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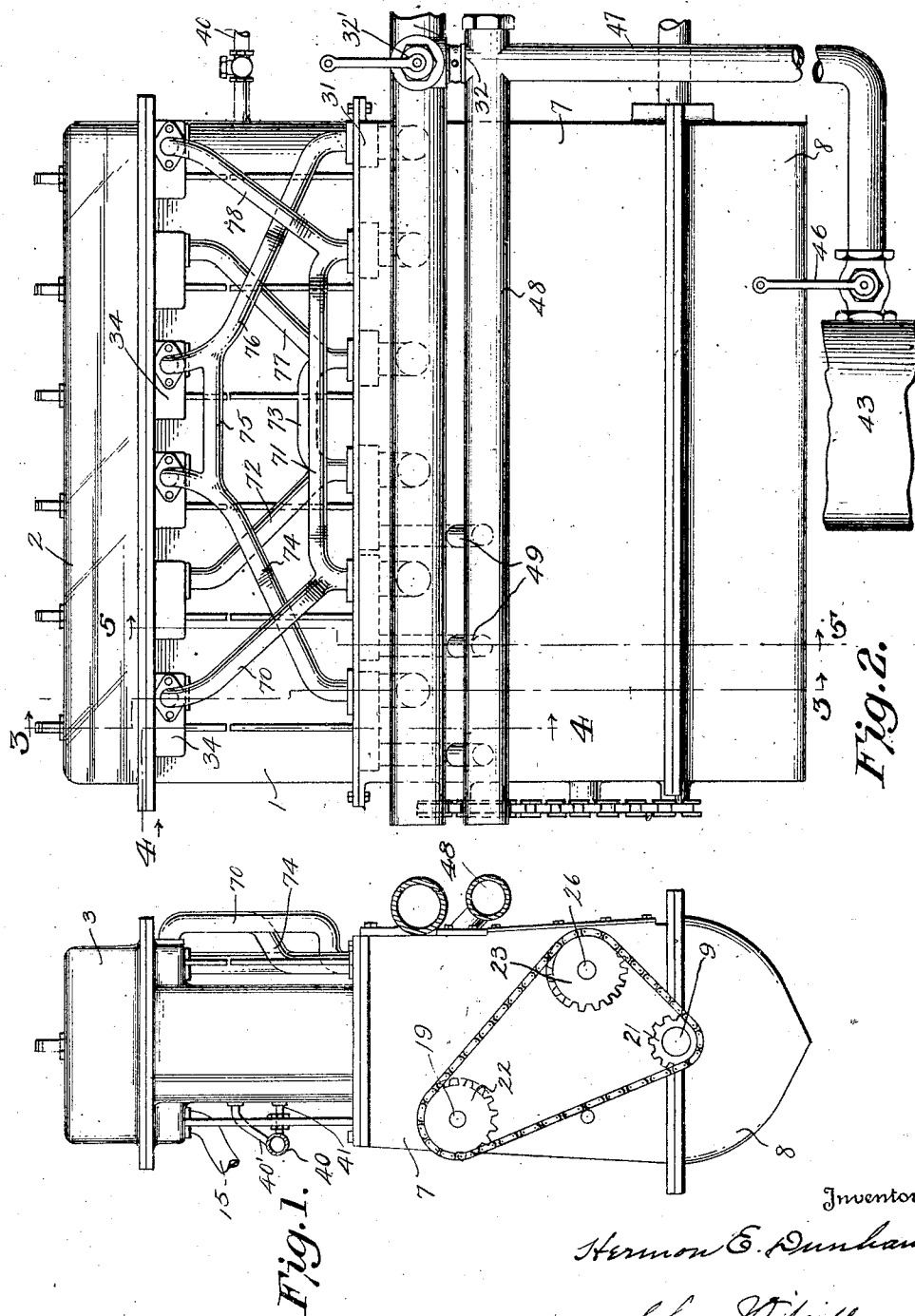
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H. E. DUNHAM

INTERNAL COMBUSTION ENGINE

Filed May 29, 1920

4 Sheets-Sheet 1



Inventor

Herman E. Dunham

Chas. D. Hill

Attorney

Oct. 12, 1926.

