E. E. GRAY.

METHOD OF GENERATING POWER AND APPARATUS THEREFOR.

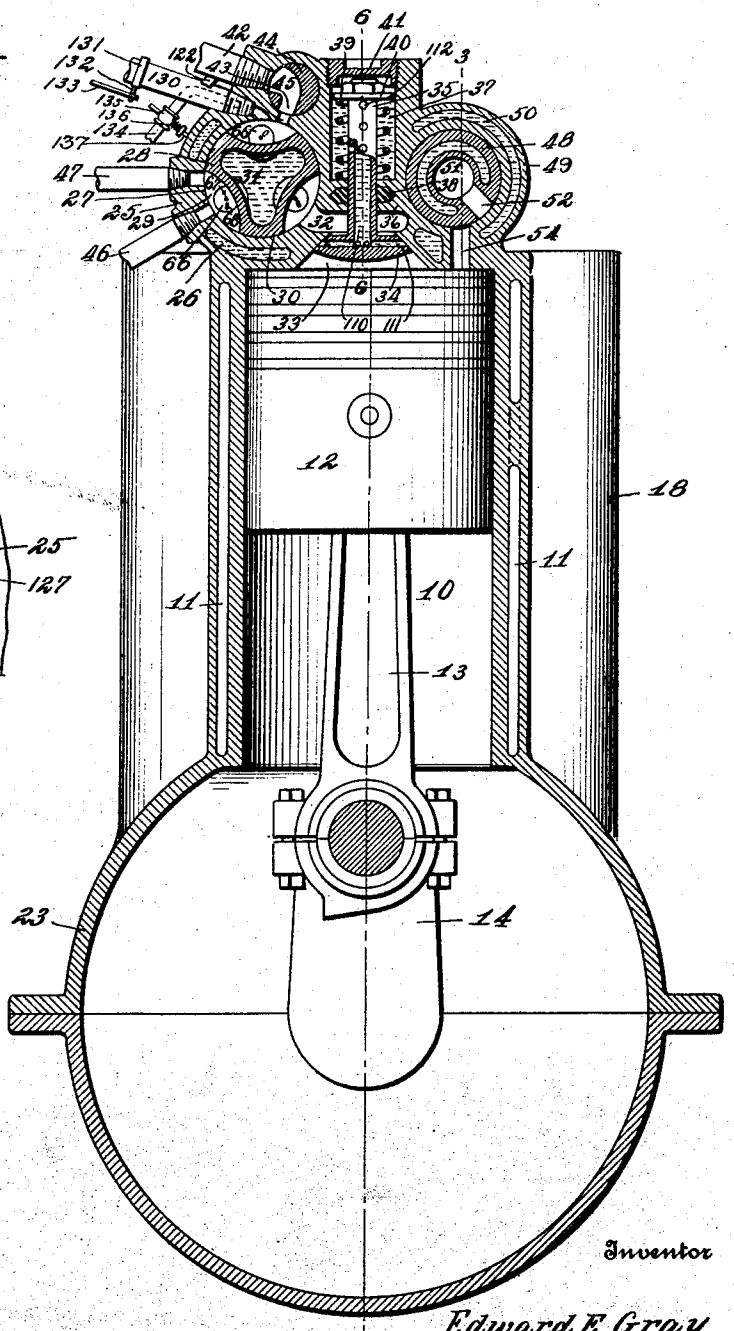
APPLICATION FILED MAR. 23, 1914.

1,147,085.

Patented July 20, 1915.

4 SHEETS—SHEET 1.

Fig 1



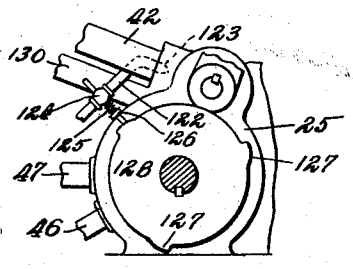


Fig 7

Witnesses

H. C. Robinette

N. C. Morse

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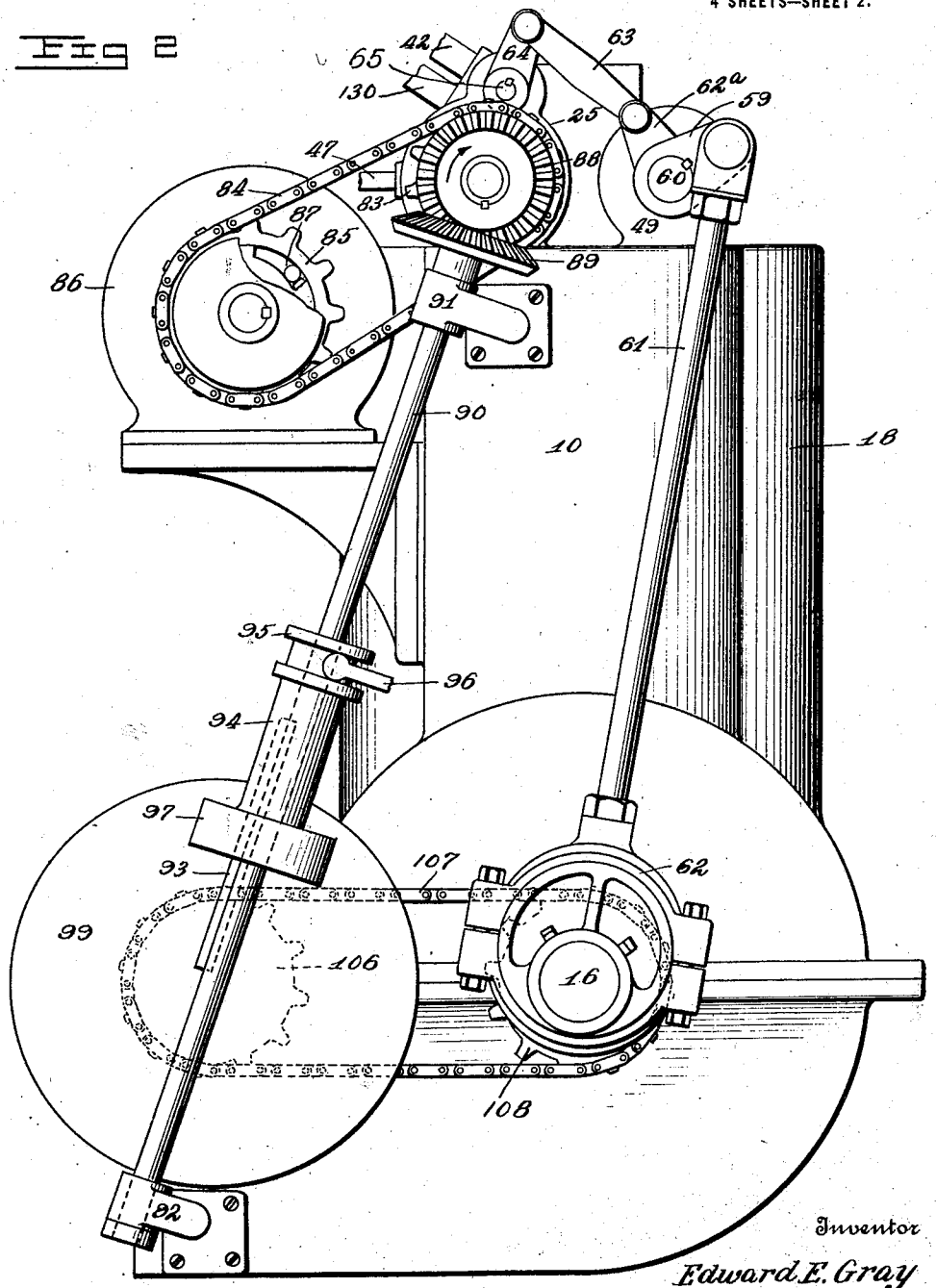
APPLICATION FILED MAR. 23, 1914.

