

Jan. 15, 1963

A. CANDELISE
MEANS FOR BURNING HYDROCARBONS IN AN INTERNAL
COMBUSTION ENGINE CYCLINDER

3,073,289

Filed March 4, 1960

4 Sheets-Sheet 1

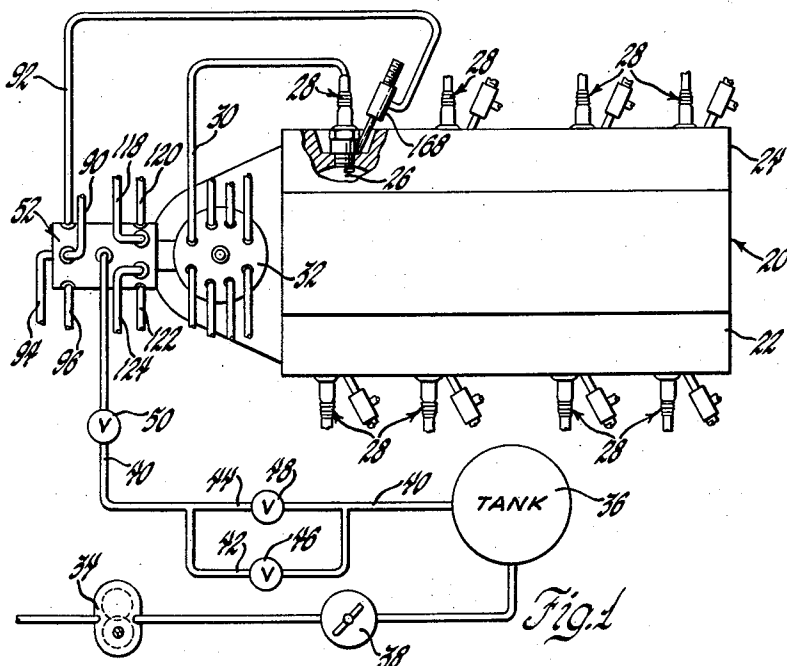
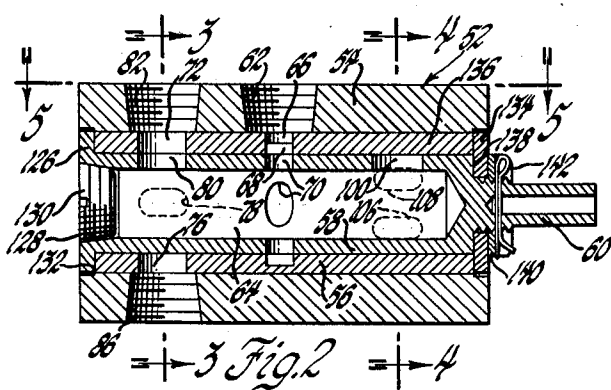
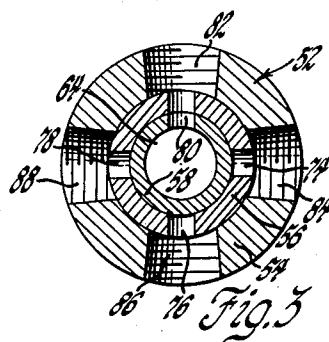
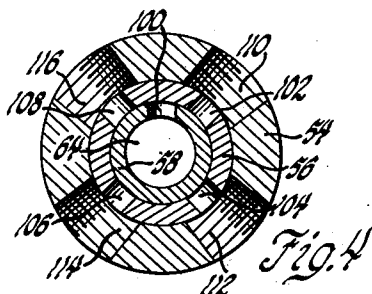
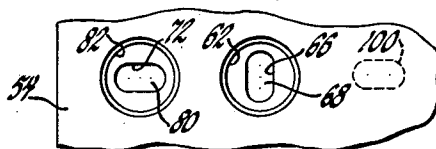


Fig. 5

INVENTOR.

Alfred Candelise

BY

D. R. McEwen

ATTORNEY

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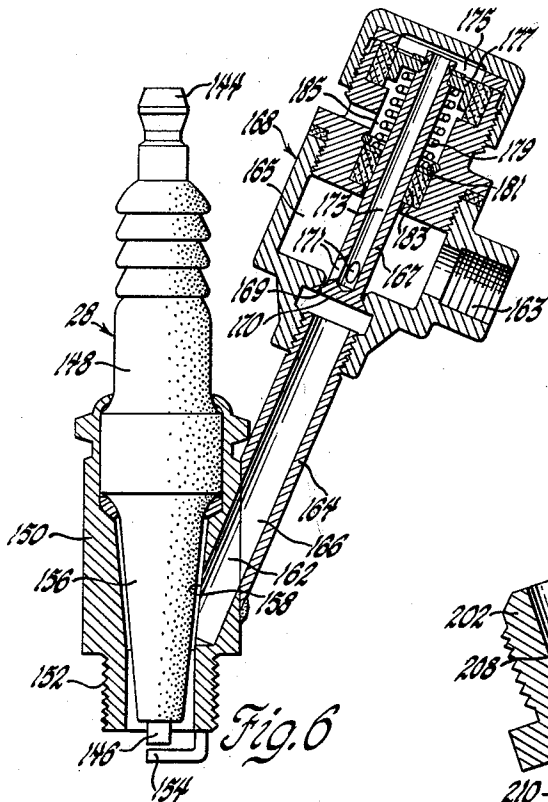


