second pivot of said one connecting rod, and a linearly moving pivot at the outer end of said other connecting rod being connected to said displacer or said piston, the distance between the two pivots on each of said piston and displacer connecting rods being equal and for each said half of the engine lying on one side of the said longitudinal plane of symmetry, the following relationship applies:

$$m_1 - m_4 + \lambda\nu(m_3 + 2m_4) \cos \varphi_0 = 0$$

and that the angle γ_0 is equal to

$$-\arctan \frac{\nu(m_3 + 2m_4) \sin \varphi_0}{m_1 + m_2 + m_3 + m_4 + \rho_k m_6}$$

whereas the mass m_5 of the counter-weight, concentrated in the center of gravity of the counter-weight, is equal to:

$$\frac{1}{\rho_0}\sqrt{(m_1 + m_2 + m_4 + \rho_k m_6)^2 + (\lambda\nu(m_3 + 2m_4) \sin \phi_0)^2}$$

in which relations:

m_1=the portion of the mass of the connecting rod having two pivots and one centre of rotation, that is obtained, when the mass of this connecting rod is divided between the center of rotation and the two pivots in accordance with the lever rule and which is imagined to be concentrated in that pivot of this connecting rod, which is coupled, possibly by means of a coupling mechanism and/or a rod, to the piston or the displacer increased by half the mass of this piston or this displacer; and this coupling mechanism and/or rod;

m_2=the portion of the mass of the connecting rod having two pivots and a center of rotation, obtained in accordance with the lever rule, which is imagined to be concentrated in the center of rotation;

m_3=the portion of the mass of the connecting rod having two pivots and one center of rotation, increased by the portion of the mass of the connecting rod having only two pivots, both portions obtained by the lever rule and imagined to be concentrated in the common pivot of the two connecting rods;

m_4=the portion of the mass of the connecting rod having two pivots that is obtained, when the mass of this connecting rod is divided between the two pivots in accordance with the lever rule and which is imagined to be concentrated in that pivot of this connecting rod, which is coupled, possibly by means of a coupling mechanism and/or a rod, to the displacer or the piston and of the coupling mechanism and/or the rod when present;

m_6=the mass of the crank, which is imagined to be concentrated at the center of gravity thereof;

ρ_0=the relative distance between the center of the crank shaft and the center of gravity of the counter-weight with respect to the radius of the crank $=r_0/r$;

ρ_k=the relative distance between the center of the crank shaft and the center of gravity of the crank pin with respect to the radius of the crank $=r_k/r$;

λ=the radius of the crank divided by the distance between the center of rotation of the connecting rod having a center of rotation and two pivots and the pivot of this connecting rod, which pivot is coupled to the piston or the displacer;

ν=the distance between the center of rotation of the connecting rod having a center of rotation and two pivots and the pivot of this connecting rod, to which the pivot of the second connecting rod is connected, divided by the radius of the crank;

φ_0=the angle which, in the case of the connecting rod having two pivots and a center of rotation, is included between the lines connecting each pivot with the center of rotation and measured from the line, which connects the center of rotation with the pivot, which is connected to the piston or displacer, towards the longitudinal plane of symmetry of the engine;

γ_0=the angle which, if the center of rotation lies on that side of the plane through the axis of rotation of the crank shafts which is opposite to the side where the pivot of the driving rod having two pivots and a center of rotation connected to the piston or displacer is present and the radius of the crank is at right angles to this plane, is enclosed between this radius of the crank and the line connecting the center of gravity of the counter-weight and the axis of rotation of the crank shaft, as measured from the radius of the crank in a direction which, at least initially, extends from the longitudinal plane of symmetry of the engine.

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