1,147,085.

Patented July 20, 1915.

4 SHEETS—SHEET 2.

Fig 2



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METHOD OF GENERATING POWER AND APPARATUS THEREFOR.

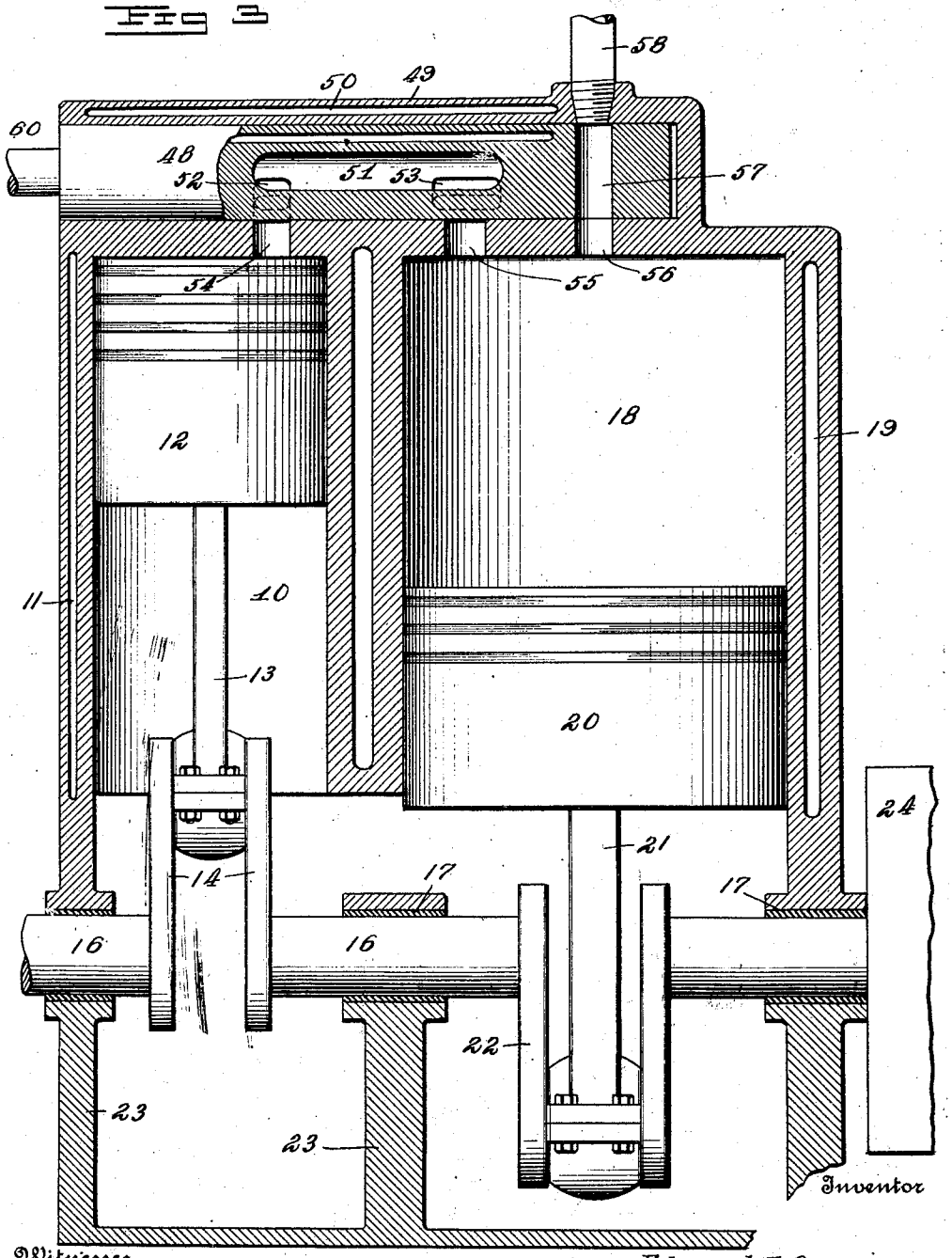
APPLICATION FILED MAR. 23, 1914.

1,147,085.

Patented July 20, 1915.

4 SHEETS—SHEET 3.

Fig 3



Witnesses

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METHOD OF GENERATING POWER AND APPARATUS THEREFOR.

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4 SHEETS—SHEET 4.

Fig 4

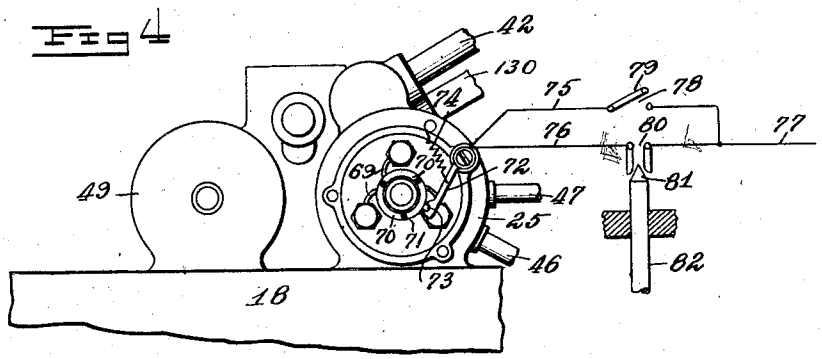


Fig 6

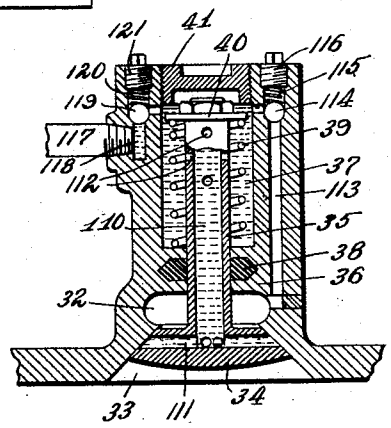
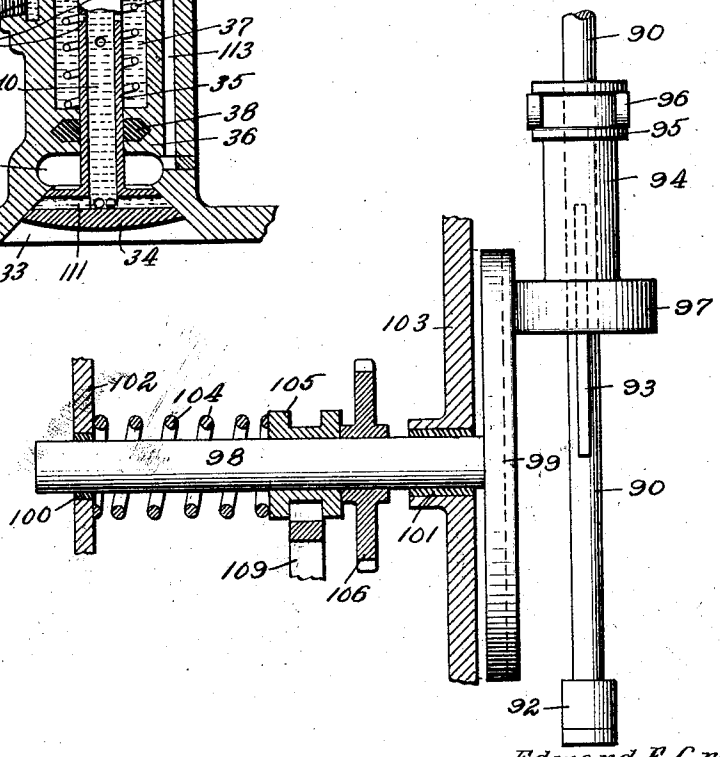


Fig 5



Witnesses

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UNITED STATES PATENT OFFICE.