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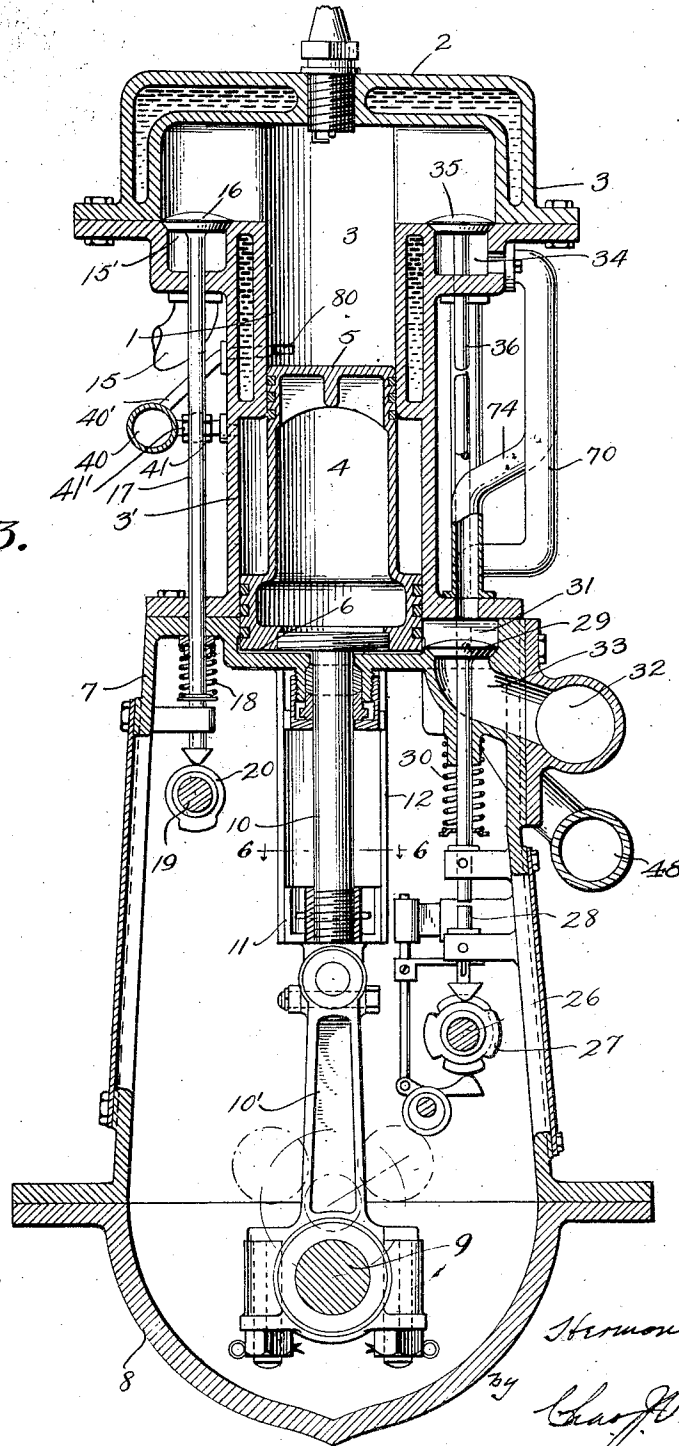
H. E. DUNHAM

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Fig. 3.



Inventor
H. E. Dunham
Charles M. Mull
Attorney

Oct. 12, 1926.

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H. E. DUNHAM

INTERNAL COMBUSTION ENGINE

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Fig. 4.

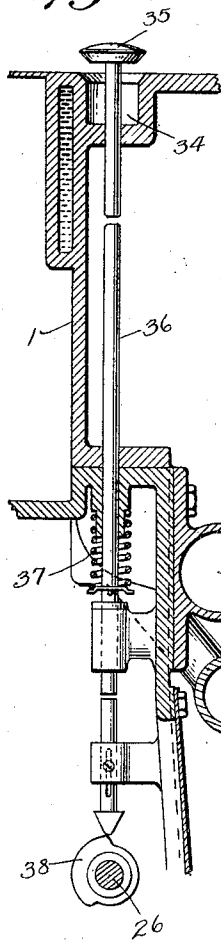


Fig. 5.

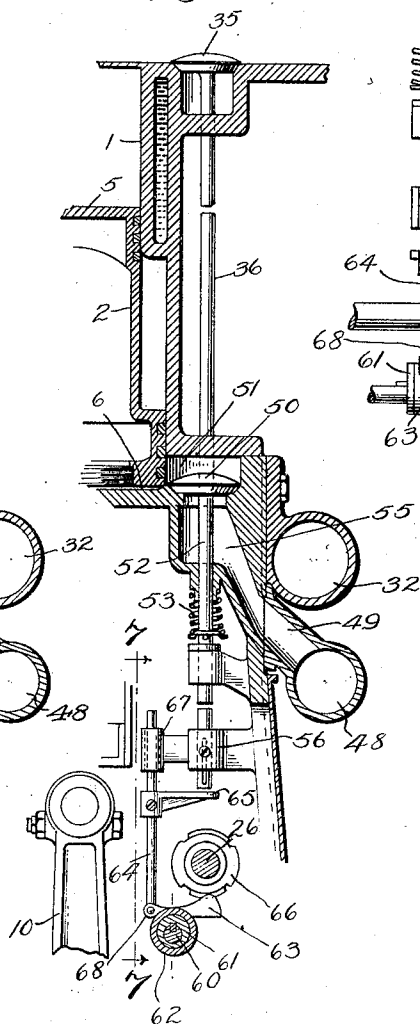
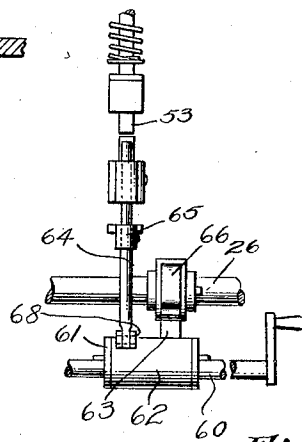


Fig. 7.

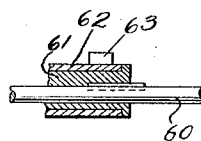


Fig. 8.

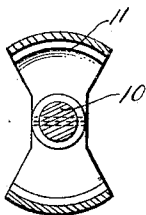


Fig. 6

Inventor
Harmon E. Dunham
Charles W. Hull
Attorney

By

Oct. 12, 1926.

