

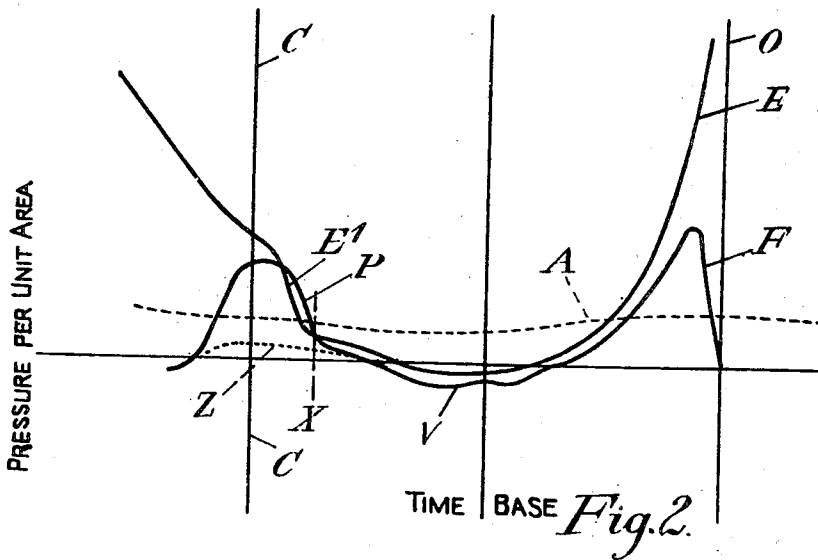
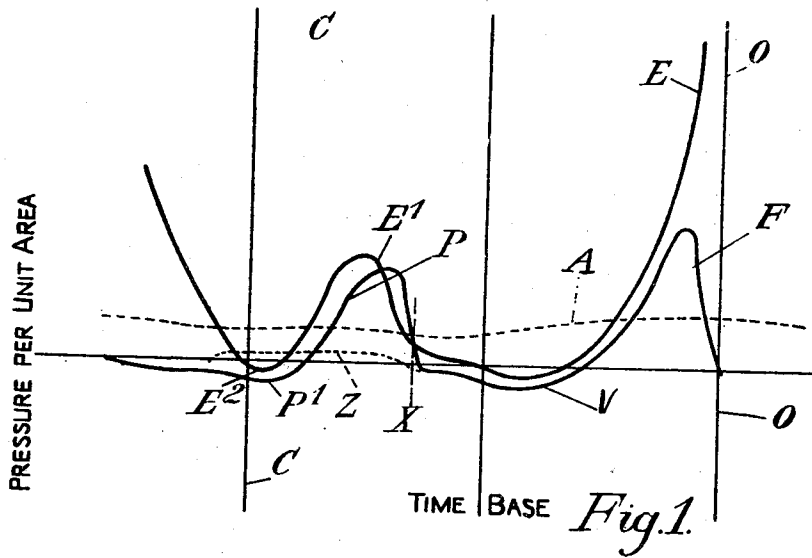
July 19, 1949.