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METHOD OF GENERATING POWER AND APPARATUS THEREFOR.

1,147,085. Specification of Letters Patent. Patented July 20, 1915.

Application filed March 23, 1914. Serial No. 826,647.

To all whom it may concern:

Be it known that I, EDWARD E. GRAY, a citizen of the United States, residing at Plano, in the county of Kendall and State of Illinois, have invented certain new and useful Improvements in Methods of Generating Power and Apparatus Therefor, of which the following is a specification.

This invention relates to methods of generating power and apparatus therefor; and it comprises more particularly a method of operating an internal combustion engine in which during each stroke, or during certain strokes of a power piston, a plurality of charges of hot combustion gases are caused to impart impulses, in more or less rapid succession to said piston, the number of such impulses in any stroke being variable; and the invention also comprises an engine in which such method may be carried out; the invention being more fully set forth in the accompanying description and claims.

A principal object of the invention is to provide for developing power by direct combustion of suitable fuel and expansion of the resultant combustion gases in such manner as to secure flexibility in operation and control of internal combustion engines to a degree far beyond that heretofore attainable.

Another object of the invention is to provide an internal combustion engine especially adapted for use on automobiles and other motor vehicles, said engine to have such flexibility of operation and control in the matter of speed and power requirements as to render possible the elimination of variable speed transmission gearing between the engine and the drive wheels of the vehicle so universally employed heretofore.

Another object of the invention is to accomplish the foregoing and other desirable results in a relatively simple manner while attaining high efficiency and consequent economy in engine operation.

Other objects of the invention will appear as the description proceeds.

Internal combustion engines have become highly developed in many respects within recent years, but no method has heretofore been devised for controlling and varying their speed of operation except within comparatively narrow limits. The difficulty has been largely due to the fact that in all types of internal combustion engines which have thus far proved of any practical value, the impulse for each working stroke of the piston is provided by the explosion or other rapid combustion of a single combustible charge, this charge being ignited usually rather near the start of the working stroke and the expansion of the resultant hot combustion gases from this single explosion being relied upon to drive the piston to the other end of its stroke. This method necessarily results in wide variation in the intensity of driving effort on the crank shaft during the working stroke, varying from a sharp maximum at the moment of explosion or ignition to a relatively low minimum at the conclusion of the working stroke. The result is a jerky or non-uniform thrust on the crank; and anything more than the roughest approximation to speed regulation is obviously out of the question. Greater smoothness of operation has been attained to some extent by multiplying the number of cylinders and arranging the relative angular positions of the several cranks in such manner as to secure a more constant resultant effort on the shaft. Internal combustion engines have also been proposed in which a power piston uncovers several explosion ports successively during its power stroke and thus receives a plurality of impulses; but the number of impulses per stroke in such engines remains constant. But the question of accurate and flexible regulation of the speed of the engine shaft has remained to a large extent untouched. A certain degree of speed regulation has been possible by the familiar expedient of advancing or retarding ignition of the combustible charge; but, as is well known, this method is effective only within relatively narrow limits and is entirely insufficient for the wide range of speed variation requisite in operating a motor vehicle, for example. It has therefore been necessary to interpose variable speed transmission gearing between the engine shaft and the driving wheels of the vehicle, the engine being permitted to run at its slightly variable normal speed, while the various component numbers of the transmission gearing are shifted as required to transmit modified motion from the engine shaft to the drive wheels. Such transmission devices are of various types; but they are all more or less complicated and are notoriously troublesome and unsatisfactory, as well as expensive in first cost and up-keep. It is highly desirable,

therefore, that such variable speed transmission gearing be eliminated, and that the speed of the vehicle be controlled solely by regulating the speed of the engine. The attainment of this end forms, as stated, an important object of the present invention.

Broadly considered, the invention contemplates driving a reciprocable piston or equivalent power member by means of separate fluid pressure impulses, of which a plurality may be applied to the power member during a single working stroke or phase movement thereof, and varying the number and rapidity of succession of such impulses per stroke or phase movement without any necessary fixed relation to the speed of said power member.

Especially marked advantages are realized in applying the principles of my invention to internal combustion engines; and the invention thus finds its greatest utility at present in connection with engines of this general description. In the following discussion, therefore, the application of the principles of the invention to internal combustion engines, and more particularly to engines of the reciprocating type, will be referred to at length in illustrating the best embodiment of the invention now known to me.

According to the present invention, the force for driving the movable power transmitting or motor element of the engine, as for example the piston in the case of a reciprocating engine, is derived not by igniting a single relatively large charge of combustible mixture at each working stroke or analogous movement of the motor element, but by igniting relatively small or fractional charges of combustible mixture and causing them to act successively on the piston during the working stroke, the number of charges per stroke being capable of variation. In other words, I make use of a plurality of explosions during each working stroke; and the number of explosions per stroke may be varied from zero to any desired maximum in accordance with power requirements. That is to say, the range of variation may, and ordinarily does, include different pluralities of impulses per stroke. In this way the amount of power necessary at any given moment may be supplied with substantially perfect accuracy; and consequently the speed of the engine may be controlled with similar accuracy. It is obvious that in many cases under this mode of operation, the charges exploded during the latter part of any working stroke do not expand to anything like the extent possible. It is therefore particularly advantageous in the present invention to expand the exhaust gases from a high pressure cylinder to a low pressure cylinder in order that they may expand as far as is practicable and thus utilize the energy of the gases as far as possible. I accordingly prefer to employ a compound engine in carrying out the method herein disclosed. It is to be understood, however, that the invention is not limited to a compound engine.

The successively acting relatively small charges may be caused to act on the piston in any suitable manner. Thus, the charges may be ignited in the high pressure cylinder itself, or they may be ignited outside the cylinder and the resultant hot combustion gases caused to enter the high pressure cylinder in suitable succession. The important point is that the rapidity with which these charges are ignited and consequently the rapidity with which the successive resultant impulses act on the piston shall be variable at the will of the engine operator to control and vary the speed of the engine shaft as requirements may dictate.

In order to properly regulate cylinder temperatures and also to obtain the full benefits of compounding the expansion, it is very desirable that a controllable amount of water or water vapor be introduced into the high pressure cylinder with each of the successively ignited charges. Most advantageously a small amount of water is caused to enter with each charge at the moment of ignition, this water flashing instantly into steam which, after acting in conjunction with the hot combustion gases on the high pressure piston, is exhausted therewith into the lower pressure cylinder where it does further work. The absorption of heat by the evaporation of the water thus introduced aids materially in keeping the cylinder walls at the proper working temperature.