Fig. 6

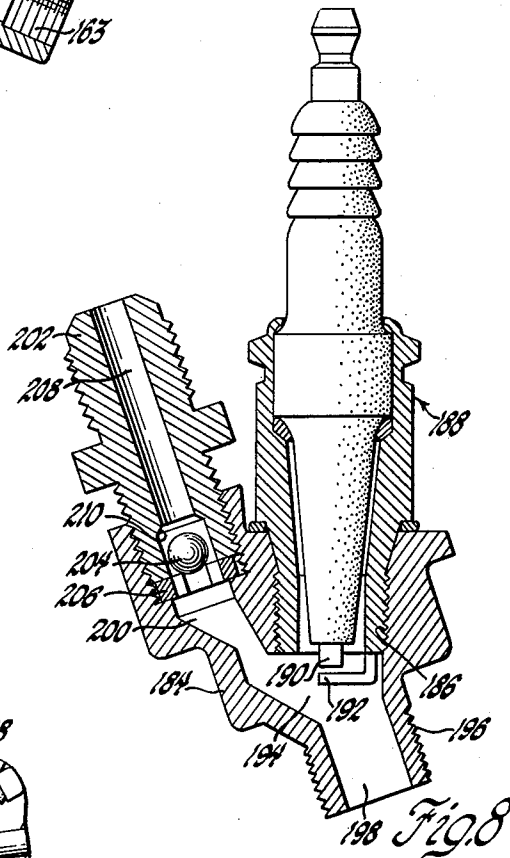


Fig. 8

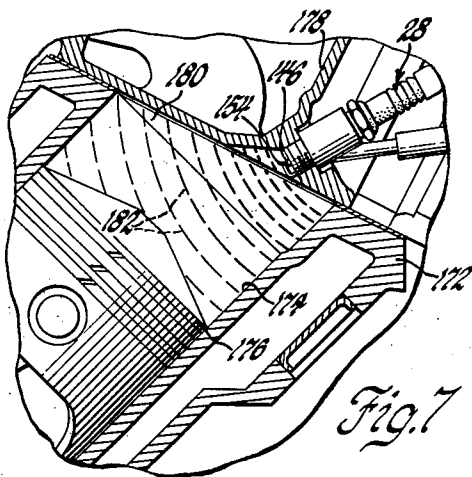


Fig. 7

INVENTOR.
Alfred Candelise
BY
D. R. McGraw
ATTORNEY

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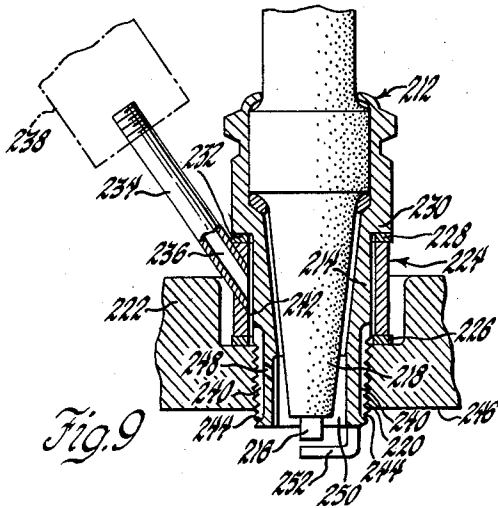