H. D. CARTER
INTERNAL-COMBUSTION ENGINE

2,476,816

Filed June 12, 1945

2 Sheets-Sheet 1



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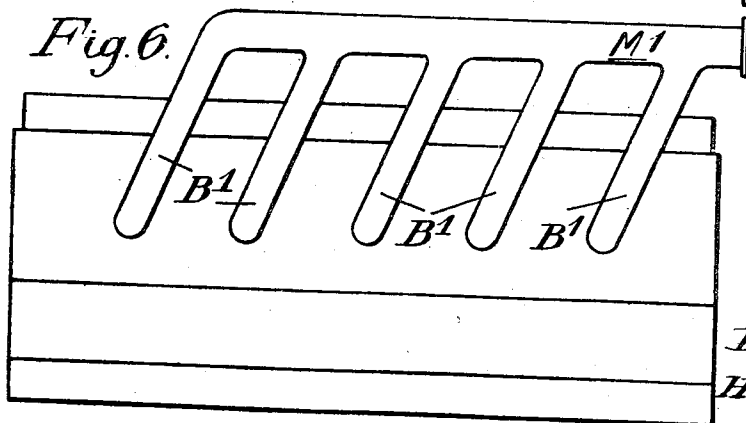
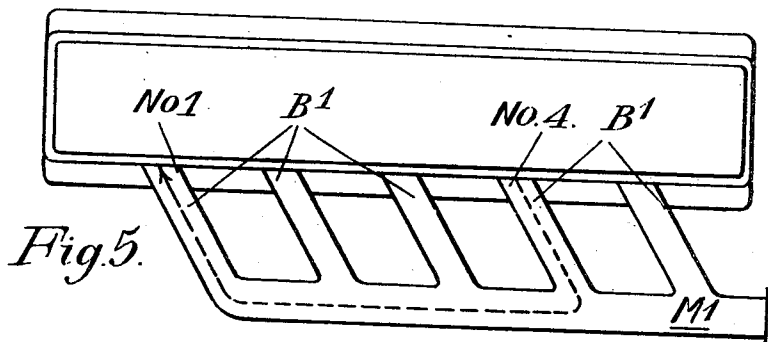
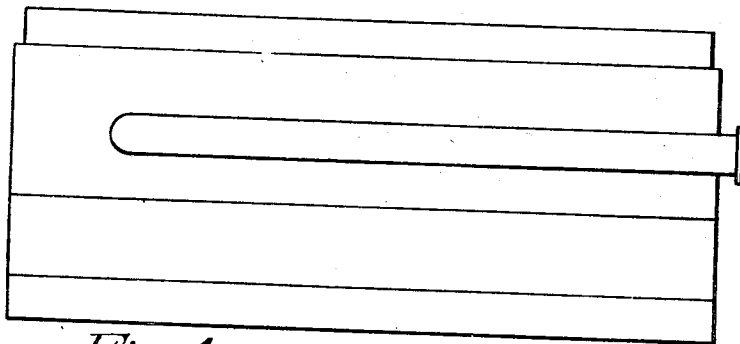
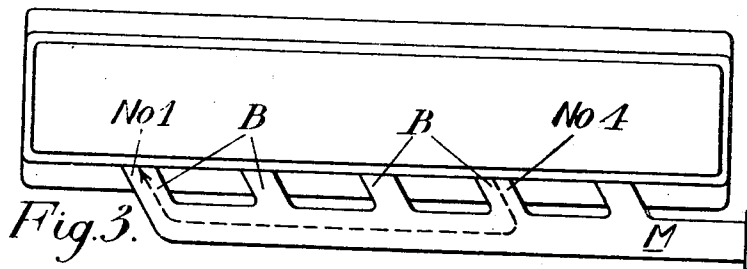
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2 Sheets-Sheet 2



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INTERNAL-COMBUSTION ENGINE

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8 Claims. (Cl. 123-65)

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This invention relates to multi-cylinder two-cycle internal combustion engines of the loop scavenge type and also to such engines as the uniflow, poppet valve, opposed piston and sleeve valve types.

In such engines upon the opening of the exhaust ports, valves or sleeves, a rapid discharge of exhaust gas from the engine cylinder takes place. This causes a rise in pressure in the form of a fundamental exhaust pressure pulse in the exhaust branch and exhaust manifold and pipe. This is followed by a rarefaction usually comprising a depression in pressure below atmosphere. If the ports are opened as rapidly as possible with as great an area as mechanically can be provided, a depression below atmosphere of some magnitude may result, the amplitude of the positive pressure pulse and ensuing rarefaction being in addition dependent upon the proportions of exhaust branch and exhaust piping systems used, the indicated mean pressure, port or valve timing and engine speed. The rarefaction is usually followed by a positive pressure pulse as a result of reflection from the open end of the pipe or some equivalent thereof arranged in the exhaust system. Such a pressure pulse is usually of relatively small magnitude and has hitherto been used in an endeavour to help to fill the engine cylinder with the maximum weight of air, oxygen or combustible mixture before the port, valves or sleeves (hereinafter referred to as port or ports) close on the compression strokes.