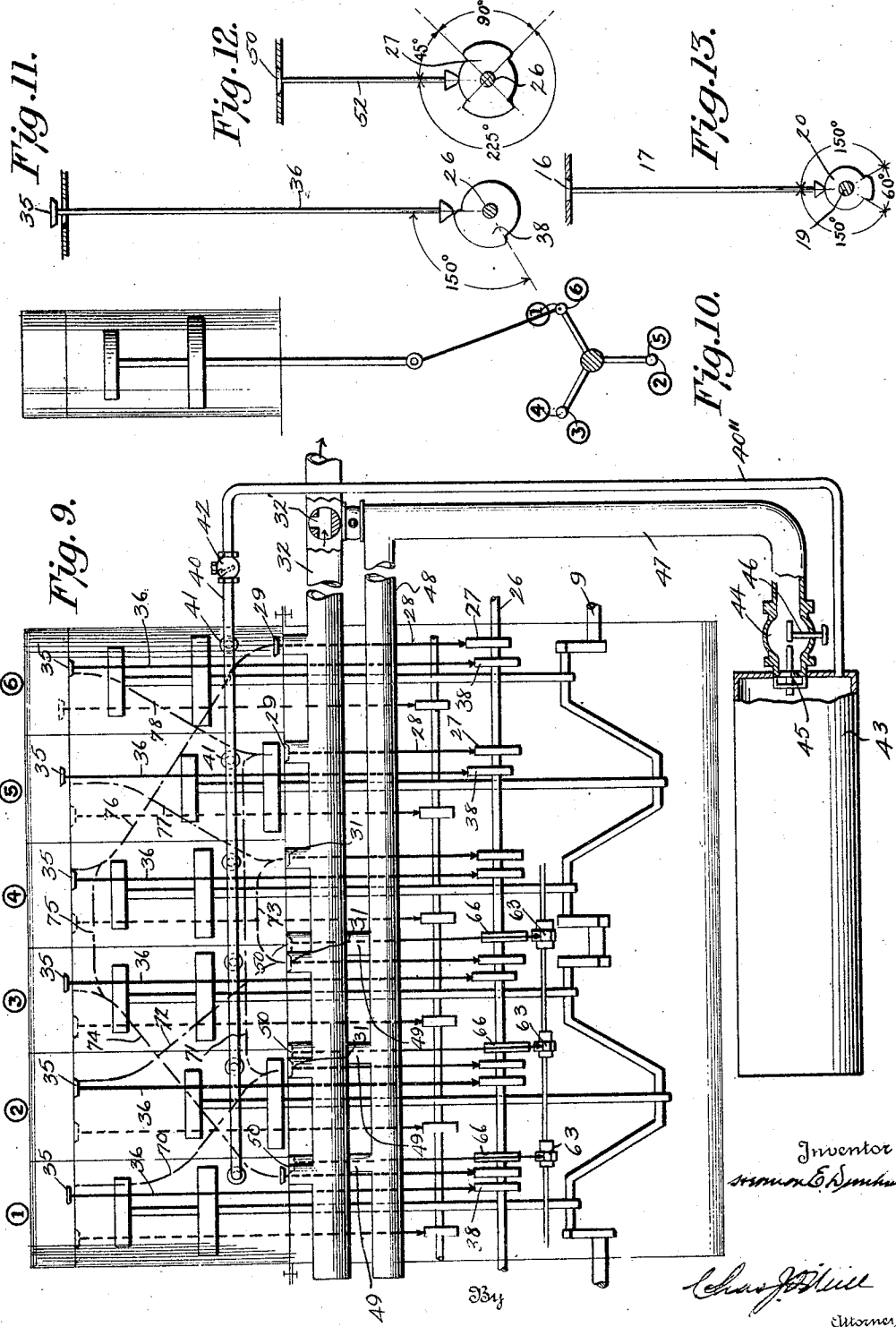
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H. E. DUNHAM

INTERNAL COMBUSTION ENGINE

Filed May 29, 1920

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UNITED STATES PATENT OFFICE.

HERMON E. DUNHAM, OF SEATTLE, WASHINGTON; ELIZABETH B. DUNHAM EXECUTRIX OF SAID HERMON E. DUNHAM, DECEASED.

INTERNAL-COMBUSTION ENGINE.

Application filed May 29, 1920. Serial No. 385,304.

The invention relates to a new type of multicylinder internal combustion engine and a novel method of starting and operating the same, involving a greatly increased efficiency and economy of operation, due primarily to the diversion of part of the expanding charge in a cylinder in which the explosion cycle is taking place to the opposite side of a piston or pistons moving in an opposite direction, whereby the expanding gases will be effective in driving the corresponding pistons in opposite directions, substantially counterbalancing the vertical components of the several forces on the crank shaft, so that the latter practically floats in its bearings, and utilizing practically all of the heat units developed by the combustion of the fuel and converting the same into effective work, the expansion of the gases preferably being carried to a point below that of atmospheric pressure, so that the ultimate exhaust products are substantially devoid of force and heat. The novel mode of and mechanism for distributing the explosive charges to multiple cylinders of the engine also admits of the engine, and the vehicle or other machine operated thereby being started from a position of rest by means of air which has been compressed by the normal operation of the engine, or by the engine operating as a pump when it is desired to brake the engine and the apparatus operated thereby, so that the engine may be started and stopped very quickly and smoothly, without any shifting of gears, or operating clutches or hand or power brakes, and without calling into play the usually complicated and expensive electric starting gear. The foregoing, and other characteristic features and advantages of the novel method and apparatus involved in the invention will appear more fully in the annexed specification and claims, which are predicated upon the accompanying drawings exemplifying the invention as applied to a six cylinder engine of the four-cycle type. In the drawings:—

Fig. 1 is an end elevation of the engine with certain of the elements shown in cross section.

Fig. 2 is a front elevation.

Fig. 3 is a vertical transverse section on line 3—3 of Fig. 2.

Fig. 4 is a partial section on line 4—4 of Fig. 2.

Fig. 5 is a similar section on line 5—5 of Fig. 2.

Fig. 6 is a section, on line 6—6 of Fig. 3, of the piston rod guide.

Fig. 7 is a detail view showing the means for operating the air inlet valves.

Fig. 8 is a partial longitudinal section of the cam roller forming part of the apparatus illustrated in Fig. 7.

Fig. 9 is a skeleton diagram of the engine and its operating devices.

Fig. 10 is a similar diagram in end elevation.

Figs. 11, 12 and 13 are diagrammatic views of the by-pass valve, the exhaust valve, and the fuel inlet valve and their operating cams, respectively.