Fig. 9

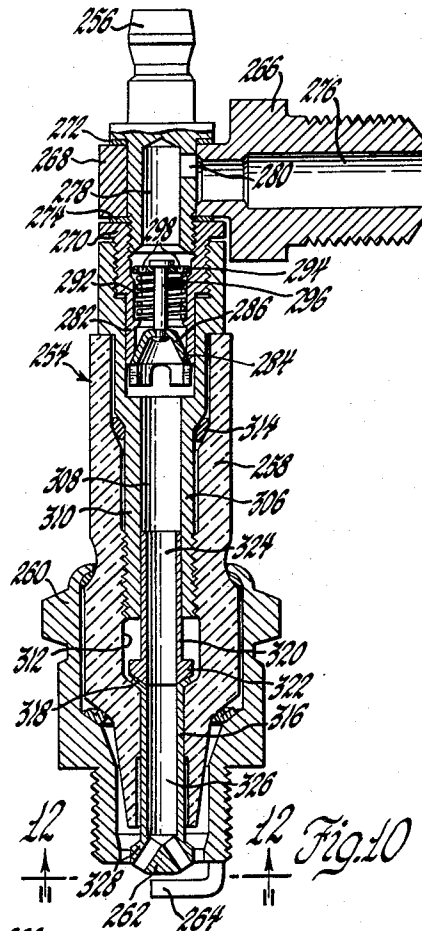


Fig. 10

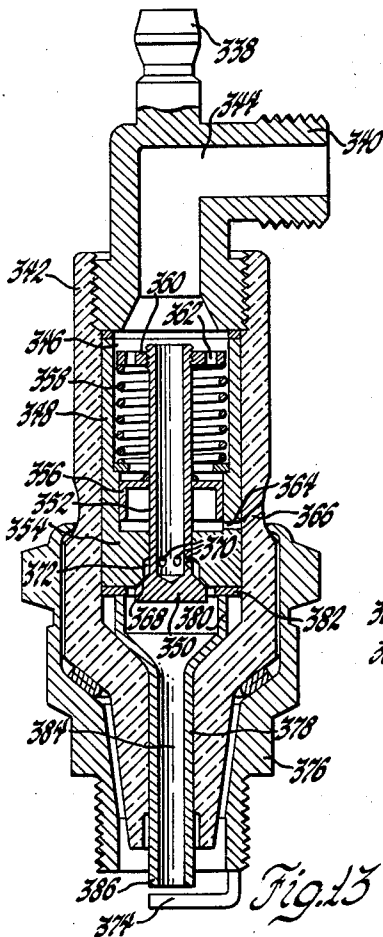


Fig. 11

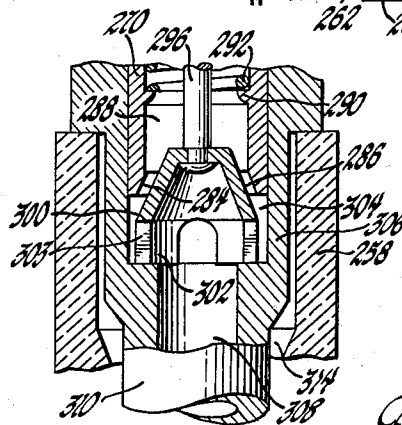


Fig. 12

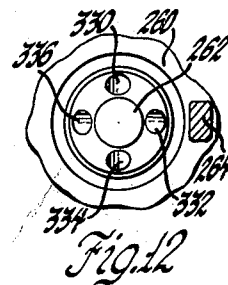


Fig. 13

INVENTOR.
Alfred Candelise
BY
D. D. McGraw
ATTORNEY

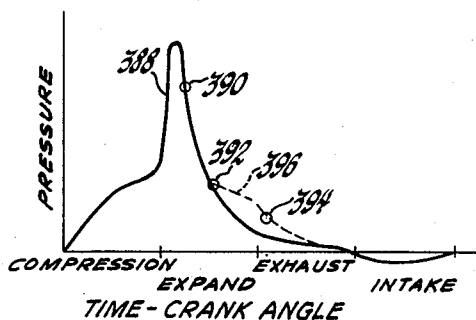
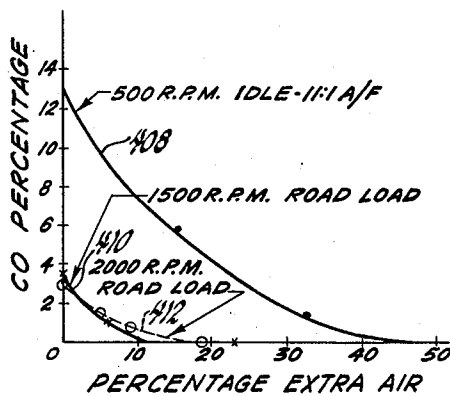
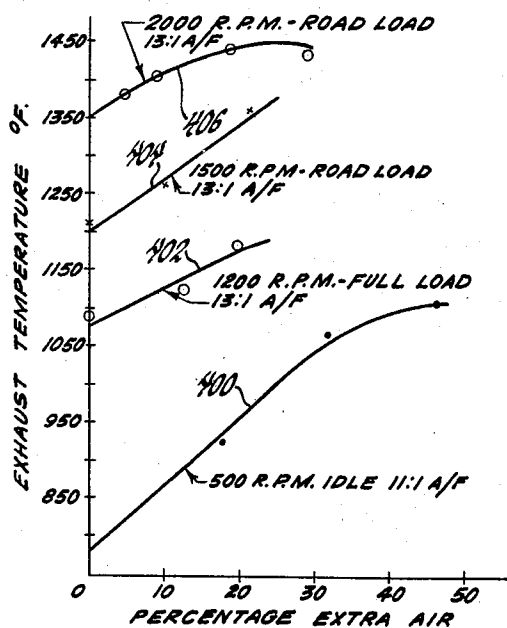
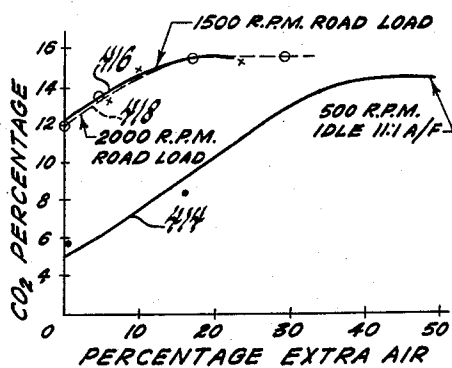
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INVENTOR.

Alfred Candelise

BY

R. D. McGraw

ATTORNEY

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**MEANS FOR BURNING HYDROCARBONS IN AN
INTERNAL COMBUSTION ENGINE CYLINDER****Alfred Candelise, Flint, Mich., assignor to General
Motors Corporation, Detroit, Mich., a corporation of
Delaware****Filed Mar. 4, 1960, Ser. No. 12,857****3 Claims. (Cl. 123—26)**

The invention relates to a mechanism for more completely burning the hydrocarbons introduced into the cylinders of an internal combustion engine during engine operation. It particularly concerns the burning of the hydrocarbons which normally remain in the unburned state for various reasons and pass out of the engine through the exhaust system.

During the operation of internal combustion engines of the type normally employed in automotive vehicles, for example, a charge of fuel and air mixture is introduced into an engine cylinder and is compressed. The charge is ignited and burning of the fuel takes place. It has been found that much of the fuel remains in the unburned state, however, and is discharged through the engine exhaust system to the atmosphere. This particularly occurs during engine idling conditions. One of the reasons for the incomplete burning is that there is insufficient air within the combustion chamber to permit complete combustion of all of the fuel introduced. During engine idling the fuel-air charge must be rich in fuel in order to ignite. Excess fuel is therefore provided for this purpose.

The unburned hydrocarbons which are discharged to the atmosphere contribute materially to the atmospheric contamination condition commonly referred to as smog. They also represent a loss in overall efficiency since the energy normally contained therein is not utilized. It has been found that compressed air may be introduced into the combustion chamber of the engine at desirable times and under desirable pressures so as to more completely burn the hydrocarbons contained therein. This results in greater efficiency and also materially reduces the amount of unburned hydrocarbons being discharged to the atmosphere. It has been found that the amount of carbon monoxide which was formerly present in the exhaust gases of such engines can be substantially eliminated by complete combustion in this manner. This eliminates an important danger to the occupants of such vehicles since it is well known that carbon monoxide is poisonous and detection of its presence in the passenger section of the vehicle is not readily accomplished. The introduction of compressed air during the latter portion of the normal combustion period and continuing through at least a portion of the power stroke also results in lowering the temperature and amount of the exhaust gases left in the combustion chamber at the time of the intake valve opening, so that the volumetric efficiency of the engine and the combustion efficiency are increased. This results in increased power output of the engine and improved detonation characteristics. These benefits can be attained while utilizing a compressed air source driven by the engine and capable of continually delivering air at a minimum gage pressure of 30 p.s.i. and in a rate range of 0.5 to 1 c.f.m. per engine cylinder while the engine is operating at idle and low speed conditions.

It has long been proposed to introduce air under pressure during the latter portion of the expansion cycle of engines of this nature in order to obtain additional power from the energy represented by the pressure of the air. It has also been known to introduce compressed air during the combustion portion of the cycle in order to augment the burning gases to give a second expansion and to permit the burning gases to heat the compressed air so

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introduced to increase the expansion of that air and thereby increase the power of the engine. Systems of this nature are disclosed in United States Patents 1,430,480, Whaley and 1,904,755, Barthomew, for example. The structure disclosed by these patents, however, did not yield sufficiently satisfactory results to warrant their use. This was due to various reasons including the type of air compressor mechanism used or available to furnish the air and the type of mechanisms used to introduce the air into the engine cylinder at the proper time. A system of this nature requires a source of air under pressure which will deliver sufficient quantities at sufficient pressures to accomplish the desired results.

The invention herein disclosed and claimed is carried out by providing structural mechanisms which introduce compressed air in sufficient quantities and at proper pressures for obtaining highly efficient results. Mechanisms embodying the invention also provide the introduction of the air at positions relative to the combustion chamber and the fuel-air mixture contained therein which increase the burning efficiency of the fuel. They also provide for proper timing of the air relative to the various cylinders of a multi-cylinder engine so that maximum benefits from the introduction of the air into the combustion chambers may be realized. The invention includes a system having a source of air connected to an air timing and distribution mechanism which will distribute the air to each cylinder at the proper time and in the proper quantities. The invention also includes structures for the introduction of air so timed into each cylinder as to provide improved air distribution characteristics within the cylinders. These structures include modified spark plugs, fittings which are utilized in conjunction with standard spark plugs, and modified spark plug gaskets.