The essential principles of the present invention may obviously be carried out in various forms of engines differing from each other in details of construction. In order to illustrate more clearly the nature of the invention, I have, however, shown in the accompanying drawings one type of engine embodying the principles of my invention.

In these drawings, Figure 1 is a central longitudinal section through the high pressure cylinder; Fig. 2 is an elevation showing the mechanism for actuating the valves; Fig. 3 is a section through both cylinders on the line 3—3 of Fig. 1; Fig. 4 is a detail of the ignition means; Fig. 5 is a detail, partly in section, of the mechanism for controlling the rotation of the charging valve; Fig. 6 is a detail section of the admission valve on the line 6—6 of Fig. 1, the parts being shown on a somewhat larger scale; and Fig. 7 is a detail illustrating one form of carbureting means.

Referring to the drawings, 10 is the high pressure cylinder, water jacketed at 11, within which is arranged to reciprocate piston 12, connected by rod 13 to crank 14, the

crank being fixed to the engine shaft 16 carried in suitable bearings as at 17. 18 is the low pressure cylinder, water jacketed as at 19 within which reciprocates piston 20 connected by rod 21 to crank 22 on the engine shaft. The cranks are best housed in a casing 23 of any suitable type. As shown, the displacement of the low pressure cylinder is materially greater than that of the high pressure cylinder, and the cranks are set 180 degrees apart. The engine shaft is best provided with a relatively heavy fly wheel 24 fixed thereto.

In the example here illustrated, air is compressed to a suitable pressure, to as high as 200 pounds for example, outside the engine, and is carbureted at or just prior to admission to the engine. Separate charges of combustible mixture thus formed are ignited prior to actual admission into the high pressure cylinder itself, the ignited charges being then admitted in controlled sequence to the high pressure cylinder through a suitable inlet valve. As here illustrated, the high pressure cylinder is provided at one end with an extension or housing 25, water jacketed as at 26, and provided with a slightly tapered cylindrical bore or chamber 27 within which is arranged to revolve a charging valve or member 28, provided with a plurality of pockets 29, in this instance three, extending longitudinally of the valve member. The bearing faces 30 of the valve are suitably tapered to conform with the tapering interior of chamber 27 so as to form a close sliding fit therewith. This charging member may be, and advantageously is, hollow as shown at 31, to provide for internal water cooling. The charging valve is arranged to be revolved by mechanism to be hereinafter fully described. Chamber 27 communicates with the interior of the high pressure cylinder by way of a passage or combustion space 32, opening into the cylinder through tapered or conical port 33 of ample width located in the end of said cylinder in the present example. This port is controlled by a conical inlet valve 34 whose stem 35 projects with a sliding fit through the wall 36 into a chamber 37 the purpose of which will be explained later. The valve stem may be packed as at 38 to insure a tight joint. A spring 39 under compression between a collar 40 on the valve stem and the bottom of said chamber normally holds the valve firmly on its seat. A screw threaded plug 41 is arranged to tightly close the outer end of the chamber in which the valve stem works.

Combustible mixture under pressure is supplied to the pockets of the revoluble charging valve through a conduit 42 and a port 43 in the valve housing, the connection between said conduit and said port being controlled by a revoluble member 44 provided with a port or passage 45. By suitable rotation of this controlling valve member, connection between 42 and 43 may be established or cut off as required. Leading into chamber 27 is a compressed air conduit 46, and adjacent thereto is a discharge outlet 47, the inner ends of conduits 46 and 47 being so located that each of the pockets 29 at a certain point in its travel is open to both conduits 46 and 47 simultaneously. The purpose of this arrangement will be explained later.

Opposite to the charging valve and at the same end of the cylinder is arranged the revoluble exhaust valve 48, contained in a housing 49 which may be water cooled as at 50, the valve being slightly tapered to closely fit a correspondingly shaped bore in the housing. The exhaust valve has a longitudinal passage or port 51 from which lead branches 52 and 53 which are arranged substantially parallel to each other and extend radially from said central passage to the periphery of the valve member. Branch 52 is arranged to register at proper times with exhaust passage 54 leading from the high pressure cylinder, while branch 53 is arranged to register simultaneously with inlet 55, whereby the exhaust gases from the high pressure cylinder may be admitted to the low pressure cylinder for further expansion.

Leading from the low pressure cylinder is exhaust port 56 with which is arranged to register at proper times a passage 57 extending transversely through the valve member 48 and serving to connect port 56 with discharge outlet 58 through which the exhaust from the low pressure cylinder is discharged into the atmosphere.

The exhaust valve is oscillated to bring passages 52 and 53 into and out of registry with ports 54 and 55, respectively and to bring the passage 57 into and out of registry with exhaust outlet 58, by means of crank 59 suitably keyed to the valve stem 60 and actuated by valve rod 61, driven by eccentric 62 adjustably secured to the engine shaft. Means are also provided for preventing the passage of combustible mixture into the pockets of the charging valve during the exhaust stroke of the high pressure piston. In the present example this is accomplished through the agency of a crank 62^a also keyed to valve stem 60 and connected by link 63 to crank 64 keyed to stem 65 of the controlling valve 44. The arrangement of parts is such that when exhaust valve 48 is in proper position to connect the high and low pressure cylinder, the controlling valve 44 is turned to cut off communication between charging conduit 42 and port 43.

The operation of the parts thus far mentioned may be briefly described as follows:

The pocketed charging valve is arranged to be rotated in clockwise direction. During a working stroke of the high pressure piston, each pocket as it passes port 43 receives a charge of combustible mixture under pressure; and then passing further, the pocket is placed in communication with the space or passage 32, whereupon the charge is ignited by means to be described later. The pressure developed by the ignition of the charge forces the valve 34 inwardly, the highly heated explosion gases flashing past the lifted valve into the high pressure cylinder. The pocket in question is next brought into registry with scavenging ports 46 and 47, compressed air entering through 46 and sweeping out any remaining combustion gases in the pocket through port 47. The valve pocket is then again presented to charging port 43 and goes through the same cycle of operations again. Each pocket of the charging valve goes through repeatedly the same cycle of operations just described, receiving a compressed charge, igniting the charge which then enters the high pressure cylinder, and then being scavenged in the third and last step of the cycle. The charging valve is rotated at a rate sufficient to produce the necessary or desired number of explosion impulses on the high pressure piston during the downward or working stroke under the particular conditions of operation at any given moment. In other words the frequency or rapidity of succession of these impulses, that is, the number of impulses per stroke and the intervals between succeeding impulses, may be varied at will by varying the speed at which the charging valve is revolved. There is no necessary fixed relation between the speed or rate at which this charging member revolves and the speed of the engine. Thus the rapidity of succession with which the combustible charges are fired in impelling relation to a power-transmitting or motor element of the engine, in this instance the reciprocating piston, may be varied asynchronously with respect to the movement of said motor element or member. It is not to be inferred, however, that this method of operation necessarily excludes automatic actuation and control of the revoluble charging member, although for certain purposes, and especially where the engine is employed on an auto vehicle, it is most desirable that such control be effected at the will of the operator, rather than automatically.

