Jan. 17, 1939. M. KADENACY 2,144,065

INTERNAL COMBUSTION ENGINE

Filed Sept. 4, 1936 2 Sheets-Sheet 1

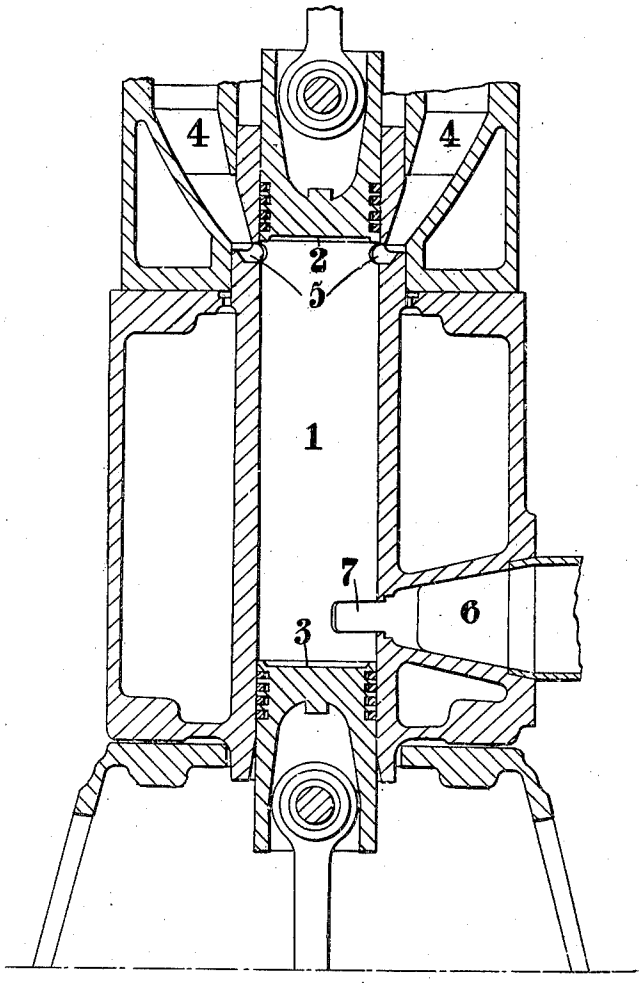


Fig. 1.

M. Kadenacy
Inventor

By: Glascock Downing & Seibold
Attys.

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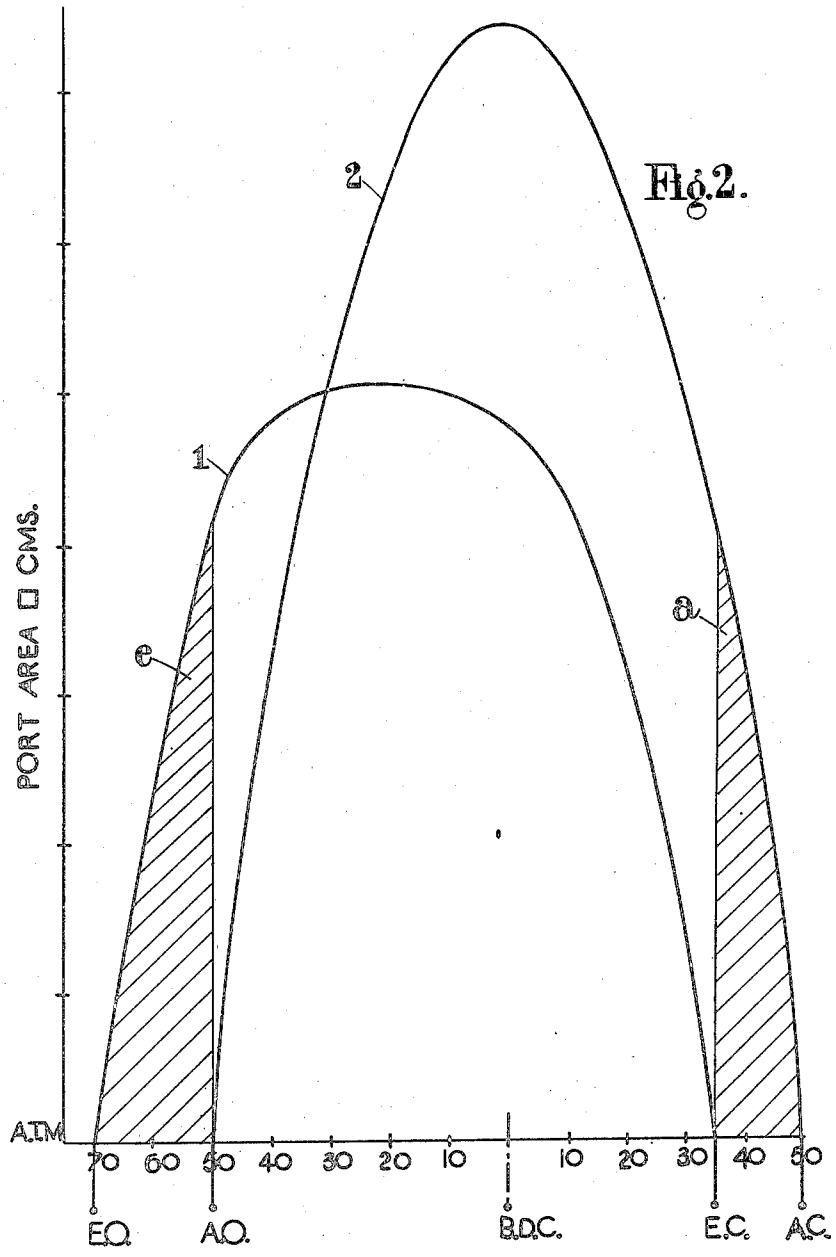