In the drawings:

FIGURE 1 is a schematic illustration of a system embodying the invention and includes one of the forms of air introduction mechanism associated with the spark plug of an internal combustion engine.

FIGURE 2 is a cross section view of an air timing and distribution mechanism used in the system disclosed in FIGURE 1.

FIGURE 3 is a cross section view of the mechanism of FIGURE 2 taken in the direction of arrows 3—3 of that figure.

FIGURE 4 is a cross section view of the mechanism of FIGURE 2 taken in the direction of arrows 4—4 of that figure.

FIGURE 5 is a partial view of the mechanism of FIGURE 2 with parts broken away and illustrating some of the control orifices of that mechanism.

FIGURE 6 is a view of a spark plug with parts broken away and in section and so constructed that air may be introduced into the engine combustion chamber through the spark plug body.

FIGURE 7 is a cross section view taken through the block and head of an internal combustion engine with parts broken away and illustrating an engine combustion chamber during a portion of the power stroke and particularly showing the flame front progression in the combustion chamber.

FIGURE 8 is a view of a spark plug with an adapter mechanism which may be used to introduce air into the cylinder of an engine.

FIGURE 9 is a section view of a portion of an engine having another modification of the air introduction mechanism embodying the invention.

FIGURE 10 is a section view of a spark plug having another modification of the air introduction mechanism of the invention.

FIGURE 11 is an enlargement of a portion of FIG-

FIGURE 10 and showing the position of portions of that mechanism when air is being introduced to the engine combustion chamber.

FIGURE 12 is an end view of the air outlet end of the mechanism of FIGURE 10 as taken in the direction of arrows 12—12 of that figure.

FIGURE 13 shows another modification of the spark plug for introducing air into an engine combustion chamber.

FIGURE 14 shows a pressure-time diagram which illustrates engine performance when an engine is operated in the ordinary manner and when the engine is operated with the system embodying the invention.

FIGURE 15 is a graphic illustration of the exhaust temperatures obtained plotted against the percent of extra air by volume added.

FIGURE 16 is a graphic illustration of the percent of carbon monoxide found in the exhaust gases emitted as plotted against the percent of air added.

FIGURE 17 is a graphic illustration of the percent of carbon dioxide found in the exhaust gases as plotted against the percent of air added.

The system illustrated schematically in FIGURE 1 is shown in connection with a V-8 type engine 20 having parallel banks 22 and 24 of cylinders 26. The engine is provided with any well known fuel-air induction system and exhaust gas system and the elements comprising these systems are therefore not illustrated. Each cylinder 26 is provided with a spark plug 28 which ignites the fuel-air mixture in the cylinder combustion chamber in the well known manner. The spark plugs 28 are connected to ignition wires 30 to the distributor 32, which may be of any well known type, for properly timing the ignition sparks of the various spark plugs. As is the common practice, the distributor 32 is driven in timed relation with the engine crankshaft.

A source of compressed air such as the schematically illustrated pump 34 may be provided. This pump may be driven by the engine 20 at a speed such that the pump capacity will maintain air in the air tank 36 at a desired pressure. Commercial pumps are now available on the market which will operate under the various engine speed conditions to provide the required volume of air for the system at within the required pressure range for satisfactory operation of the system. A pressure regulator valve 38 may be provided intermediate pump 34 and tank 36 if desired. The air conduit 40 from tank 36 may be divided into two parallel conduits 42 and 44 which contain control valves 46 and 48, respectively, for providing a rough and fine adjustment of the air being removed from tank 36 and delivered to the engine 20. Another control valve 50 is positioned in the portion of conduit 49 beyond the point where the parallel conduits 42 and 44 are connected to deliver air into the single conduit 40.

Conduit 40 delivers air passing through valve 50 into a rotary air distributing and timing valve mechanism 52 which is mounted adjacent engine 20. Valve mechanism 52 is illustrated in greater detail in FIGURES 2 through 5 and includes a housing 54 having a bore formed there-through in which a valve bushing 56 is received. The valve control cylinder 58 is rotatably received within the bushing 56 and has a driven end 60 which may be connected with the drive shaft of the distributor 32 or otherwise driven by the engine crankshaft so as to rotate in timed relation to the crankshaft of the engine 20.

Conduit 40 is connected with valve mechanism 52 at passage 62 and delivers air under pressure to the air distribution chamber 64 formed in the portion of cylinder 53 contained within bushing 56. This is accomplished by providing a port 66 in the central portion of bushing 56 and extending radially into an annular chamber 68 formed in the interior surface of the bushing. Port 66 connects with passage 62 of housing 54 and is maintained in the connection position by the proper installation of the bushing in that housing. The bushing may be held

in the housing in any suitable manner such as press fitting it in place.

Cylinder 58 may be provided with one or more ports 70 extending radially through the wall of the cylinder and connecting chamber 64 with annular chamber 68 of bushing 56. As cylinder 58 rotates within the bushing 56, air under pressure is maintained in air distribution chamber 64 through this port, chamber and passage construction.

Ports 66 and 70 may be oblong. The major axes of these ports extend transversely of bushing 56 and cylinder 58 and the minor axes extend longitudinally of these elements. This permits full flow of air from port 66 and annular chamber 68 into air chamber 64 through port 70 while cylinder 58 is rotated.

Four ports 72, 74, 76 and 78 are provided adjacent one end of the bushing 56 and extend radially through the cylinder wall. These ports 72, 74, 76 and 78 are shown in FIGURES 2 and 3 and have their centerlines positioned in a common plane which passes through the cylinder at substantially right angles thereto. The centerline of each port is normal to the centerline of the two adjacent ports. This construction is used when an eight-cylinder engine is equipped with the system. It is obvious that a modified port arrangement would be required if engines with more or less than eight cylinders were used. Cylinder 58 has one port 80 extending through the cylinder wall so that its centerline is in the plane of the axes of ports 72, 74, 76 and 78. The four ports in bushing 56 are illustrated as being oblong in respective arrangement with four circular outlet passages 82, 84, 86 and 88 which are formed to extend radially through the wall of housing 54 and may be threaded to receive suitable fittings for the connection of air lines leading to four of the engine cylinders. The major axes of the oblong ports 72, 74, 76, 78 and 80 preferably extend longitudinally of bushing 56 and cylinder 58 while their minor axes extend transversely of those elements. These five ports may be of the same size while passages 82, 84, 86 and 88 are of somewhat greater diameter than the length of the major axes of the associated ports. This provides easy arrangement of the ports of bushing 56 during bushing installation, and permits port 80 to pass through positions of exact alignment with each of the ports 72, 74, 76 and 78 during rotation of cylinder 58. Air from chamber 64 will therefore be distributed to air lines 90, 92, 94 and 96 in the proper timed relation as cylinder 58 is rotated.