In the specific embodiment of the invention here shown, the controlling valve 44 is turned to cut off communication between ports 42 and 43 at or shortly before the end of the working stroke of the high pressure piston; and as long as the controlling valve is in this position, that is, substantially throughout the exhaust stroke of the high pressure piston, the charging member revolves idly, no charges being received by its pockets and therefore none being fired into the high pressure cylinder. This operation of the controlling valve is subject to modification under certain conditions as will appear hereinafter. At about the same time that the controlling valve is thus turned to cut off the charging ports, the exhaust valve 48 is rotated to open communication between the high pressure and low pressure cylinders; whereupon, during the movement of the high pressure piston on its upward or return stroke, the high pressure exhaust gases pass over into the low pressure cylinder where they expand further and drive the low pressure piston downwardly. The high pressure piston having reached the limit of its return stroke and the low pressure piston having at the same time reached the limit of its downward or working stroke, the controlling valve 44 is turned to connect 42 and 43, while valve 48 is turned to cut off communication between the high and low pressure cylinders and to place the low cylinder exhaust port 56 in communication with exhaust pipe 58 through transverse passage 57. The high pressure piston is then driven downwardly by the successive explosion impulses imparted to it by the continued rotation of the charging valve, while the low pressure piston moves upwardly and exhausts waste expanded gases to atmosphere. The described movements of the controlling valve and exhaust valve are effected, as before explained, by means of the eccentric 62 on the engine shaft acting through the crank and link connections clearly shown in Fig. 2 and therefore occur in timed relation to the piston strokes.

Means for igniting successively the charges presented to the ignition space 32 by the revolving charging valve will now be more fully described. In the rear end of the charging valve are screwed or otherwise suitably secured spark plugs 66, one for each valve pocket. The sparking terminals of each plug are indicated at 67—68 in Fig. 1. These plugs are electrically connected, respectively, as at 69 to segments 70 of a commutator (Fig. 4), the several segments being insulated from each other as at 71. This commutator and the spark plugs connected thereto are mounted to revolve with the charging valve. Mounted on the valve housing is a brush holder 72 carrying a brush 73, pressed against the commutator as by spring 74. The brush holder is connected in the present example to the live terminal of the secondary winding of a spark coil (not shown) by a pair of branch leads 75 and 76 which unite to form a single lead 77 connected to the spark coil. The timer in the primary circuit of the spark coil makes the same number of contacts per revolution of

its revoluble member as there are charging pockets in the revoluble charging valve; in this instance three. The revoluble member of said timer is arranged to be positively driven from the charging valve stem at the same number of revolutions per minute as the valve itself. The timer mechanism may be of any usual or suitable construction; and since it may be of the ordinary commercial type now in general use, it is deemed unnecessary to illustrate same here. The branch lead 75 has a gap as at 78 which is normally open, but which may be closed by a switch 79. The other branch lead 76 may be opened and closed at 80 by a circuit breaker 81 arranged to be operated through a suitable connection such as rod 82 actuated by an eccentric (not shown) on the engine shaft. The arrangement is such that the circuit is open substantially throughout each high pressure exhaust stroke and closed during each working stroke.

From the foregoing it is evident that there will be a spark across the gap between the terminals of each and every spark plug once each revolution of the charging valve during each high pressure working stroke, that is, every time one of the charging pockets reaches the proper position to have its charge fired into the combustion space 32.

Any suitable arrangement for variably revolving the charging valve without fixed relation to the engine speed may be employed. In the present instance the valve stem is provided with a sprocket 83 connected by a sprocket chain 84 to a sprocket collar 85 arranged to be driven by a variable speed electric motor 86 through a suitable roller or ball clutch 87 keyed to the motor shaft. The motor is energized in any suitable manner as, for example, by means of a storage battery; and its speed may be controlled and varied in any suitable manner, by any known or suitable controller which it is unnecessary to illustrate here. The charging valve may be rotated by means of this motor alone, if desired. I prefer, however, to employ the electric motor only in starting the engine from rest, and to employ other variable speed means to drive the charging valve after the engine has speeded up. In the present example the stem of the charging valve is shown as also provided with bevel-gear 88 which is arranged to mesh with a gear 89 carried by a shaft 90, journaled as in brackets or the like, 91 and 92, on the engine casing. On this shaft is splined as at 93 a sleeve 94 which can move longitudinally on the shaft, but which is arranged to drive said shaft. This sleeve is provided with a grooved collar 95 with which is adapted to engage the forked end or head of a lever or rod 96 to shift the sleeve along said shaft. The rod 96 may be controlled and actuated in any suitable way as by means of a hand or foot lever located in a position convenient for the engine operator. Said sleeve is also provided with a friction cylinder 97, the purpose of which will presently appear.

A shaft 98 (Fig. 5) carrying friction disk 99 is suitably journaled as at 100 and 101 in brackets or the like, 102 and 103. This shaft is movable longitudinally in its journals and is normally pressed toward the right to force friction disk 99 against friction cylinder 97 by a spring 104 abutting against 100 and exerting thrust on a collar 105 fixed to the slidable shaft. Shaft 98 also carries fixed thereto a sprocket 106, arranged to be driven through sprocket chain 107 and sprocket 108 carried by the engine shaft. It is evident that rotation of the engine shaft will drive shaft 98, thereby rotating friction disk 99 and transmitting rotational movement through disk 97 and sleeve 94 to shaft 90, which in turn will rotate the charging valve through the agency of gears 89 and 88. The speed at which shaft 90 is thus rotated may obviously be varied by shifting sleeve 94 so as to move contact cylinder 97 toward or from the center of friction disk 99, the speed diminishing to zero as the cylinder is moved toward the center of the disk, and increasing as the cylinder is moved toward the disk periphery.

A forked lever 109, actuated in any suitable manner as by a convenient hand or foot lever connection, is arranged to engage a groove in collar 105 and to move said collar and the shaft 98 toward the left, against the action of spring 104, and thereby to draw friction disk 99 slightly away from disk or cylinder 97 when necessary.

It is very desirable in the present invention to introduce water, water vapor or steam into the high pressure cylinder along with the combustible charge. The water thus introduced serves a double purpose. In the first place it prevents the cylinder walls from becoming heated to an inconvenient high temperature; and furthermore in thus functioning, it is transformed into steam which can be usefully employed in the secondary expansion in the low pressure cylinder. The best results are obtained by introducing a small quantity of water with each one of the relatively small charges substantially at the instant of ignition; and to this end the inlet valve here illustrated is of a peculiar construction now to be described.

The stem of the inlet valve is hollow as shown, to provide a water passage 110 from the lower end of which extend a plurality of radial branches 111 terminating at the conical peripheral face of the valve head. The upper portion of the hollow valve stem has suitable lateral orifices 112 affording communication between passage 110 and the

cylindrical water chamber or reservoir surrounding the upper part of the valve stem. The combustion or ignition space 32 is connected to the upper part of said water reservoir by means of a by-pass 113 provided with a ball check valve 114 which is normally held on its seat by a spring 115, whose degree of compression may be varied by adjusting threaded abutment 116. Water preferably under pressure is supplied to the water reservoir through a supply conduit 117 opening into passage 118 leading to the reservoir and controlled by a ball check valve 119 normally held to its seat by a spring 120, having an adjustable threaded abutment 121.