Fig. 2.

M. Kadenacy
Inventor

By: Glascock Downing & Seddl
Attys

Patented Jan. 17, 1939 2,144,065

UNITED STATES PATENT OFFICE

2,144,065

INTERNAL COMBUSTION ENGINE

Michel Kadenacy, Paris, France, assignor of one-half to Armstrong Whitworth Securities Company, Limited, London, England

Application September 4, 1936, Serial No. 99,487
In Great Britain September 6, 1935

3 Claims. (Cl. 123—51)

This invention relates to two-stroke cycle internal combustion engines of the kind wherein at least a substantial portion of the burnt gases leaves the cylinder at a speed much higher than that obtaining when an adiabatic flow only is involved, and in such a short interval of time that it is discharged as a mass leaving a depression behind it which is utilized in introducing a fresh charge into the cylinder by opening the inlet orifice with the required delay after the opening of the exhaust orifice to ensure that the burnt gases are then moving outwardly through the exhaust orifice or duct and that a suction effect is exerted at the inlet orifice as a consequence of the exit of the said mass.

In constructing or modifying a two-stroke cycle internal combustion engine of the kind set out above according to the present invention the relationship between the effective area of the exhaust lead, i. e. the effective area of exhaust orifice opened before inlet opens, and the angle of the exhaust lead, i. e. the crank angle between exhaust and inlet opening is arranged to conform with the following equation:—

$$\frac{W}{100\ KAv}=\frac{a}{360\ N}=t$$

where W is the cylinder volume in cm^3, A the area of exhaust lead in cm^2, v a hypothetical mean velocity of mass exit of the burnt gases of the order of 450 metres per second (it should be understood that this is not an actual value), K a constant depending upon the form of the exhaust orifice and the area opened per unit movement of the piston or crank shaft (in other words allowance must be made for the gradual opening of the exhaust ports and for variation in the rate of opening of the ports in that the rate of opening of the ports varies with the method of actuation used), a is the angle in degrees of exhaust lead, N the speed of the engine in revolutions per second, and t is a time interval such as to ensure that the mass exit of the burnt gases from the cylinder will be completed in the interval elapsing between exhaust and inlet opening.

In the accompanying drawings:—

Figure 1 is an example of an engine to which the present invention may be applied, and

Figure 2 is an exhaust and inlet port area diagram for a cylinder of 1.5 litres capacity.

In Figure 2 the curve 1 relates to the opening of the exhaust orifice and the curve 2 the opening of the inlet orifice. The ordinates of the curves represent port areas and the abscissae crank angles.

EO and EC indicate the moments of exhaust opening and closure respectively and AO and AC the moments of inlet opening and closure respectively. BDC indicates bottom dead centre.

The above equation has been derived from the following considerations:

The total time occupied for the mass exit of the burnt gases to occur will be influenced by the area of the exhaust orifice available, see portion e of the exhaust curve, for example, since this area will determine the length of the column formed by the burnt gases in leaving the cylinder. This area of exhaust orifice is not opened instantaneously but progressively, so that the mean area available should be considered.

If the abovementioned column is too long, in other words if the orifice is too small, the time occupied by the mass exit of the burnt gases will be too great and this exit may not be completed in the time available before the inlet is or can be opened, or the expansion of the rear portion of the mass of burnt gases will become a dominant factor.

These factors must be taken into consideration in constructing an engine having a suitable timing of inlet opening, or in providing a suitable timing for an existing engine, whether this timing be obtained by altering the existing timing of the engine or by altering the area and/or rate of opening of the exhaust orifice, or by a combination of these possible alterations.