Cylinder 58 has another port 100 similar to port 80 but positioned adjacent the other end of the cylinder. This port has its major axis extending longitudinally of the cylinder and in axial alignment with the major axis of port 80.

Bushing 56 has four ports 102, 104, 106 and 108 which are formed in a manner similar to ports 72, 74, 76 and 78 and adjacent the end of the bushing opposite those ports. The centerlines of these ports extending radially of the bushing are positioned in a plane which is transverse to the bushing. Each of these centerlines is normal to the centerlines of the adjacent ports. When used with an 8-cylinder engine, however, they are oriented at a 45° angle from the centerline of the similar ports 72, 74, 76 and 78 so that air passing from chamber 64 through port 100 is discharged to each of the ports 102, 104, 106 and 108 with a respective timing 45° later than air discharged through ports 72, 74, 76 and 78, respectively, during rotation of cylinder 58. Housing 54 is provided with circular outlet passages 110, 112, 114 and 116 with their centerlines substantially in the plane of the centerlines of ports 100, 102, 104, 106 and 108, so that the four of these ports in bushing 56 are in substantial centerline alignment with these passages. These outlet passages are also threaded to receive fittings connecting with air distribution lines leading to the engine cylinders. These air lines 118, 120,

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122 and 124 are then each connected to one of the engine cylinders.

Cylinder 58 is illustrated as having an end flange 126 and a threaded passage 128 formed in the flanged end in order to permit the formation of chamber 64 within the cylinder. Passage 128 is then provided with a plug 130 to seal off chamber 64. Flange 126 abuts the end 132 of bushing 56 and locates cylinder 58 axially relative to that bushing so that the various ports are in the proper longitudinal alignment. An annular retaining plate 134 is secured in housing 54 adjacent the end 136 of bushing 56 and also abuts a shoulder 138 on the end of cylinder 58 opposite flange 126. The driven end 60 of cylinder 58 is provided with a suitable bearing 140 which engages plate 134 and is held in position by pin 142. Driven end 60 is suitably constructed to provide a positive drive from the drive shaft of distributor 32.

The spark plug construction 28 illustrated in detail in FIGURE 6 and in the installed position in the schematic illustration of FIGURE 1 permits the introduction of air under pressure from air line 92, for example, into one cylinder 26. The spark plug 28 includes a high tension terminal 144 which is electrically connected with the center electrode 146. Suitable insulation 148 is provided to insulate electrode 146 and its connection with terminal 144 from the spark plug shell 150. Shell 150 is provided at its lower end with a threaded section 152 which is used to install and secure the spark plug in a wall of cylinder 26. Electrode 154 is secured to shell 150 and positioned adjacent electrode 146 to provide the spark gap. The lower end 156 of insulation 148 extends through chamber 158 of shell 150. This chamber extends from the shell 150 through the threaded section 152 and is open to the cylinder 26 when the spark plug is installed.

Insulation end 156 is spaced from the walls of chamber 158 to provide an air passage for the air being injected into the cylinder. A passage 162 is formed through the side wall of shell 150 so that it connects with chamber 158. A tube 164 is brazed or otherwise suitably secured to the outer surface of shell 150 so that the passage 166 through the tube is in alignment with passage 162 in the shell. A check valve housing 168 is secured to tube 166. Air line 92 of FIGURE 1 may connect with housing 168 at opening 163 to provide air under pressure to the check valve 170 during operation of the system. Check valve 170 is so arranged that the air pressure in line 92 must overcome the pressure in passage 166 in order to admit air to the engine cylinder. Check valve 170 is therefore closed when the forces acting on the valve and exerted by the combustion pressures are greater than the forces created by the pressure of the air supply, even though air under pressure may be delivered through air line 92 to the valve housing 168.

The check valve mechanism of housing 168 includes chamber 165 formed in the housing and receiving compressed air through opening 163 from the air distribution valve. Check valve 170 is formed as a poppet valve with a hollow valve stem 167 which extends through chamber 165. The head of the valve 170 seats on valve seat 169 provided in housing 168 so that the head is exposed to the combustion chamber of the engine through chamber 158 and passages 162 and 166 of the spark plug. Several openings 171 are provided in the stem 167 so that they connect chamber 165 with the passage 173 in the valve stem. These openings have their axes at an angle to the axis of the valve stem and converging upwardly for air flow purposes to be described. The upper end of the valve stem extends into valve actuating chamber 173 formed in the upper end of housing 168 so that air under pressure is contained in this chamber.

A valve actuating piston 177 is connected to valve stem 167 and operates within chamber 175. The side walls of chamber 175 which engage piston 177 therefore act as cylinder walls for the piston. A compression spring 179 acts against piston 177 and a spring seat 181 retained in housing 168 so that the valve 170 is urged into engage-

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ment with valve seat 169 by the spring. Piston 177 fits the cylinder walls of chamber 175 so as to provide an effective air seal. A similar air seal is provided by valve stem guide 183 adjacent spring seat 181. Spring chamber 185 is vented to atmosphere to prevent the entrapment of air behind piston 177. The air provided by the air line to opening 163 fills chamber 165, valve stem passage 173, and chamber 175 and acts on piston 177 to urge the valve toward the open position against the pressure of spring 179 and the pressure in the engine combustion chamber on the face of valve 170. When the force of air acting on piston 177 overcomes the force of spring 179 and the combustion chamber pressure acting on the valve seat, the valve is opened and air under pressure passes between valve 170 and valve seat 169 and into passage 166. It then enters the combustion chamber through passage 162 and spark plug chamber 158. Due to the angular position of openings 171, the air tends to pass directly from chamber 165 into passage 166, but is also permitted to flow into passage 173 and chamber 175 to maintain the air pressure therein which is acting on piston 177.