The operation of the charge inlet valve above described will be readily understood from the foregoing. As each charge is fired into the chamber 32, an extremely high pressure momentarily results, which allows a small quantity of gas to pass around through passage 113, and check valve 114, into the upper part of the water reservoir. Almost simultaneously the gas pressure in chamber 32 lifts valve 34 from its seat, allowing the intensely hot explosion gases to pass out into the high pressure cylinder thereby decreasing the pressure in chamber 32. At the instant that valve 34 is thus lifted the high pressure gas trapped in the water reservoir forces sufficient water out through the passages in the conical valve head to equalize the difference in pressures between chamber 32 and the water reservoir. It is apparent therefore that a sudden squirt of water will take place through the inlet valve 34 at the moment when the valve is completely surrounded with a mantle of burning gases rushing into the high pressure cylinder. The water thus injected immediately flashes into steam with the attendant advantages above set forth.

Means should be provided for supplying air under pressure to be carbureted and introduced into the high pressure cylinder by way of the rotary charging valve; and compressed air is also provided for scavenging the pockets of the charging valve as above described. Any suitable means for this purpose may be employed. For example an air pump may be driven from the engine shaft to compress air in a suitable storage tank or reservoir, from which the compressed air may be led by suitable ducts to the charging valve for mixture with fuel or for scavenging purposes. This pump may be conveniently arranged for automatic control like a well known type of compressor in common use in connection with air brake systems, whereby the pump operates only so much of the time as is necessary to maintain a given desired pressure in the compressed air reservoir.

The reservoir should be of sufficiently large capacity to insure maintenance of a substantial reserve of compressed air for starting the engine from rest. The reservoir may also be provided with suitable pressure regulating means so that pressure of any desired degree may be maintained. The specific forms of pump and reservoir to be used constitute no part of the present invention and do not require illustration.

The air may be carbureted in any convenient way to form a combustible mixture. In the present example the fuel is assumed to be gasolene, for purposes of illustration; and it is introduced into the compressed air just as the air enters a pocket of the charging valve. In Fig. 7 is illustrated one form which the carbureting device may assume. A gasolene supply pipe 122 enters conduit 42 near its discharge end and is provided with a suitable atomizing jet or nozzle 123 which may be a needle valve provided with suitable flow-adjusting means (not shown). A valve 124 in the supply is normally held closed by a spring 125 acting on extension 126 of the valve stem. Cams 127 are carried by a member 128 arranged to rotate with the charging valve and to engage extension 126 of the valve stem successively as the valve rotates, the number and arrangement of the cams being such that the valve is opened just as the advancing edge of each pocket of the charging valve comes to the charging port 42—45—44. Gasolene being supplied to the pipe 122 under suitable pressure, gasolene is injected through the atomizing nozzle as each pocket passes the charging port.

The operation of the engine is obvious from the foregoing description. Assuming the engine to be at rest, the shifting fork 109 is pulled to the left to disengage friction disk 99 from the friction cylinder 97. By manipulating a suitable controller, current is then passed through the small starting motor which operates through its chain and sprocket connections to rotate the charging valve. This causes a sufficient number of charges to be fired into the cylinder to start the engine. After the engine has attained sufficient speed, the friction disk 99 is allowed to contact with the friction cylinder 97, the shaft 98 of the friction disk being now rotated, of course, through its sprocket and chain connections by the engine shaft. Current being now shut off from the motor, whose sprocket collar 85 now runs idle shaft 90 is driven thereafter from the engine shaft and rotates the charging valve through the bevel gear connections between the shaft and the valve stem. The rapidity of succession or sequence with which the charges are fired into the cylinder may be varied as desired, by shifting sleeve 94 along its shaft by means of forked rod or lever 96 in the manner already described. Movement of the

sleeve toward the center of the friction disk obviously diminishes the speed at which friction cylinder 97 is rotated, this speed being zero when the friction cylinder is at the center of the disk. Movement of the sleeve in the opposite direction increases the speed at which the friction cylinder is rotated, a maximum being attained at the periphery of the friction disk. Evidently the described arrangement permits the speed of the charging valve, and hence the rapidity of succession of the impulses supplied to the piston, to be varied without fixed relation to the speed of the engine. This provides for substantially perfectly flexible control of the speed at which the charging valve is rotated, and consequently of the power and speed performance of the engine.

The operation of the high and low pressure pistons in their respective cycles has been fully discussed above and does not need to be described further.

It is to be noted that the separate individual charges introduced by the rotating charging valve are best relatively small, much smaller than the charge ordinarily employed in the single explosion type of engine. The number of such charges introduced during any working stroke of the engine varies of course with the varying requirements to which a given engine is subjected; and it may also obviously vary in different engines constructed in accordance with the present invention even when such engines are operating under the same conditions. Ordinarily the sequence of charges will be most rapid when the engine is being started.

While I have illustrated in the present example means for maintaining the ignition circuit open during the high pressure exhaust stroke, and in practice this is a convenient arrangement, it is not essential to provide such means for the reason that in the specific form of engine here shown, the charging port is closed during the high pressure exhaust and thus no charges are introduced into the pockets of the charging valve during this stroke. If the charging valve is rotating very slowly at the moment the high pressure piston begins its exhaust stroke there may occasionally be a residual charge in one of the pockets not yet ignited which would be fired during the exhaust stroke if the ignition circuit remained closed. But this would do no special harm because the ignited charge would simply expand into the low pressure cylinder, the high and low pressure cylinders being in free communication during the high pressure exhaust stroke. It is to be understood therefore that means for periodically interrupting the ignition, while convenient, are not essential and may be dispensed with.

If means for breaking the ignition circuit are employed, as described, it is evident that the charging port may remain open continuously instead of being closed during high pressure exhaust. In such case the charges received by the pockets during exhaust would remain unignited and would be scavenged to waste. This would mean uneconomical operation of the engine; but by providing means for cutting off compressed air from conduit 46 during high pressure exhaust this waste can be avoided. Furthermore, the engine will still operate if the charging port always remains open and the ignition is uninterrupted. Under these conditions, charges fired into the high pressure cylinder during the exhaust stroke of its piston pass largely into the low pressure cylinder at once. The fact that the low pressure piston is of much greater area than the high pressure piston insures large excess of pressure on the low pressure piston and hence uninterrupted operation of the engine. Variations such as those just mentioned are typical of many changes which may be made within the scope of the present invention.

In describing starting the engine, it was assumed that the high pressure piston had stopped at some point during its downward or power stroke, the charging port being open and the ignition circuit closed. With the present type of engine, however, the high pressure piston may come to rest at any point in either stroke when the engine stops. If the piston comes to rest during its exhaust stroke, it is evident that in the particular embodiment of the invention here illustrated the charging port 42—43 will be closed and the ignition circuit open; and under these conditions rotation of the charging valve does not suffice to start the engine, unless auxiliary means of some nature are provided to introduce combustible mixture into the pockets of the charging valve and to insure ignition thereof. For this purpose various expedients may be adopted. In the present example I provide a secondary compressed air conduit 130 opening directly into the chamber of the rotary charging valve. This conduit has a valve 131, provided with an arm 132 secured to its stem. The valve may be opened or closed by means of a rod or the like 133 connected to said arm and operated in any convenient way as by a hand lever or pedal, not shown. The secondary conduit is also provided interiorly near its discharge end with a nozzle for atomizing liquid fuel, said nozzle being similar to that in the main charging conduit, and its fuel supply pipe 134 being provided with a valve 135 normally held closed by a spring 136 acting on shouldered extension 137 of the valve stem. This valve is arranged to be lifted by any convenient mechanism to spray fuel from the atomizer as each charging pocket passes the end of

the secondary conduit. This may be effected, for example, by a rotatable member provided with cams, said member being conveniently mounted upon or otherwise driven by the shaft of the electric starting motor. This valve actuating mechanism may be similar to that operating the valve of the main fuel supply pipe, and it is deemed unnecessary therefore to illustrate it.