Over the chosen speed range it is necessary to ensure that the time elapsing before the inlet opens and the area of exhaust orifice available in this time will suffice to ensure that the mass exit of the burnt gases will be completed during this interval.

The time element which will suffice for this purpose will enable the crank angle between inlet and exhaust opening and also the area of exhaust orifice effectively opened in this crank angle to be established, and if this time requirement is satisfied for the highest engine speed, this will ensure that it will be satisfied at all lower engine speeds, i. e., over the whole or the chosen working speed range.

If either the area of exhaust lead or the angle of exhaust lead is chosen or is fixed and the mean speed of mass exit can be assumed with practical approximation, then the other of these two factors can also be determined so as to ensure that the desired object will be attained.

The inventor has found that calculations of sufficient accuracy to ensure practical results may be made by assuming that the cylinder vol-

ume of burnt gases is discharged, without expansion, at a hypothetical mean speed. This hypothetical mean speed of discharge will vary according to the fuel employed, the mixture and the conditions of combustion, among other factors. For fuel oil with good combustion a hypothetical mean speed of 450 metres/sec. may be taken although this hypothetical speed may be as low as 300 metres/sec. or as high as 600 metres/sec.

The length of the column formed by the passage of the mass of burnt gases through the exhaust orifice will be

$$\frac{W}{KA \times 100} \text{ metres}$$

For practical purposes it may be taken that $K=\frac{1}{2}$.

The time occupied by this mass exit will be

$$\frac{W}{100\ KAv} \text{ secs.}$$

The time elapsing between exhaust opening and inlet opening will be

$$\frac{a}{360} \times \frac{1}{N} \text{ secs.}$$

so that to satisfy the conditions of the invention, the following relationship should exist,

$$\frac{a}{360\ N} = \frac{W}{100\ KAv}$$

This will provide a relationship between A and a.

For practical purposes the two time elements equated above must suffice to ensure that the mass exit of the burnt gases occurs, but must not be too long. Further the angle a must be as short as possible in order to permit a suitable utilization of the crank angle available for charging.

For this time element the value .002 secs. for example may be taken as a basis for an engine of 1 litre capacity, and a speed of 1500 R. P. M., this value ensuring that the increased time interval at lower engine speeds is satisfactory for the purpose of the invention. Factors of correction should be introduced into this value for very large or very small cylinder volumes.

By this it is to be understood that this time will suffice to ensure that a mass evacuation of the cylinder occurs, but that this time may be increased or reduced if it is convenient. If this time element t is fixed, this will also fix the exhaust lead required at any engine speed and also the maximum lead required for the highest engine speed; and it will also fix the exhaust area required.

Since $a=360\ Nt$

and $A=\frac{W}{100\ Ktv}$

in practice it will be found convenient to base the calculations on an angular interval of 25° between exhaust and inlet opening for an engine speed of 25 revs./sec. with a hypothetical mean speed of mass exit of the burnt gases of 450 meters/sec.

By way of example in a 3-cylinder opposed piston engine constructed by the applicant, the volume of each cylinder was 1220 ccs., the area of exhaust lead 19.66 cm^2, and the angle of exhaust lead 20°.

A single cylinder of such an engine is illustrated in Figure 1 of the drawings, which shows a cylinder bore 1, open at both ends, with two pistons 2, 3 working in opposition in this bore, each controlling respectively inlet and exhaust ports 5, 7 located at opposite ends of the cylinder and leading to ducts 4, 6 respectively, the individual pistons being operated by separate crank shafts or by a single crank shaft (not shown).

Assume a hypothetical mean speed of mass exit of the burnt gases of 450 metres/sec., and that $K=\frac{1}{2}$.

The length of the column of exhaust gas will be 1.25 metres.

The duration of time of mass exit will be $\frac{1}{360}$ secs. This will be the time the crank rotates through 20°. In other words the maximum engine speed that will be attained with the required timing of inlet opening will be 1200 R. P. M.

It was desired with this engine to have the required timing of inlet opening at all speeds up to 2400 R. P. M.

Based on the above data, this would require the area of exhaust lead to be increased to 39.32 cm.^{2}, with a lead of 20°.

It was found in practice that these figures were amply sufficient and that with an area of exhaust lead of 30 cm.^{2} and a lead of 22° the desired result was still obtained, these figures showing that the hypoethetical mean speed of mass exit should have been in the neighbourhood of 500 metres/sec.