FIGURE 7 illustrates a cross section view of a typical engine combustion chamber in which compressed air may be introduced in accordance with the invention. The engine block 172 has a cylinder wall 174 defining a cylinder in which a piston 176 is mounted for reciprocation. The engine head 178 is suitably secured to the engine block over the cylinder to provide a combustion chamber 180. Suitable intake and exhaust valves may be provided to introduce the fuel-air mixture to the combustion chamber and to remove the exhaust gases therefrom. The spark plug 28 is secured in the head 178 so that the electrodes 146 and 154 are exposed to the combustion chamber and will ignite the fuel-air mixture in the well known manner. The fuel-air mixture within the chamber begins to burn in the area immediately adjacent the spark plug electrodes upon spark ignition and the flame front, represented by dashed lines 182, moves away from the point of initial ignition through the combustion chamber. During the expansion stroke of the piston 176 the piston is moving away from the head 178, thereby increasing the volume of the combustion chamber. At the same time the flame front progresses through the combustion chamber. The products of combustion together with some unburned hydrocarbons are found intermediate the spark plug electrodes and the progressively moving flame front. These are in the form of gases since they have been vaporized and are also subjected to high temperatures. Even though the burning is complete behind the flame front insofar as is possible, the unburned hydrocarbons remaining may be substantial. This results because insufficient oxygen to complete combustion is contained in the fuel-air mixture required to initiate combustion. Simply stated, there is more fuel introduced in the fuel-air mixture than there is air to complete the burning operation. While the remaining unburned hydrocarbons are subjected to elevated temperatures in the neighborhood of 600° to 800° F., they cannot burn. Air is therefore introduced through the spark plug 28 behind the flame front and mixes with the various gases including the unburned hydrocarbons. This supplies sufficient oxygen to complete the burning of the hydrocarbons during the latter portion of the expansion stroke and this burning operation may continue in the combustion chamber during a portion of the exhaust stroke. The gases exhausted from the combustion chamber will then contain combustion products and substantially smaller amounts of unburned hydrocarbons than is the case when the engine is operated in accordance with common practice. In some instances no unburned hydrocarbons will remain. The air passing through the spark plug chamber 158 also passes over and around the electrodes 146 and 154 of the spark plug and provides a cooling effect as well as tending to keep the electrodes free of deposits.

The modification illustrated in FIGURE 8 provides a

different structure for the introduction of air into the engine combustion chamber. A Y shaped adaptor or fitting 184 is provided with a spark plug receiving passage 186 in which any suitable spark plug 188 may be installed. The spark plug electrodes 190 and 192 extend into a chamber 194 formed within the fitting 184. Fitting 184 is also provided with a connection 196 which will fit into the spark plug opening normally provided in an engine. A passage 198 extends through connection 196 and connects chamber 194 with the engine combustion chamber. Another passage 200 is formed in one of the branches of fitting 184 and is constructed to receive an air line connection fitting 202 so that an air line such as air line 92 of FIGURE 1 may introduce air into the engine combustion chamber through passage 200, chamber 194 and passage 198. Fitting 202 may be provided with a ball check valve 204 which is retained within the fitting by a suitable retainer 206. This retainer permits the valve 204 to move under influence of compressed air and combustion chamber pressures to open and close passage 208 of the fitting. The retainer is perforated to permit free passage of air therethrough. Valve 204 is normally open to permit air to flow from the fitting 202 to the engine combustion chamber. When the combustion chamber pressure exceeds the pressure in the fitting passage 208, however, ball check valve 204 is moved upwardly to engage valve seat 210 and prevent a mixture of fuel and air or combustion gases from entering the air supply line. This modification accomplishes the same results as does the modification of FIGURE 6 insofar as the introduction of air into the combustion chamber is concerned. It has certain advantages in that standard spark plugs such as those now on the market may be used with the modification. Since the spark plug electrodes 190 and 192 extend into the compressed air stream they also receive beneficial cooling and cleansing effects.

Another modification of the air injection mechanism is illustrated in FIGURE 9. In this construction the spark plug 212 has an elongated metallic shell end 214 which surrounds the inner electrode 216 and the electrode insulation shell 218. The shell end 214 may be threaded at 220 so that the plug can be screwed into the combustion chamber wall 222. This wall may be a portion of the engine combustion head or the engine block. The additional length of shell end 214 is realized in the area where the spark plug gasket is normally received. In this modification a spark plug gasket 224 is provided which is cylindrical in form and axially longer than the usual gasket. The assembly includes deformable gaskets 226 and 228, which may be of the type commonly used with spark plugs. These gaskets have their facing surfaces in engagement with the annular cylinder portion 230 of the assembly 224 at opposite ends thereof. Gasket 226 also engages wall 222 to seal the spark plug and gasket assembly at that point and gasket 228 engages shoulder 232 of the spark plug shell 214 in order to seal the assembly at that point. A passage is provided through cylinder 230 in which tube 234 secured in such a manner that the tube will not interfere with the wall 222 when the assembly is installed. Tube 234 has a passage 236 which connects with the interior portion of cylinder 230 and through which air may be introduced from an air line such as air line 92 of FIGURE 1. A check valve assembly 238 may be provided at the air line end of tube 234 and will operate in a manner similar to that of the check valve 170 of FIGURE 6 or check valve 204 of FIGURE 8.

The outer surface of the threaded portion 220 of the spark plug shell end 214 is provided with a plurality of circumferentially spaced slots 240 which extend longitudinally of the spark plug shell and are cut through the threads. The slots 240 are cut deeper than the spark plug threads so that air passages are provided between the shell end 214 and the wall 222 when the assembly is

in the installed position. Slots 240 extend into the portion of the shell adjacent the elongated gasket 224 and permit air to flow from the chamber 242 provided by cylinder 230 and the spark plug shell. The outer ends 244 of slots 240 preferably terminate short of the extreme end of the shell threaded portion 220 so that air passing through the slots into the engine combustion chamber is directed outwardly from the spark plug assembly. Some of the air flow will be across face 246 of the combustion chamber wall 222. Ports 248 may be provided in the threaded end 220 of the spark plug shell so as to connect some or all of the slots 240 with inner chamber 250 of the spark plug assembly. Air will then also be directed around the inner electrode 216 and the outer electrode 252 and into the combustion chamber in a direction substantially normal to the chamber wall 222. This modification permits easy installation of this portion of the system and also directs the compressed air into the combustion chamber in various directions. It provides more complete and quicker mixing of the compressed air with the various gases contained in the combustion chamber at the time of air introduction. It also provides an electrode cooling and cleansing effect.