In order to start the engine when the high pressure piston has come to rest during its exhaust stroke, it is only necessary to close the switch 75, open valve 131 and start the electric motor, all three operations being conveniently effected by common actuating means, if desired; whereupon the charging valve rotates and fires successive charges into the high pressure cylinder. Since the high and low pressure cylinders are in free communication in this phase, the low pressure cylinder is forced down by reason of its greater area, while the high pressure cylinder completes its exhaust stroke. As soon as the engine is well started, current is shut off from the motor, switch 75 is opened and valve 131 closed, the engine then continuing its normal operation.

No specific means for reversing the engine is here illustrated; although the use of any suitable mechanism, where necessary, is contemplated. When the single acting engine here illustrated is used on an automobile or the like, it is sometimes more convenient to employ a reversing gear between the engine and the driving wheels of the vehicle, and to actuate the same by any suitable type of clutch device.

While I have illustrated a single acting engine in the present instance, the principles of the invention may of course be embodied in a double acting engine by comparatively simple alterations in design. For example, the arrangement of charging and exhaust valves here shown may be provided at both ends of a closed cylinder; and in such an arrangement, the engine may be readily reversed by shifting the positions of the valves at the opposite cylinder ends in a well known manner. It is also to be understood that the invention is not restricted to compound engines, although for many purposes, its advantages are realized to a greater extent in a compound engine than in a simple engine. The principles of the invention are also applicable to multicylinder engines, either simple or compound.

The engine of the present invention as here illustrated is adapted for use with practically any fuel which can be mixed in the form of vapor or gas with air to form a combustible charge, such as gasolene, benzin, alcohol, fuel gas, etc. For the sake of simplicity, a single acting engine has been selected to illustrate the principles of the invention. It is to be understood, however, that the same principles can be embodied in a double acting engine by obvious modifications in design.

While the invention has been described more particularly in connection with internal combustion engines, and while, as stated it is peculiarly adapted to and of greatest present utility in such use, nevertheless in its broader aspects the invention is not limited in its application to internal combustion engines.

What I claim is:

1. The method of generating power which comprises subjecting a movable motor element to successive fluid pressure impulses, and varying the rapidity of succession of such impulses while said element is moving and without fixed relation to the speed thereof, the range of variation including different pluralities of impulses per phase movement of said element.

2. The method of generating power which comprises expanding a plurality of separate portions of hot combustion gases successively in impelling relation to a movable motor element, and varying the rapidity of succession of such impulses while said element is moving and without fixed relation to the speed thereof, the range of variation including different pluralities of impulses per phase movement of said element.

3. The method of generating power which comprises subjecting a reciprocable piston to successive impulses derived from the expansion of a compressed fluid, and varying the rapidity of succession of such impulses while the piston is moving and without fixed relation to the speed thereof, the variation being conducted in such manner as to subject said piston to different pluralities of impulses per working stroke.

4. The method of operating an internal combustion engine which comprises igniting separate combustible charges successively in impelling relation to a reciprocable piston, and varying the rapidity of succession of such impulses while said element is moving and over a range of variation which includes different pluralities of impulses per phase movement of said element.

5. The method of operating an internal combustion engine which comprises firing combustible charges successively in impelling relation to a movable motor element of said engine, and varying the rapidity of firing in accordance with power requirements while the engine is operating and without fixed relation to the speed of the engine, the range of variation including different pluralities of impulses per phase movement of said element.

6. The method of operating an internal combustion engine which comprises firing relatively small combustible charges in very rapid succession in impelling relation to a

movable motor element of said engine, and varying the rapidity of firing in accordance with power requirements while the engine is operating and without fixed relation to the speed of the engine, the range of variation including different pluralities of impulses per phase movement of said element.

7. The method of operating a reciprocating internal combustion engine which comprises firing a plurality of fractional combustible charges successively in impelling relation to the engine piston during a working stroke thereof, and varying the rapidity of succession while the engine is operating and in such manner as to act upon said piston with different pluralities of charges per working stroke.

8. The method of operating a reciprocating internal combustion engine which comprises firing charges successively in impelling relation to the engine piston, and varying the rapidity of firing in such manner as to subject the piston to different pluralities of impulses per working stroke in accordance with power requirements.

9. An engine comprising the combination, with a power cylinder and a piston reciprocable therein, of means operable to subject said piston to a plurality of separate fluid pressure impulses during a working stroke, and mechanism for regulating the operation of said means in such manner as to vary the rapidity of succession without fixed relation to the engine speed and the number of such impulses per working stroke over a suitable range of different pluralities in accordance with power requirements.

10. An engine comprising the combination, with a power cylinder and a piston reciprocable therein, of means for subjecting said piston to a variable plurality of separate fluid pressure impulses successively per working stroke, and means movable at variable speed to vary the rapidity of succession of such impulses in such manner as to subject said piston to different pluralities of impulses per working stroke.

11. In an internal combustion engine, the combination, with a power cylinder and a piston reciprocable therein, of means for igniting a plurality of combustible charges successively in impelling relation to said piston during a single stroke thereof, and means movable at variable speed to vary the number of charges per stroke thus ignited over a range of values including different pluralities.

12. In an internal combustion engine, the combination, with a power cylinder and a piston reciprocable therein, of means for igniting a plurality of combustible charges successively in impelling relation to said piston during a single stroke thereof, means for varying the number of charges per stroke thus ignited, and means for utilizing the energy of the gases exhausted from said power cylinder.

13. In an internal combustion engine, the combination, with a power cylinder and a piston reciprocable therein, of means for igniting a plurality of combustible charges successively in impelling relation to said piston during a single stroke thereof, means for varying the number of charges per stroke thus ignited, and a second power cylinder arranged to receive the exhaust from the first cylinder.

14. In an internal combustion engine, the combination, with a power cylinder and a piston reciprocable therein, of means for igniting a plurality of combustible charges successively in impelling relation to said piston during a single stroke thereof, means adapted to be operated during the operation of the engine for varying the number of charges per stroke thus ignited, and means for introducing water into said cylinder.

15. In an internal combustion engine, the combination, with a power cylinder and a piston reciprocable therein, of means for igniting a plurality of combustible charges successively in impelling relation to said piston during a single stroke thereof, means adapted to be operated during the operation of the engine for varying the number of charges per stroke thus ignited, and means for introducing water into said cylinder with each charge ignited.

16. In an internal combustion engine, the combination, with a power cylinder and a piston reciprocable therein, of means for igniting a plurality of combustible charges successively in impelling relation to said piston during a single stroke thereof, means for varying the number of charges per stroke thus ignited, means for introducing water into said cylinder, and means for further expanding the exhaust from said cylinder to perform useful work.

17. In an internal combustion engine, the combination, with a movable power-transmitting element and a shaft arranged to be driven thereby, of means for igniting separate combustible charges successively in impelling relation to said power-transmitting element, and variable speed transmission mechanism connecting such igniting means with said shaft, whereby the rapidity of succession with which such charges are ignited may be varied without fixed relation to the speed of the shaft.