Referring to the drawings 1 indicates the main cylinder casting, which is preferably formed as a single casting, and comprising six cylinders numbered 1 to 6, inclusive, as indicated in Fig. 9, which cylinder casting is provided with a top or cover 2, bolted to the member 1 and provided with firing chambers and valve chambers corresponding to the respective cylinders. The cylinder block is connected by suitable base flanges to the top of the frame 7, which, with the lower base member 8, constitutes the housing for the crank shaft and the cam shafts for operating the several valves, as is usual in engines of this general type. Each cylinder includes an upper section 3 and a lower section 3', which latter is of larger diameter than the upper section, the respective sections adapted to receive the ends 5 and 6 of a differential piston 4, the cylinder engaging walls of the pistons being provided with the usual form of packing rings. The lower piston head 6 is formed by an annular extension of the piston body to provide a shoulder which serves to compress air in the cylinder space traversed by the lower end of the piston, in substantially the same manner and for the same purpose as described in my Patent No. 1,106,194, dated August 4, 1914. Each piston 4 is connected by means of a piston rod 10 and a connecting rod 10' to a suitable crank shaft 9 journaled in the ends of the engine frame or casing 7. The lower end of the piston rod is provided with a slide 11, which engages guide brackets 12 rigidly secured to the under side of the top of the frame, as shown in Fig. 3 and serves

to brace and support the piston rod against lateral thrusts. It will be understood that the arrangement and disposition of the several cranks on the shaft 9 may be designed to meet any particular order or sequence of operation of the several cylinders and pistons, and in the particular exemplification of the apparatus, the cranks are so disposed that the several cylinders are fired in the following order:—No. 1, No. 4, No. 2, No. 6, No. 3, and No. 5, so that one cylinder fires for every 120° rotation of the crank shaft.

Each cylinder is connected near its top with a fuel inlet pipe 15, which delivers the explosive charge from a suitable manifold, not shown, which is connected with a carburetor or other suitable charge-forming device, said fuel inlet pipe communicating with a port 15' which is controlled by a valve 16 normally held to its seat by a spring 18 on rod 17, which latter is guided in suitable openings formed in the engine castings, as illustrated in Fig. 3. The lower end of each inlet valve stem is in cooperative engagement with a corresponding cam 20, the several cams being fixed at proper intervals upon a longitudinal shaft 19 journaled in the ends of the casing 7.

Upon the end of the shaft 19 is secured a sprocket wheel 22, driven by a chain 23 which, in turn, is driven from a sprocket gear 21 on the end of the crank shaft 9, said chain also engaging a sprocket wheel 23 on the end of a second cam shaft 26, the ratio between the sprocket gear 21 and the sprocket wheels on the cam shafts 19 and 26 being such that two revolutions of the crank shaft 9 produce a single revolution of each of the shafts 19 and 26.

The cam shaft 26 is journaled in the casing 7 on the opposite side of the latter from the cam shaft 19 and, as indicated, is driven at one-half the speed of the crank shaft. Fixed at regular intervals on said shaft 26 is a series of cams 27, each having diametrically oppositely disposed raised portions approximately 90° in extent, and which serve to open the exhaust valves associated with the several cylinders and hold them open through approximately 180° of the crank shaft travel and in this particular case, during the entire downward strokes of the pistons.

It will be noted that the lower end of each cylinder is formed in the upper face of the frame or casing 7, as illustrated in Fig. 3, and communicates with a valve chamber 31 in which operates the exhaust valve 29, which serves to open and close communication between the exhaust manifold 32, bolted to the side of the casing, through an exhaust duct 33, said valve being provided with a stem 28 operating in suitable guides, the lower end of the stem cooperating with the corresponding cam 27

on the shaft 26, the dwells or high portions of the cam serving to lift the valve from its seat against the tension of the spring 30, which normally seats the valve, and is sufficiently strong to prevent the valve opening under operating pressure.

Near the top of each cylinder, opposite the fuel inlet port, there is provided a chamber 34, the upper edge of which forms a seat for a by-pass valve 35, carried by an elongated stem 36, which is suitably guided in bearings in the engine structure, said valve being normally held to its seat by a spring 37 as shown in Fig. 4, and being unseated by means of a cam 38 carried by the cam shaft 26, the raised portion or dwell of the cam being substantially 150° in extent so that the by-pass valve 35 is held open during 300° of rotation of the crank shaft 9. Each cam 38 is so adjusted on the shaft 26 that it opens the by-pass valve 35 of the corresponding cylinder when the piston in the latter has moved downward on its power stroke a distance equal to approximately 60° of the crank throw, so that the by-pass valve of each cylinder remains open until the corresponding piston reaches approximately its upper limit on each exhaust stroke. Connected to the by-pass valve chamber 34 of each cylinder, and extending to, and connecting with the exhaust valve chamber 31 of a companion cylinder is a by-pass pipe or conduit which serves, on the one hand, to convey part of the expanding gases from a cylinder in which an explosion is taking place to the opposite end of a cylinder or cylinders, the pistons of which are about to begin their upward movements, and, on the other hand, serves to convey the burnt gases or products of combustion from a cylinder in which the piston is on its exhaust stroke, to the exhaust valve chamber of a companion cylinder or cylinders, whence said gases are ultimately exhausted into the exhaust manifold 32.