FIGURE 10 shows another modification of the mechanism which may be used to introduce the compressed air into the engine cylinder. In this modification the compressed air is introduced through the interior of the spark plug with the air connection to the spark plug being made adjacent the spark plug terminal. A check valve is provided as an integral part of the spark plug.

The spark plug 254 of FIGURE 10 includes a terminal 256 and an insulation shell 258, a metallic shell 260 in which the insulation shell is mounted, an inner electrode 262, an outer electrode 264, and various elements providing an electrical connection from the terminal 256 to the electrode 262 through the insulation shell 258. The terminal 256 is adjacent to a fitting 266 to which an air line such as air line 92 of FIGURE 1 may be attached to provide compressed air to the spark plug. In the construction illustrated fitting 266 is provided with an annular flange section 268 through which the lower portion of terminal 256 extends in order to attach the fitting to the main body of the spark plug. A valve seat member 270 is provided with interior threads into which the lower end of terminal 256 is threaded to hold fitting 266 and the terminal in place. This arrangement also electrically connects terminal 256 to member 270. Gaskets 272 and 274 are provided on either side of the fitting flanged section 268 to prevent leakage of air. Fitting 266 has a passage 276 which connects with the terminal-receiving opening in flanged section 268. Terminal 256 has a longitudinal passage 278 and a radially extending passage 280 which conduct air from fitting 266 to the interior of valve seat member 270. The lower end 282 of the valve seat member is provided with a conical section inner surface 284 which acts as the seat for check valve 286. Passage 288 in member 270 connects terminal passage 278 with one side of the valve 286. A spring seat 290 is formed on the interior surface of passage 288 and a coiled compression spring 292 is received on the opposite side of seat 290 from valve 286. Details of this portion of the structure are best seen in FIGURE 11. Spring 292 acts against spring seat 294 which is attached to valve 286 by rod 296 so that the spring urges valve 286 to the closed position against surface 284. Spring seat 294 is provided with several openings 298 through which air may pass during the operation of the mechanism. Valve 286 is illustrated as having a cup formation with a tapered section 300 mating with surface 284 of valve seat 270. The valve is also provided with a generally cylindrical portion 302 which extends below the end of valve seat 270 and into valve chamber 304. Apertures 306 are formed in the walls of portion 320 to permit air flow beyond the valve when the valve is fully opened in the position illustrated in FIGURE

11. Chamber 304 is formed in sleeve 306. This sleeve acts as a mount for member 270 and also as an electrical conductor for the electrical operation of the spark plug. Valve seat member 270 is threaded into the upper end of sleeve 306. Valve chamber 304 is connected to a passage 308 leading through sleeve 306 to conduct compressed air which passes member 270 onward into the combustion chamber. The reduced end 310 of sleeve 306 is secured within the insulation shell 258 and passage 312 is sealed by a seal 314. The upper end 316 of inner electrode 262 is flared at 518 to extend into passage 312 and locate the position of the inner electrode in the insulation shell 258. Tubular member 320 is secured within the passage 308 of sleeve 306 in a suitable manner such as by press fitting or brazing. An enlarged head 322 is provided at the lower end of member 320 and this head engages the flared end 318 of electrode 262 to seal the air passage provided by passages 324 and 326 through member 320 and electrode 262, respectively. The lower end of electrode 262 is provided with an enlarged head 328 at the terminal end of passage 326. Openings 330, 332, 334 and 336 are provided in head 328 so that they connect with passage 326 and extend angularly downward and outward. These openings discharge the compressed air into the combustion chamber of the engine. Although four openings are illustrated, a different number of openings may be used if desired. In the construction best seen in FIGURE 12 it may be noted that opening 332 discharges air so that it impinges upon outer electrode 264, thereby assisting in keeping that electrode clean and also having a cooling effect on it. The air discharged through the electrode openings passes into the combustion chamber in a conical spray pattern to provide effective air delivery.

The modification shown in FIGURE 13 is generally similar to the modification illustrated in FIGURE 10 but is somewhat simplified in construction. The spark plug terminal 338 is integrally formed with the air line fitting 340 and is threaded into the insulation shell 342. An air passage 344 connects with the valve spring chamber 346 contained within the shell 342 and the valve seat sleeve 348. Valve 350 has a hollow stem 352 which is mounted for reciprocation in the closed end 354 of sleeve 348. A valve stem guide 356 is secured within the sleeve 348. Valve spring 358 seats against a shoulder formed inside sleeve 348 and reacts against spring seat 360 which is mounted on the upper end of valve stem 352. Openings 362 are provided within spring seat 360 to prevent entrapment of air in the portion of chamber 346 occupied by spring 358. The lower end of chamber 346 underneath guide 356 is vented to the atmosphere through passage 364 in sleeve 348 and a mating passage 366 extending through seal 342. The closed end 54 of sleeve 348 is provided with a valve seat 368 against which the valve is urged by spring 358. Several orifices 370 extend through the wall of the hollow valve stem 352 immediately adjacent the valve seat 350 so that air is available at the valve seat 368 to keep the seat clear of foreign matter when the valve is opened. Since air passing through orifices 370 is received within seat chamber 372 when the valve is closed, a larger area is provided on which the compressed air acts and tends to open the valve against the forces of spring 358.

The outer electrode 374 of the spark plug is attached to the spark plug metal shell 376 in the conventional manner. The inner electrode 378 is provided as a hollow tube which extends through and below the end of insulation shell 342 to a point adjacent the electrode 374 to establish the spark gap of the plug. The upper end 380 of the tubular electrode 378 is outwardly flared and in engagement with the lower end of sleeve 348 through a washer 382 to provide electrical contact from terminal 338 to the electrode 378.

When valve 350 is opened, air passes through passage 344 and chamber 346 into the hollow stem 352 of the

check valve. The air then passes through orifices 370. When the valve is opened only a slight amount the air passes through chamber 372 and then through the inner electrode passage 384. As the valve is open to the full extent, the air may pass directly from orifices 370 into electrode passage 384. The air is discharged through the end 386 of electrode 378 and some of the air passes over outer electrode 374, tending to clean and cool that electrode. The outer electrode 374 also acts to break up the air flow and disperse the compressed air throughout the combustion chamber.

FIGURES 14 through 17 show typical operating curves obtained with an engine utilizing a system embodying the invention. Air was injected at a center injection point of 38° before bottom dead center in the expansion stroke at approximately 150 p.s.i.