It should be noted that by means of the invention the result is ensured that inlet opens after exhaust only with the required delay to ensure that the burnt gases are moving outwardly through the exhaust orifice or system as a consequence of their mass exit from the cylinder. At any engine speed the earliest moment at which inlet can be opened in order to obtain advantage from the evacuation of the cylinder by the mass exit of the burnt gases will be the moment when the rear end of the mass of burnt gases, during its outward motion as a consequence of its mass exit from the cylinder, has passed the point at which the inlet orifice is situated and causes a suction into the cylinder at this inlet.

It will be appreciated that, other things being equal, as the engine speed increases, the moment at which inlet opens becomes situated more and more closely to the earliest moment defined above, until a maximum speed is reached when inlet opens at this earliest moment.

Two objectionable actions may arise which will cause the operation of the engine to be defective:

(1) At certain speeds disturbances are produced by the return of the burnt gases, which mixes the fresh air with the burnt gases and forces the charge out of the cylinder.

(2) At higher speeds the depression extends over a larger crank angle and as this depression also exists in the exhaust pipe it draws on the charge admitted into the cylinder and thereby reduces the weight of air in the final charge; consequently by closing exhaust before the return occurs at low engine speeds, the successful operation of the engine at higher speeds will be ensured.

This result may be obtained in the opposed piston engine referred to above, in which one piston controls the inlet ports and the other controls the exhaust ports by causing the crank of one piston to lead that of the other piston by a suitable amount.

Further, it is of great advantage to have the inlet and exhaust ports opened at the highest velocities, as in this way the rapid exit of the burnt gases and the inflow of the fresh charge will be facilitated.

In this engine by suitably offsetting the cranks with respect to the cylinder, the pistons may be caused to open the exit and inlet ports at the highest linear speeds.

In certain cases it may occur that the return of the burnt gases at low speeds takes place too soon to permit the engine to be charged or to permit a suitable and convenient closure of exhaust before the return of the burnt gases occurs, and in this case the engine will be modified in order to cause the return to occur sufficiently late for the purpose required.

This result may be obtained for example by utilizing means such as those described in my copending application No. 738,016 (Patent No. 2,110,986) for delaying the return of the gases; or by flaring the exhaust pipe outwardly, or within limits by lengthening the exhaust pipe. This result may also be obtained by arranging that the exhaust takes place at a moment when a depression exists or is produced in the exhaust pipe. For example in a multi-cylinder engine the exhaust from the individual cylinders may be so connected together that a cylinder exhaust into a pipe in which a depression has been previously produced by the exhaust from another cylinder and before this depression has been destroyed by the return of the burnt gases.

It should be noted that the invention is applicable to engines both in cases when the charge is admitted to the engine directly from the atmosphere and when it is introduced by a compressor.

The sole difference between these two cases consists in the difference in admission pressure at which the air enters the cylinder. Thus, for example, if we have an engine which is established in such a way that at the moment of opening the admission, the depression in the cylinder is 7 metres of water for example, the atmospheric air is pushed into the cylinder with a force of 700 gms. per sq. c. m. If a compressor is connected on the engine and this compressor gives a pressure of 300 gms. per sq. c. m., then in this case the air is pushed into the cylinder with a pressure of 700 gms., plus 300 gms., making a total of 1 Kg. Consequently it will be advantageous to provide compressors of the centrifugal type for example. Air can pass freely through these compressors, independently of the rotation of the rotor and consequently the first and massive entry of air into the cylinder will not be restricted as in a volumetric compressor.

The advantage of this type of compressor is that it permits the engine to work by direct admission through the compressor, even when the latter has stopped and is not working.

Any compressor so used could be arranged so that the air normally passes freely to the engine from the atmosphere, the compressor then being actuated when required in order to increase the charge passing through the compressor or for supercharging such as is necessary for example on an aircraft engine.

What I claim is:—

1. A two-stroke cycle internal combustion engine of the kind set forth wherein the area of exhaust lead and the angle of exhaust lead conform with the following equation:—

$$\frac{W}{100\ KAv}=\frac{a}{360\ N}=t$$

where W is the cylinder volume in cm.^{3}, A the area of exhaust lead in cm.^{2}, v a hypothetical mean velocity of mass exit of the burnt gases of the order of 450 metres per second, K a constant depending upon the form of the exhaust orifice and the area opened per unit movement of the piston or crank shaft, a is the angle of exhaust lead in degrees and N the speed of the engine in revolutions per second, the time t being such as to ensure that the mass exit of the burnt gases from the cylinder will be completed in the interval elapsing between exhaust and inlet opening.

2. A two-stroke cycle internal combustion engine as claimed in claim 1, wherein a equals 20° where N equals 25 revolutions per second.

3. A two-stroke cycle internal combustion engine of one litre capacity as claimed in claim 1, wherein t is equal to .002 secs.

MICHEL KADENACY.