The particular disposition and arrangement of the by-pass conduits in the engine illustrated, are indicated in Figs. 2 and 9, said conduits being shown in full lines in the former figure, and by single dotted lines in the diagram represented by Fig. 9. By-pass pipe 70 leads from chamber 34 of cylinder No. 1 to the exhaust valve chamber 31 opposite the lower end of cylinder No. 2, the lower end of the by-pass pipe registering with an opening in the base flange immediately above the exhaust valve chamber 31 as illustrated in Fig. 3. Near its lower end, the by-pass pipe 70 is connected with a branch 71 which communicates with the exhaust valve chamber 31 of cylinder No. 5, where it is joined by by-pass pipe 78, connecting valve chamber 34 of cylinder No. 6, with the exhaust valve chamber of cylinder No. 5. Similarly, a by-pass pipe 72 con-

nects the by-pass chamber of cylinder No. 2, with the exhaust valve chamber of cylinder No. 3, and is connected by a cross-over 73 with the by-pass pipe 77, which, in turn, connects the by-pass valve chamber of cylinder No. 5 with the exhaust valve chamber of cylinder No. 4. Pipe 74 likewise provides a by-pass from valve chamber 34 in cylinder No. 3 to the exhaust chamber 31 in cylinder No. 1 and is connected by a cross-over 75 with by-pass pipe 76 which connects valve chamber 34 of chamber No. 4, with the exhaust valve chamber 31 of cylinder No. 6. It will be understood, of course, that the particular construction and arrangement of the by-pass pipes or conduits will depend upon the number and disposition of the cylinders in a given engine and also upon the particular order in which the cylinders are fired. The function and co-operation of the several by-pass pipes will be explained in connection with the description of the operation of the engine as a whole.

Connected with each of the air compression spaces, in the lower enlarged sections of the several cylinders, is an outlet pipe 41 which delivers the air, compressed by the annular shoulder on the lower part of the piston, into a manifold 40 which extends across the engine, as illustrated in Figs. 1, 3 and 9. Located in each cylinder wall at a point just above the lower limit of travel of the upper end of the piston 4 is a port 80, which is connected with the manifold 40 by means of a pipe 40'. Each of said pipes 41 is provided with suitable check valve 41' to prevent back pressure. The purpose and function of the manifold 40 and the port 80 in each cylinder are the same as described in my prior Patent No. 1,106,194, the compressed air from the manifold 40 being admitted to each cylinder just before the upper end of the piston therein reaches the lower end of its suction stroke, to supply an excess of air to produce complete combustion of the fuel charge after the latter has been compressed and fired, and also serving to sweep out or scavenge the cylinder of the products of combustion just before the piston reaches the end of its power stroke and during the first part of the exhaust stroke, as is more fully explained in my prior patent aforesaid.

As indicated, the present invention also includes means for starting the engine, either alone, or when coupled to the vehicle or other machine which it is employed to drive. To effect this operation, the manifold 40, which receives air under pressure from the several cylinders, is connected by a bleeder pipe 40'' to a pressure tank 43, which may be located at any convenient place adjacent the engine, said bleeder pipe being provided with a check valve 42 to prevent back pressure from the tank. The out-

let from the tank 43 is by way of a valve 45 mounted in casing 44, secured to one end of the tank and coupled to a pipe 47, which, in turn, is connected with a horizontal pipe 48, running longitudinally of the engine. Branch conduits 49 from header pipe 48, connect the same with air inlet valve chambers 55, formed in the engine casing adjacent the respective cylinders, each chamber 55 communicating with the corresponding exhaust valve chamber 31, through an opening normally closed by a valve 50, as illustrated in Fig. 5, so that, when a given valve 50 is opened, air under pressure from the tank 43 will be admitted to the corresponding exhaust valve chamber whence it is distributed under the lower face of the piston in the corresponding cylinder and to certain of the other cylinders of the engine to start the latter.

Each valve 50 is provided with a stem 52, which is suitably guided for vertical reciprocation in bearings formed in the casing, and is normally held to its seat by a spring 53. The lower end of the valve stem 52 is engaged by an adjustable tappet 65 mounted upon a rod 64, the upper end of which is guided in bracket 67, projecting from the inner side of the engine frame. The lower end of rod 64 is connected to ears 68 formed upon a sleeve 62, which, in turn, is rotatably mounted on an eccentric sleeve 61 rigidly secured to a shaft 60 journaled in the ends of the engine casing below the crank shaft 26, the outer end of the shaft 60 being provided with a suitable means, such as a hand crank, a foot lever, or the like (not shown) for turning the shaft through 180°. Upon the opposite end of each sleeve 62, is secured a rocker arm 63, which is adapted to be moved into and out of the path of movement of a cam 66 fixed to the cam shaft 26. Each cam 66 is provided with two opposite operating faces or dwells, and each of said cams is fixed to the shaft in such relation that it opens the air intake valve 50 just after the exhaust valve of the same cylinder is closed, and closes the said air intake valve just before the corresponding exhaust valve opens. When the shaft 60 is turned in one direction, the eccentric sleeves 61 withdraw the rock levers 63 from the path of movement of the cams 66 so that the air intake valves are not operated. When, however, the shaft 60 is turned in the other direction, the eccentric sleeves 61 raise the corresponding rock levers 63 into position to be engaged by the high portions of the cams 66, thereby causing each intake valve 50 to be opened and closed twice during each revolution of the cam shaft 26.

It will be noted from Fig. 9 that only three of the six cylinders are provided with air intake valves and operating mechanism therefor, namely, cylinders Nos. 1, 2, and 3,

but this particular disposition and arrangement of the air intake valves is sufficient to produce a sufficiently powerful torque to start the engine from a position of rest, when air under pressure from tank 43 is admitted to the engine, as will be more particularly described hereinafter.