FIGURE 14 shows a pressure-time diagram with time being indicated in terms of crank angle. Curve 388 is plotted to indicate the pressures existing in the combustion chamber during the compression, expansion, exhaust and intake portions of the engine cycle of a typical four stroke cycle engine. Point 390 is the point at which combustion within the combustion chamber is theoretically complete. It is noted that this point occurs during the first half of the expansion stroke and is on the side of the curve beyond the point of maximum pressure. When operating with the system which embodies the invention, compressed air is introduced approximately at point 392 and continues to flow into the combustion chamber until point 394 is reached. When no air is introduced, the curve 388 will follow the full line. When air is introduced, however, the curve deviates along the dashed line 396. The change in pressure results primarily from the combustion of the previously unburned hydrocarbons.

FIGURE 15 illustrates the changes obtained in exhaust temperature (measured in degrees Fahrenheit) as the percent of extra air introduced into the combustion chamber was increased. Curve 400 shows that the exhaust temperature increases from about 780° F. with no extra air added to about 1050° F. with 30% extra air added, this increase being a substantially straight line variation. The temperature increase then begins to level off to about 1125° F. when 50% extra air is introduced. This curve represents exhaust temperature changes with an engine running at an idle speed of 500 r.p.m. with an air-fuel ratio of 11:1.

Curve 402 shows the exhaust temperature change when an engine was operated under full load at approximately 1200 r.p.m. with a 13:1 air-fuel ratio. As the percent of extra air changed from 0 to 25%, a net increase in exhaust temperature of approximately 125° F. has been noted.

Curve 404 shows the exhaust temperature increase when an engine was operating under road load at 1500 r.p.m. with a 13:1 air-fuel ratio. A net exhaust temperature change of about 175° F. was obtained as the percent of extra air was increased from 0 to 25%.

Curve 406 shows the exhaust temperature change when an engine was operating under road load at 2000 r.p.m. with a 13:1 air-fuel ratio. The exhaust temperature increased approximately 100° as the percent of extra air added changed from 0 to 25% and no further appreciable exhaust temperature increase was obtained when a greater percentage of extra air was added.

All of the curves in FIGURE 15 clearly indicate that combustion of the unburned hydrocarbons is obtained in the combustion chamber and that this combustion is substantial. The combustion results in greater engine power as well as in the reduction of unburned hydrocarbons.

FIGURE 16 shows the reduction in carbon monoxide as percentage of extra air was varied from 0 to 50%. When the engine was operating at an idle speed of 500 r.p.m. and a 11:1 air-fuel ratio, carbon monoxide was found to provide approximately 13% of the exhaust gases emitted when no extra air was introduced. This percentage is halved by the introduction by approximately 10% extra

air and is reduced to zero when the percentage of extra air introduced is increased to approximately 46%. Curve 408 illustrates this effect. The greatest amount of carbon monoxide is obtained under the engine idle conditions during which the amount of fuel in the air-fuel ratio is largest.

As the engine was operated at higher speeds and under road load conditions, lesser amounts of carbon monoxide were found in the exhaust gases. With the engine operating in the normal manner at 1500 r.p.m. under road load conditions and using no extra air, the percentage of carbon monoxide present was between 3 and 4%. When approximately 12% extra air was introduced the amount of carbon monoxide present was reduced to zero. Curve 410 illustrates this performance. Dashed curve 412 shows the engine operation at 2000 r.p.m. under road load conditions. The presence of approximately 3% of carbon monoxide, when no extra air was introduced, was reduced to zero when approximately 18% extra air was introduced.

FIGURE 17 shows the increase in the percent of carbon dioxide in the exhaust gases under various engine load and speed conditions as the percentage of extra air was increased. The presence of additional carbon dioxide indicated more complete combustion. Curve 414 shows the increase of carbon dioxide from approximately 5% to more than 14% as the percentage of extra air was increased from zero to 40%. These results were obtained when the engine was operating at an idle speed of 500 r.p.m. and an air-fuel ratio of 11:1. Curve 416 shows that the percentage of carbon dioxide in the exhaust gases increased from approximately 12% to 15.5% with the introduction of 20% extra air. Dashed curve 418 shows that the carbon dioxide content of the exhaust gases increased from slightly less than 12% to approximately 15.5% when 20% extra air was introduced. These curves illustrate and confirm the fact that additional combustion takes place in the combustion chamber as extra air is introduced in accordance with the system embodied in the invention.

It has been found that the center point of the air injection timing is most effective at about 38° before bottom dead center in the engine expansion stroke, although the engine is relatively insensitive to timing changes under a range from 60° to 10° before bottom dead center. The entire period of air injection has been varied in tests and has been found to be most effective when it covers approximately at 100° range of crank angle. As may be noted by the curves in FIGURES 14 through 17 the percentage of extra air necessary to obtain substantially complete combustion approaches 50% with very rich mixture at light loads. In terms of air volume, however, this is a relatively small amount of air and is well within the capabilities of compressors now available. It has been found that border line detonation characteristics are improved

by the use of air injection under these conditions and a definite reduction in detonation intensity results with increased amounts of extra air.

What is claimed is:

1. A timed air injection system for an internal combustion engine, said system comprising a source of compressed air and means for introducing compressed air from said source into the engine combustion chambers behind the flame fronts in the combustion chambers during the engine expansion strokes; said means including air distribution and timing valve means for receiving compressed air from said source and timed with the rotation of the engine crankshaft to distribute timed compressed air in relation to the combustion cycles in the combustion chambers thereof, means adapted to be connected with the engine combustion chambers for introducing compressed air into the engine combustion chamber from said valve means, and compressed air conduit means interconnecting said valve means and said introducing means, said compressed air timed to be received in said chambers after the flame front has progressed beyond said introducing means.
2. A system for introducing a pressurized fluid into a combustion chamber having a flame front source and an operating cycle and a flame front cyclically advancing from the flame front source through the combustion chamber, said system comprising a source of pressurized fluid, means operable in timed relation with the operating cycle in the combustion chamber and receiving pressurized fluid from said source and connecting with the combustion chamber at a point behind the flame front cyclically advancing therein during one portion of the operating cycle and for introducing pressurized fluid into the combustion chamber only after the flame front has passed the connecting point during each operating cycle.
3. The system of claim 2, said timed relation operable means including pressurized fluid distribution and timing means and fluid introducing means connected with the combustion chamber adjacent the flame front source.

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