The object of the present invention is to provide in an improved simple and efficient manner for the pressure charging of the engine cylinders before their exhaust ports close.

In accordance with my present invention, I utilise the fundamental exhaust pressure pulse from one cylinder for pressure charging another cylinder which previously exhausted, just prior to and up to the moment when its exhaust port closes.

By investigation and experiment I have found that considerable energy is available in the fundamental exhaust pressure pulses (only a part of which has hitherto been used indirectly in producing a partial vacuum effect to assist scavenging, &c.) and I have further found that by a suitable combination of length and cross-sectional area of exhaust branch, manifold and pipe, with the speed, port timing and indicated mean pressure of the engine, the fundamental exhaust pressure pulse of a succeeding cylinder can be controlled and re-phased at a previous cylinder so that it reaches its peak at or a little before the

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closing of the exhaust port of such previous cylinder, with the result that it becomes a pressure charging pulse at the latter cylinder which therefore receives a charge which is well above the usual air manifold pressure. By controlling and rephasing the fundamental exhaust pressure pulse of one cylinder so that it becomes the pressure charging pulse of a previous cylinder, I obtain a much more effective pressure charging than can be obtained by utilising any pressure rise in the exhaust system from a cylinder resulting from the exhaust discharge and ensuing pressure pulses to recharge such cylinder.

I prefer to provide a surplus of scavenging air for each cylinder as compared with the cylinder volume in order to fill with air the exhaust branch in the region of the exhaust port which is to receive the pressure charging wave from a previously opened exhaust port in the system. The exhaust branch and manifold should also be so proportioned in regard to cross sectional area and length, that when the pressure charging pulse from the succeeding cylinder arrives at a previous cylinder in sequence, it will cause a compression or densification of air and not of exhaust gases to occur in the said previous cylinder.

Referring to the accompanying explanatory drawings:

Figure 1 is a diagram showing the pressure conditions occurring in an exhaust manifold resulting from a discharge of exhaust gases from a cylinder.

Figure 2 is a diagram similar to that of Figure 1 but showing the pressure pulse resulting from a discharge of exhaust gases from a cylinder after it has been controlled and rephased so that it becomes the pressure charging pulse of the cylinder which exhausted previously to the one producing the pressure pulse.

Figures 3 and 4 are plan and elevation of an engine cylinder showing a usual arrangement of exhaust manifold.

Figures 5 and 6 are views similar to Figures 3 and 4 but showing a design of exhaust manifold suitable for use in the application of this invention.

The diagram, Figure 1, is one that might be obtained from a five or six cylinder engine with a common exhaust manifold, pressures in lbs. per sq. in. being represented by vertical ordinates; a time base (which may conveniently be crankshaft degrees) being represented horizontally moving from right to left. The ports of a loop scavenge engine are indicated as opening

at line O and closing at line C. The line E shows the rapid pressure drop in the cylinder upon a port opening, and F shows the positive fundamental pressure pulse, which results in the exhaust branch and manifold. V indicates the ensuing rarefaction which may be sub-atmospheric, and P shows the abrupt rise in pressure and interruption of the scavenging process due to the next cylinder in sequence exhausting, the pressure pulse having been propagated in the exhaust gas medium from that cylinder through the exhaust branch along the manifold and into the exhaust branch and cylinder of the previous cylinder in sequence. This causes a rise in pressure in the engine cylinder as indicated by the ensuing rising part of the line at E¹. This is followed by a drop in pressure along the flank of the pulse P, and this pressure drop may even be below atmospheric as is indicated at P¹, the cylinder pressure following suit at E². Thus at port closing on the line C, the pressure is subatmospheric. In a less extreme it might be above atmospheric, but not appreciably above the pressure of the scavenging air as shown by the line A.