Under ordinary circumstances, the air stored in the tank 43 is under the normal pressure induced in the manifold 40 as hereinbefore explained, and is sufficient to start the engine alone, as the pressure can be readily maintained at fifteen pounds or more above atmosphere, which, with a reasonable tank capacity, is ample to start the average engine. When, however, it is desired to start the engine without coupling or disconnecting the same from the vehicle or other machine which it drives, another phase of the invention is brought into operation, namely, the self-braking effect of the machine, produced by closing the exhaust manifold 32 by means of a three-way valve 32' therein, which is adapted to cut off the exhaust and divert the exhaust gases by way of a pipe 47 into the tank 43, said pipe 47 being connected to the exhaust manifold 32 at a point adjacent to said valve 32' as illustrated in Fig. 9. This choking of the exhaust builds up a heavy back pressure, the several pistons in exhausting the spent gases from the respective ends of the cylinders exercising a pumping action to build up the back pressure in the exhaust manifold, which is sufficient to bring the engine and the machine operated thereby to a quick stop, but without heavy shocks or jars or undue strain on the engine parts, for, while the back pressure is built up in a relatively short time, the increase in the back pressure is in proportion to the speed of the engine, so that sudden choking or stopping of the latter is practically impossible.

The relatively heavy pressure of the air and exhaust gases stored in the reservoir during the braking operation will be found to be sufficient to start the engine and the vehicle or other machine which it drives or operates with a steady acceleration, until the engine takes up its regular cycle of operation under the action of the explosive charges, which, of course, are taken in and passed through the regular cycles when the engine is turned over. It will therefore be seen that the back pressure as built up in the exhaust manifold and the storage tank 43 is not only effective in braking the engine and vehicle, but is also immediately available for starting the engine and vehicle smoothly and evenly without necessitating the shifting of gears, clutches or ordinary brake mechanism.

While the engine illustrated in the drawings involves differential pistons, it is to be understood that the invention is not limited to this particular type of apparatus, as pis-

tons of uniform diameter throughout may be employed with advantageous effects. Likewise, the number of cylinders may be varied, as may also the order of firing the several cylinders. In fact, the engine is susceptible of many changes as to the form, arrangement and co-operation of the parts without departing from the spirit of the invention, and it is to be understood that the claims directed to the same are to be given a correspondingly broad interpretation. The invention, however, probably finds its best exemplification in an engine of the six-cylinder type, such as illustrated, in which each cylinder is provided with a differential piston which serves as an air compressor, as described, but, what is more important, affords a greatly increased or augmented surface on the lower face of each of the pistons and correspondingly increased cylinder volume below the enlarged piston head, so that a practically complete expansion of the burning gases can be obtained and all of the heat generated thereby converted into effective work, and furthermore, the expansion of the exploding charge, which is bypassed to the under side of the large ends of the pistons in predetermined order, and the pressure of the exhaust from the upper end of the cylinder in which the exhaust stroke is taking place, will be effective in producing upward forces or pressures on various pistons which may be made to counterbalance the downward pressures of the other cylinders during the explosion strokes of the latter, so that the crank shaft will be practically free of vertical stresses and the resultant frictional losses will be obviated.

The operation of the apparatus as described is as follows, reference being had to the diagram in Fig. 9, and the cylinders firing in the order, 1, 4, 2, 6, 3, 5. Assume that the charge in cylinder No. 1 has been fired and the piston of No. 1 cylinder has completed a portion of its stroke represented by a 60° rotation of the crank shaft. At this time, the valve 35 in cylinder No. 1 connecting with the by-pass 70 is opened, permitting a part of the expanding gases above the piston in cylinder No. 1 to pass under the pistons in cylinders No. 2 and No. 5 which are at the lower limits of their strokes. The expanding gases therefore are exercising a downward thrust on the piston in cylinder No. 1, which is continued to the lower limit of the piston travel, and an upward pressure on the pistons in cylinders No. 2 and No. 5 which pressure is continued until these pistons reach their upper limits of movement. The exhaust valve adjacent each of the cylinders is timed to open when the piston in the corresponding cylinder begins its downward travel and remains open during 180° of the crank throw. Therefore, it will be seen that the exhaust valve 29 adja-

cent cylinder No. 1 is open during the entire power stroke of the piston in said cylinder, and any pressure on the lower side of the piston in cylinder No. 1 is immediately relieved through the exhaust. Just before the piston in cylinder No. 1 reaches the lower limit of its stroke, it uncovers port 80 admitting air under pressure from the manifold 40 ready to scavenge the products of combustion from the cylinder above the piston. The piston in cylinder No. 1 is now ready to begin its return stroke. This air under pressure also passes by way of valve 35 in cylinder No. 1 and by-pass pipes 70, and 71, under the pistons in cylinders No. 2 and No. 5, and this condition maintains until piston No. 1 begins its reverse movement. When the piston in cylinder No. 1 reaches the lower limit of its stroke, the exhaust valve adjacent said cylinder closes. It will be noted that the reverse movement of piston No. 1 is opposed by the air pressure admitted at port 80, but this will be compensated by the upward pressure on the lower sides of the pistons in cylinders No. 2 and No. 5. As soon as the piston in cylinder No. 1 closes the port 80 this air pressure is cut off. The continuation of the reverse movement of the piston in cylinder No. 1 forces the products of combustion and the scavenging air from the upper portion of the cylinder through the by-pass valve 35 and builds up the pressure on the under sides of the pistons in cylinders No. 2 and No. 5, and when the latter pistons reach the upper limit of their movement, the exhaust valves associated with the corresponding cylinders are opened and the gases in the cylinders below the pistons therein will be expelled when the pistons in No. 2 and No. 5 begin their downward stroke. Meanwhile, the piston in No. 1 continues its upward movement, completing the exhausting and scavenging of the products of combustion and air in the upper part of the cylinder, until it reaches the upper limit of its stroke, the exhaust passing out through the exhaust valves adjacent the cylinders No. 2 and No. 5. Simultaneously with this operation, the pistons in Nos. 2 and 5 are continuing their downward movement and expelling the gases in the lower portions of the respective cylinders through the same exhaust ports. The piston in cylinder No. 1 is then ready for its suction stroke and at this time, the exhaust valve adjacent cylinder No. 1 is opened and the by-pass valve 35 in cylinder No. 1 is closed. Immediately thereafter, the fuel intake valve 16 to cylinder No. 1 is opened and the piston in said cylinder begins its downward travel, the lower face of the piston forcing the air and products of combustion in the lower part of the cylinder through the exhaust port of said cylinder No. 1 past the open exhaust valve