18. In an internal combustion engine, the combination, with a power cylinder and a piston reciprocable therein, of a movable admission member operable to admit in sequence to said cylinder during any working stroke a plurality of separate quantities of combustion gases under pressure in impelling relation to said piston, and mechanism

for controlling the rapidity of operation of said admission member, whereby the number of such quantities admitted per stroke may be varied.

19. An engine comprising the combination, with a power cylinder and a piston reciprocable therein, of means operable to subject said piston to a plurality of separate successive fluid pressure impulses in a single working stroke, and variable speed mechanism coöperating with said means and operable to vary the rapidity of succession and the number of impulses per working stroke over a range including different pluralities.

20. An engine comprising the combination, with a movable power-transmitting member, of unitary means movable to subject said member during a definite phase movement thereof to a succession of separate fluid pressure impulses, and mechanism for controlling the speed of said means and thereby varying the number of such impulses to which said member is subjected during any such movement.

21. In an internal combustion engine, the combination, with a movable motor element, of means for firing combustible charges successively in impelling relation to said motor element, and variable speed mechanism cooperating with said means and operable to vary the rapidity of firing asychronously with respect to the movement of said element.

22. In an internal combustion engine, the combination, with a combustion cylinder, a piston reciprocable therein, and a shaft arranged to be driven by said piston, of mechanism operable to fire a plurality of combustible charges in impelling relation to said piston during a stroke thereof, and variable speed gearing connecting said shaft with said mechanism and arranged to operate the latter.

23. In an internal combustion engine, the combination, with a cylinder and a piston reciprocable therein, of movable admission means connected to said cylinder, and variable speed means for operating said admission means to admit a plurality of charges to said cylinder during a single stroke of the piston and at a rate bearing no fixed relation to the speed of the engine.

24. In an internal combustion engine, the combination, with a cylinder and a piston reciprocable therein, of a revoluble charge member having a plurality of charge pockets adapted to be brought into operative relation successively with said cylinder as said member is revolved, means for supplying charges to said chambers, and variable speed means for revolving said charge member and thereby delivering a variable plurality of charges to said cylinder during a stroke of said piston.

25. In an internal combustion engine, the combination, with a cylinder, a piston reciprocable therein and a shaft driven by said piston, of a revoluble charge member operable to supply a plurality of charges to said cylinder during a single stroke of the piston, and mechanism for driving said revoluble charge member from the engine shaft but at a rate variable without fixed relation to the speed of said shaft, whereby the number of charges per stroke may be varied.

26. In an internal combustion engine, the combination, with a cylinder, a piston reciprocable therein and a shaft driven by said piston, of a revoluble charge member operable to supply a plurality of charges to said cylinder during a single stroke of the piston, mechanism for driving said revoluble charge member from the engine shaft but at a rate variable without fixed relation to the speed of said shaft, whereby the number of charges per stroke may be varied, and supplemental means for revolving said charge member when starting the engine.

27. In an internal combustion engine, the combination, with a cylinder and a piston reciprocable therein, of a revoluble member having charge pockets adapted to register successively with a passage leading to said cylinder, means for revolving said member at a rate variable without fixed relation to the speed of the engine, means for charging each pocket with combustible mixture prior to registry with said passage, and means for igniting the charge in each pocket when such pocket is in registry with said passage.

28. In an internal combustion engine, the combination, with a cylinder and a piston reciprocable therein, of a revoluble member having charge pockets adapted to register successively with a passage leading to said cylinder, means for revolving said member at a rate variable without fixed relation to the speed of the engine, means for charging each pocket with combustible mixture prior to registry with said passage, means for igniting the charge in each pocket when such pocket is in registry with said passage, and an automatic valve controlling said passage and arranged to open toward said cylinder.

29. In an internal combustion engine, the combination, with a cylinder, a piston reciprocable therein, and a shaft arranged to be driven by said piston, of a housing mounted on said cylinder, a revoluble charging valve fitting within said housing and having exterior pockets adapted as the valve is revolved to register successively with a passage leading to said cylinder, means for supplying combustible charge to each pocket prior to registry of such pocket with said passage, means for igniting the charge in each pocket when in communication with said passage, means for scavenging each

pocket after it has passed beyond said passage, and means for revolving said charging valve at a rate variable between appropriate limits but without fixed relation to the speed of the engine.

30. An engine comprising the combination, with a power cylinder and a piston arranged to work therein, of admission means movable to subject said piston to successive fluid pressure impulses, and provision for driving said admission means continuously but at a rate variable without fixed relation to the speed of the engine and over a range of variation giving different pluralities of impulses for working stroke.

31. An engine comprising the combination, with a power cylinder and a piston arranged to work therein, of a member movable to subject said piston to successive fluid pressure impulses, and means for driving said member at different speeds without fixed relation to the speed of the engine, including a speed giving a plurality of impulses per working stroke.

32. An internal combustion engine comprising the combination, with a power cylinder, a piston arranged to work therein, and a shaft driven by said piston, of a member movable to subject said piston to successive impelling charges, mechanism for driving said movable member from said shaft, and means for varying the speed of driving without fixed relation to the speed of the shaft over a range including a speed giving a plurality of charges per working stroke.

33. An internal combustion engine comprising the combination, with a power cylinder and a piston arranged to work therein, of means movable to subject said piston to successive impelling charges, and mechanism for driving said means at different speeds without fixed relation to the engine speed, including a speed giving a plurality of impelling charges per working stroke.

34. An internal combustion engine comprising the combination, with a power cylinder and a piston arranged to work therein, of means movable at different speeds to subject said piston to successive impelling charges, the rapidity of succession being proportional to the speed of said movable means, and mechanism for varying the speed of said movable means without fixed relation to the engine speed and over a range including a plurality of charges per working stroke.

35. An internal combustion engine comprising the combination, with a power cylinder and a piston arranged to work therein, of means movable to subject said piston to successive impelling charges, and mechanism for driving said means at a speed variable without fixed relation to the engine speed, the range of possible variation being from zero to a maximum speed giving a plurality of impelling charges per working stroke.

36. An internal combustion engine comprising the combination, with a power cylinder and a piston reciprocable therein, of means movable to admit a plurality of impelling charges successively to said cylinder at the same point of admission during a single working stroke of the piston, and provision for varying the operating speed of such movable means to admit different pluralities of charges per working stroke.

37. The method of generating power which comprises subjecting a movable motor element to successive fluid pressure impulses, and varying the rapidity of succession of such impulses while said element is moving and without fixed relation to the speed thereof, the range of variation including a plurality of impulses per phase movement of said element.

38. The method of generating power which comprises expanding a plurality of separate portions of hot combustion gases successively in impelling relation to a movable motor element, and varying the rapidity of succession of such impulses while said element is moving and without fixed relation to the speed thereof, the range of variation including a plurality of impulses per phase movement of said element.

39. The method of operating a reciprocating internal combustion engine which comprises firing combustible charges successively in impelling relation to the piston of said engine, and varying the rapidity of firing in accordance with power requirements while the engine is operating and without fixed relation to the speed thereof, the range of variation including a plurality of impulses per working stroke.

In testimony whereof I have signed this specification in the presence of two subscribing witnesses.

EDWARD E. GRAY.

Witnesses:
ERD NETTER,
IRVING P. WITHINGTON.