Figure 2 shows how by suitable combination of length and cross-sectional area of branch and exhaust manifold and pipe, engine speed, indicated mean pressure and port timing, the pressure charging pulse P of the succeeding cylinder in sequence has been controlled and re-phased in regard to F. It now occurs much later in the cycle, reaching its peak a little before ports closing. It enters the engine cylinder and causes a rise in pressure rather above that of the branch due to reflection with unchanged sign from the end of the cylinder (or remote piston in the case of an opposed piston engine), and the cylinder pressure line E at port closing C is shown accordingly and well above the air manifold pressure. If the pressure charging pulse from the succeeding cylinder in sequence is absent, the pressure in a tuned system in the exhaust branch might be expected to follow the dotted lines Z shown in Figures 1 and 2. Whilst there is a positive rise in pressure here, and has hitherto been used, it is effective only to a small extent as compared with utilising pulse P from the next cylinder in sequence as a pressure charging pulse.

Whilst in the above description particular reference has been made to five and six cylinder engines, the system can be applied to any two cycle engine of the multi-cylinder type, although in practice it is likely that the engine would have to have at least three cylinders. In general the greater the number of cylinders the longer the exhaust branches must be if a common manifold is used (as the pressure charging pulses are propagated from their own cylinders through the branches and pipes approximately with constant velocity at a given indicated mean effective pressure in the exhaust gas medium), unless the manifold is split into two or possibly more banks as may become desirable in certain cases in order to reduce the lengths of the exhaust branches required.

It is desirable that a surplus of scavenging air as compared with the cylinder volume should be provided in order to fill the exhaust branch in the region of the exhaust ports with air at each cycle, and that the exhaust branch shall be so proportioned in regard to the cross-sectional area and length that when the pressure charging pulse arrives at the cylinder being charged, it will cause a compression (or densifi-

cation) of air and not of exhaust gas to ensue in that engine cylinder. The surplus of scavenging air might be increased for higher degrees of pressure charging.

This invention is particularly valuable in regard to loop scavenge 2-cycle engines as the exhaust port closing timing is fixed at the same value as the opening timing. Normally this results in a loss of cylinder charge down the exhaust ports. This period of loss is converted in this invention to a period of useful pressure charging of the cylinder.

Although for illustration the loop scavenge type of engine has been described, the process is also applicable to exhaust uniflow, poppet valve, opposed piston and sleeve valve engines. In current engines of the poppet valve type or opposed piston type, it is usual to close the exhaust valves or ports at or before point X in order to prevent any interference from P and to leave the air ports open a little longer to obtain a pressure charge if possible from the scavenging air which may be increased by means such as ramming pipe effect through the air ports.

By way of example, a 5-cylinder engine may be taken with equally spaced cranks at 72° and a firing order of 1, 4, 3, 2, 5 and exhausting into a common manifold. Suppose that Figure 1 is the diagram obtained at No. 1 cylinder, the pressure charging pulse P (Figure 1) being that due to the next cylinder in sequence, No. 4. On an engine with a cylinder bore of 10" the distance from the axis of No. 1 to the axis of No. 4 cylinder via the exhaust system might well be 5' 0" and the exhaust branches approximately 6" long. The pressure charging pulse from No. 4 cylinder is propagated to No. 1 cylinder (see Figure 3) with a velocity which may usually be taken as lying between 1150 and 1750 ft. per second, the actual value depending generally upon the temperature, pressure and specific volume of the gas, and is a function of the velocity of sound in the exhaust gas medium, of the exhaust gas particles and of the exhaust gas flow in the exhaust system, but it is found that the range of velocities hereinbefore stated gives results which are substantially in accordance with observed results, that is to say the positions of the peaks of the pressure charging pulses in terms of engine crank angle calculated with the use of the said figures will be found not to differ to an extent of more than say 5° of crank shaft angle from the observed result. In the examples below a figure of 1200 ft. per second is used.