therein. During the suction stroke of piston No. 1, the intake valve remains open for 120° of crank travel and, when the upper end of the piston uncovers the port 80, air, under pressure from the manifold 40 rushes into the cylinder to provide an excess of air necessary to afford complete combustion of the fuel delivered through the intake valve from the usual form of carburetor or other charge-forming device. The port 80 remains open until it is closed by the piston when the latter has made part of its return or compression stroke, the compression continuing until the piston reaches the upper limit of its stroke.

The charge is then fired and the series of operation, as described, is repeated in the usual and regular order of a four-cycle engine. The same cycle of operations is taken up and carried out by cylinders Nos. 4, 2, 6, 3, and 5 in sequence. By reference to the diagram in Fig. 10, it will be noted that cylinder No. 1 has fired and has traveled a distance equal to 60° of crank throw, at which time the piston in cylinder No. 6 has traveled an equal distance on its suction stroke; piston No. 5 is at the lower limit of its power stroke and has forced out the gases in the lower portion of its cylinder; the piston in cylinder No. 2 is beginning its compression stroke; piston in cylinder No. 3 is beginning the last 60° movement of its scavenging and exhaust stroke; and piston in cylinder No. 4 is at the corresponding point in its compression stroke, namely 60° of crank throw short of the top dead center. The conditions in the lower parts of the several cylinders below the pistons are as follows: The piston in cylinder No. 1 is forcing the exhaust gases past the open exhaust valve 29 associated with said cylinder No. 1, a portion of the expanding gases from the top of cylinder No. 1 is passing through by-pass pipes 70 and 71 under the pistons in cylinders Nos. 2 and 5 and develops an upward power stroke on the under faces of the pistons in these cylinders, thereby assisting the piston in cylinder No. 1 in driving the crank shaft and counterbalancing the vertical thrust on said shaft, so that the latter practically floats in its bearings. The lower portions of cylinders Nos. 3 and 4 are receiving the exhaust from the upper portions of cylinder No. 5 through the by-pass valve 35 and the by-pass pipes 77 and 73 and as this exhaust pressure is augmented by the scavenging air in the manifold 40, the lower faces of the pistons in cylinders Nos. 3 and 4 will be subject to this pressure which further tends to lift these pistons and relieve the crank shaft from vertical downward pressure.

The operation in starting the engine is as follows: Shaft 60 is rotated 180° to bring the levers 63, carried by the sleeves 62 on

the eccentrics 61, into the path of movement of the cams 66 on the cam shaft 26, one cam 66 being provided for each of cylinders Nos. 1, 2 and 3, and having the cam faces thereon spaced to operate the air intake valve 50 of each cylinder immediately after the exhaust valve of said cylinder is closed, which latter operation takes place when the piston in the corresponding cylinder reaches its lower limit of travel. The air under pressure in tank 43 is admitted to pipe 47 and manifold 48 by operating valve 45 by its operating handle 46, so that the pressure from the tank will be admitted to the manifold ready to be delivered to the cylinders in regular order.

Referring to the diagram in Fig. 9, it will be noted that the pistons in cylinders Nos. 2 and 5 are at their lower limits of movement and the pistons in Nos. 3 and 4 are approaching the upper limit of their movement, so that the cam 66, corresponding to cylinders Nos. 2 and 5 will unseat air intake valves 50 corresponding to said cylinders Nos. 2 and 5 when the cam shaft 60 is operated by hand to bring the levers 63 up into engaging position. The air pressure in the manifold will therefore pass into the lower portion of cylinder No. 2, thence by by-pass 71 to the lower portion of cylinder No. 5, and by-pass 70 to the upper portion of cylinder No. 1. The opening of air intake valve at the bottom of cylinder No. 3 admits the air pressure to the lower side of the pistons in Nos. 3 and 4, so that the air pressure is operating to force piston No. 1 downward and pistons Nos. 2, 3, 4 and 5 upward. This will be sufficient to initiate the starting operation. As the cams 66 have two operating sections, or dwells, at opposite points, and substantially 90° in extent, each air intake valve will be opened immediately its corresponding piston begins its upward movement and will remain open during approximately the 180° of crank throw. In other words, the valve 50 of each cylinder will close just before the corresponding exhaust valve opens, and open just after the said exhaust valve closes.

When the piston in cylinder No. 1 reaches the lower limit of its stroke and begins its upward movement, air intake valve 50 opens to admit air to the under side of the piston therein, and also to the upper side of the piston in cylinder No. 3, by way of by-pass 74, thence by way of by-pass sections 75 and 76 to the under side of piston in cylinder No. 6, which piston is beginning its upward stroke. At this time, the by-pass valve 35 in cylinder No. 4 is closed, so that the air will not interfere with the suction stroke of the piston in said cylinder No. 4. It will thus be seen that the air pressure is admitted to the tops and bottoms of the several cylinders in regular order to pro-

duce a powerful torque on the crank shaft and start the engine. It will be noted that the several by-pass valves and the exhaust valves are operated in their regular order and sequence to maintain the proper distribution of the air pressure to the cylinders and to effect exhaust of the air after it has done its work, the latter being brought about by reason of the fact that the exhaust valves of the cylinders are opened immediately after the valves which supply the air pressure to the corresponding cylinders are closed. It will be noted further that the air under compression used to start the engine does not interfere with the supply of fuel to the respective cylinders on the suction strokes, as the by-pass valve of each cylinder is closed during the whole intake stroke so that the starting air pressure does not have access to a cylinder which is taking a fuel charge.

The air pressure normally built up in the tank 43 is derived from the air which is compressed in the portion 3' of each cylinder on the upward stroke of the corresponding piston and is sufficient to start the motor alone, because of the heavy preponderance of the pressure on the under sides of the pistons which are moving upward over and above the pressure produced in one or more of the cylinders in which the gas charge is being compressed as the areas of the lower portions of the pistons are greatly in excess of the upper portion thereof, as hereinbefore described.

It is also to be noted that the engine may be effectively employed to brake a vehicle or machine which it is employed to drive, and this is accomplished by turning the valve 32' in the exhaust manifold to deliver the exhaust gases from all of the cylinders through the pipe 47, into the tank 43, the engine operating as a pump to compress these gases to a relatively high degree, the back pressure being effective to bring the engine and the machine driven thereby quickly to rest without unnecessary shocks or jars. The heavier pressure of gas thus produced in the tank will be sufficient to start, not only the engine, but the vehicle or other machine driven thereby without necessitating the shifting of gears or clutches or brakes so that both the engine and the machine may be started quickly and smoothly by the simple manipulation of the shaft 60 which controls the operation of the air intake valves 50 associated with the first three cylinders.

What I claim is:—

1. An internal combustion engine, comprising multiple double acting cylinders and a piston in each cylinder, each cylinder having a valved fuel inlet at one end and a valved exhaust outlet at the opposite end, by-pass conduits each connecting the

upper portion of one cylinder with the lower portion of a companion cylinder, valves controlling said conduits, means for opening the respective by-pass valves during the first part of the explosion cycle in the upper part of the corresponding cylinder, and means for holding the exhaust valve of each cylinder open during the explosion cycle of said cylinder, to provide an exhaust for the lower part of said cylinder and the upper part of a companion cylinder.

2. An internal combustion engine, comprising multiple double acting differential cylinders and a differential piston in each cylinder, each cylinder having a valved fuel inlet at one end and a valved exhaust chamber at the opposite end, by-passing conduits, each connecting the upper portion of one cylinder with the lower portion of a companion cylinder, valves controlling said conduits, means for opening the respective by-pass valves during the first part of the explosion cycle in the upper part of the corresponding cylinder, means for holding the exhaust valve of each cylinder open during the explosion cycle of said cylinder to provide an exhaust for the lower part of said cylinder and the upper part of a companion cylinder, and means for delivering air under pressure to the upper portion of each cylinder near the end of the suction stroke and during the first part of the exhaust stroke of the piston therein.

3. An internal combustion engine, comprising multiple double acting cylinders and a piston in each cylinder, each cylinder having a valved fuel inlet at one end and a valved exhaust outlet at the opposite end, by-pass conduits each connecting the upper portion of one cylinder with the lower portion of a companion cylinder, valves controlling said conduits, means for opening the respective by-pass valves during the first part of the explosion cycle in the upper part of the corresponding cylinder, means for holding the exhaust valve of each cylinder open during the explosion cycle of each cylinder, an exhaust manifold connected with the several cylinders, and means for closing the outlet of said manifold; whereby the several cylinders and pistons will operate as a pump to build up a back pressure to brake the engine.

4. An internal combustion engine, comprising multiple double acting cylinders and a piston in each cylinder, each cylinder having a valved fuel inlet at one end and a valved exhaust outlet at the opposite end, by-pass conduits each connecting the upper portion of one cylinder with the lower portion of a companion cylinder, valves controlling said conduits, means for opening the respective by-pass valves during the first part of the explosion cycle in the upper part of the corresponding cylinder, means

for holding the exhaust valve of each cylinder open during the explosion cycle of each cylinder, an exhaust manifold connected with the several cylinders, a pressure tank connected with said manifold, and means for closing the outlet of said manifold and delivering the exhaust gases to said tank; whereby the several cylinders and pistons will operate as pumps to build up a back pressure in the manifold and tank to brake the engine.

5. An internal combustion engine, comprising multiple double acting cylinders and a piston in each cylinder each cylinder having a valved fuel inlet at one end and a valved exhaust chamber at the opposite end, by-pass conduits each connecting the upper portion of one cylinder with the lower portion of a companion cylinder, valves controlling said conduits, means for opening the respective by-pass valves during the first part of the explosion cycle in the upper part of the corresponding cylinder, means for holding the exhaust valve of each cylinder open during the explosion cycle of said cylinder, air inlet valves located in the exhaust valve chambers of certain of said cylinders, an exhaust manifold connected with the exhaust valve chambers of the several cylinders, a pressure tank connected with the exhaust manifold and having connections with the exhaust valve chambers controlled by the air inlet valves, and manually adjusted means for operating the air inlet valves in proper sequence to admit pressure from the tank and distribute the same to the several cylinders to start the engine.

6. An internal combustion engine, comprising multiple double acting differential cylinders and a differential piston in each cylinder, the larger piston sections acting to compress air on the up strokes, a manifold to which said compressed air is delivered, by-pass conduits connecting the upper portion of each cylinder with the lower portion of a companion cylinder, valves controlling the by-pass conduits, means for opening the respective by-pass valves during the first part of the explosion cycle in the upper part of the corresponding cylinder, a valved exhaust chamber near the bottom of each cylinder, means for holding the exhaust valve of each cylinder open during the explosion cycle of said cylinder, a pressure tank connected with the air manifold and with the exhaust chambers of each cylinder, air inlet valves in said exhaust chambers, and means for opening the inlet valves in proper sequence to admit pressure from the tank and distribute the same to the several cylinders to start the engine.

In testimony whereof I affix my signature.

HERMON E. DUNHAM.