With an exhaust port timing from bottom dead centre of 70° and a speed in the region of 340 R. P. M., the exhaust pressure charging pulse as illustrated in Figure 1 would arrive at No. 1 cylinder via the exhaust branches B and manifold M, Figure 3 approximately 40° too early in the cycle to be used for pressure charging purposes. With port timings of 64°, 60° and 55° the pressure charging pulse from No. 4 cylinder would arrive at No. 1 cylinder 28°, 20° and 10° too early respectively. Port timings may, therefore, be used to provide correct timing of the exhaust pressure charging pulses, in this example, a 50° port timing would be required.

Alternatively or in addition, the exhaust pulses may be re-phased by altering the exhaust system characteristics and particularly in regard to effective pipe lengths. Thus in the above example at 340 R. P. M. the distance over which the pressure charging pulse is propagated requires in-

creasing and this increase may be effected either in the branches or the manifold, or both. In Figure 5 branches of increased length are shown, that is increased from about 6" as shown at B, Figure 3, to a substantially increased value B', Figure 5. In order to avoid an unnecessary stand out of the exhaust manifold M' from the engine in plan view, the branch pipes may be curved upwards and used in conjunction with an overhead exhaust manifold as shown in Figure 6 or alternatively downwards if more convenient. Again alternatively, the branch pipes may be grouped around a central manifold or otherwise be suitably arranged to maintain the above characteristics, but to be of the best possible appearance and neatness. At 340 R. P. M. and with port timings of 70°, 64°, 60° and 55° the increase in lengths required over which the pressure charging pulse will be propagated are approximately 280", 200", 140" and 70" respectively at 1200 ft. per second velocity of propagation and greater lengths at higher velocities. At 500 R. P. M. these figures become 190", 135", 95" and 50", the increased lengths of the branches themselves being half these lengths, if the total increase is limited to the branches only.

At 340 R. P. M. and with 5" bore pipes, pressure charging pulses at 75 lb./sq. inch brake mean effective pressure can be expected to be of the order of 5 lb./sq. inch. With a smaller exhaust pipe they will be higher and with a larger one, lower, for example, with a 6" bore pipe the pressure charging pulse may be 3½ lb./sq. inch; with a 4" bore pipe it may be 9 lbs./sq. inch and with a 9" bore pipe it may be 1½ lbs./sq. in. In another case in a 3-cylinder engine the fundamental pulse in the exhaust branch had an amplitude of 5½ lb./sq. inch at 340 R. P. M. rising to 10 lb./sq. inch at 600 R. P. M. In another case the amplitude of the fundamental rose from 3 lb./sq. inch at 18 lb./sq. inch brake mean effective pressure up to 8 lb./sq. inch at 100 lb./sq. inch brake mean effective pressure. Smaller pipe diameters and higher speeds result in some spread or increase in period of the pulses which may also be utilised in obtaining the optimum pressure charging effect. It will be noted that in general at higher speeds, shorter pipe lengths are required.

On 6-cylinder engines, longer branch pipes are required and on 4-cylinder engines shorter ones and so on. For instance, on a 4-cylinder engine at 340 R. P. M. an additional length of pipe through which the pressure charging pulse would be propagated equivalent to 20° of crank angle is required with port timings in the earlier range given above. On engines with 6-cylinders or more alternatively the exhaust system may be split up into two banks of piping in order to provide wider spacing of the pressure charging pulses so that undue lengths of exhaust branch pipes may be avoided but arranged in such a way that in general cylinders firing in sequence do not exhaust into the same exhaust manifold, that is, alternating firing cylinders do exhaust into the same manifold, and pressure charging pulse from alternating cylinders are then used. In other words, alternating cylinders, as far as one particular bank is concerned, are in sequence. These two banks of exhaust manifolds or pipes may be joined into a common pipe at a pipe length sufficiently remote from the engine to avoid interference from one bank to the other of the pulses generated therein.

I may if desired split the exhaust manifolds and pipes into more than two banks in order to

select the cylinders to be charged by any particular fundamental pressure pulses.

It will be appreciated that the exhaust pressure pulse from one cylinder need not necessarily be used for pressure charging the cylinder which previously exhausted; for example, the pressure pulse from one cylinder may serve for the charging of the cylinder which exhausted next but one before. With a common exhaust system, in say a 7-cylinder engine, as far as any one cylinder is concerned, the pressure pulse of the next cylinder in sequence when exhausting would have a nuisance value only, as it would occur too early and would interrupt the scavenging period but only for a limited number of crankshaft degrees. This might be a disadvantage but not vital; in some circumstances this interruption of the scavenging period may have the advantageous effect of stopping the flow of the scavenge air during such part of the scavenging period as is inefficient (due to the scavenge air wastefully tending to take the shortest path from the air ports in the cylinder wall to the exhaust ports).

It will be appreciated that theoretically for a given speed of engine and brake mean effective pressure, optimum conditions can be arranged, but as soon as either of these quantities is altered, optimum conditions will no longer obtain. In practice, however, it is possible to arrange the various factors concerned in such a way as to provide substantial exhaust pulse pressure charging over a wide range of speeds and brake mean effective pressures.

It will be noted that this invention is not concerned with any question of the sudden or gradual release of exhaust gases, with the way in which they leave the cylinder, with the pressure pulse resulting in the exhaust system at the exhausting cylinder, nor with any subsequent rarefaction or reflected positive or negative pulses resulting from such release.

What I claim is:

1. A method of operating a multi-cylinder two-cycle internal combustion engine, consisting in controlling and re-phasing the fundamental exhaust pressure pulse from one cylinder so that it reaches a peak at or a little before the closing of the exhaust port of another cylinder which previously exhausted with the result that the latter cylinder receives a charge which is well above the usual air manifold pressure.

2. A method of operating a multi-cylinder two-cycle internal combustion engine by controlling and rephasing the fundamental exhaust pressure pulse as claimed in claim 1 consisting in adjusting the exhaust port timing.

3. A method of operating a multi-cylinder two-cycle internal combustion engine by controlling and rephasing the fundamental exhaust pressure pulse as claimed in claim 1 consisting in varying the effective pipe lengths in the exhaust system.

4. A method of operating a multi-cylinder two-cycle internal combustion engine by controlling and rephasing the fundamental exhaust pressure pulse as claimed in claim 1 consisting in adjusting the exhaust port timing, and varying the effective pipe lengths in the exhaust system.

5. A method of operating a multi-cylinder two-cycle internal combustion engine as claimed in claim 1 consisting in adjusting the cross sectional area of the exhaust branches and pipe to control the amplitude of the pressure charging pulses.

6. A method of operating a multi-cylinder two-

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cycle internal combustion engine as claimed in claim 1 consisting in providing the engine with a surplus of scavenging air to fill the exhaust branch with more or less pure air which is returned to the cylinders by means of the charging pulses.

7. A method of operating a multi-cylinder two-cycle internal combustion engine as claimed in claim 1 in which the fundamental exhaust pressure pulse assists in charging a cylinder which exhausted next but one before it, utilizing such fundamental exhaust pressure pulse to assist in stopping the flow of the scavenge air from the cylinder which exhausted next before it during the part of the scavenging period as is inefficient due to the scavenge air wastefully tending to take the shortest path from the air ports in the cylinder wall to the exhaust ports therein.

8. A method of operating a two-cycle internal combustion engine having at least three cylinders, comprising controlling and rephasing the fundamental exhaust pressure pulse from one cylinder so that it reaches the exhaust port of another cylinder which previously exhausted immediately before the commencement of the

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compression stroke in such cylinder and causes the pressure in the exhaust branch of such cylinder to rise to a maximum at or a little before the closing of the exhaust port, with the result that such cylinder receives a charge which is well above the usual air manifold pressure.

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