July 28, 1953 B. C. FISHER 2,646,782

APPARATUS FOR CONTROLLING FLAME PROPAGATION IN INTERNAL-COMBUSTION ENGINES

Filed Sept. 21, 1948 3 Sheets-Sheet 1

Fig. 3

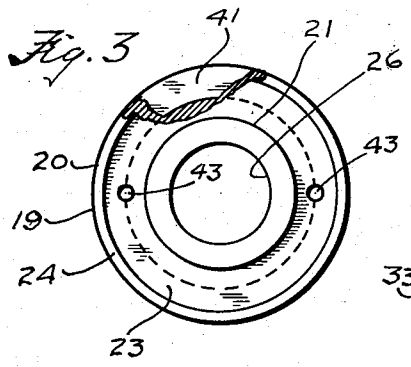

Fig. 4.

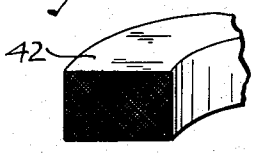

Fig. 1.

Fig. 2.

INVENTOR
BERNARD C. FISHER
BY
Robert Harding Jr.
ATTORNEY

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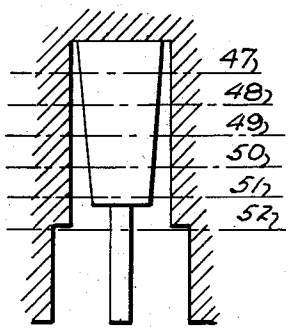


Fig. 6.

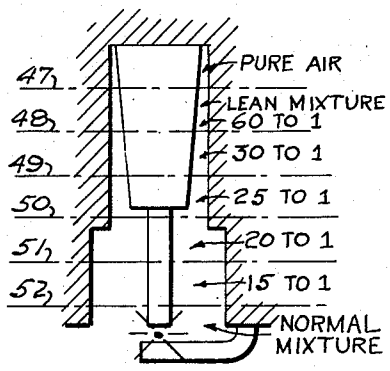


Fig. 5.

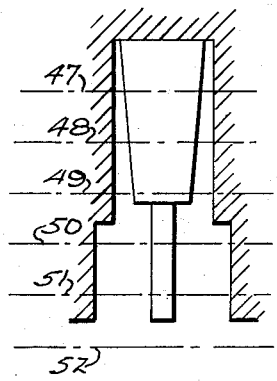


Fig. 7.

Fig. 9.

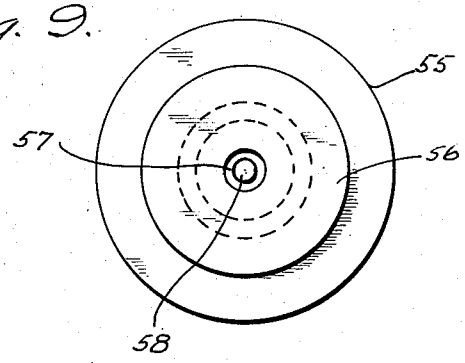


Fig. 8.

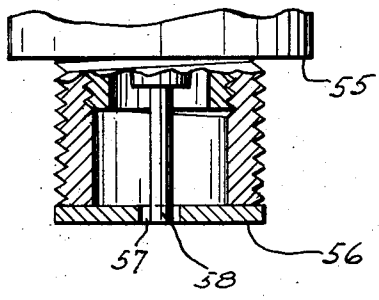


Fig. 13.

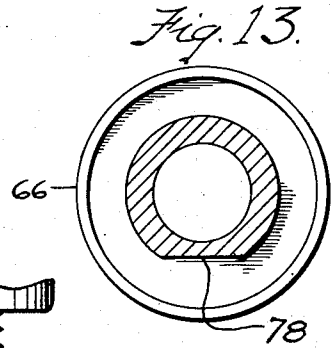
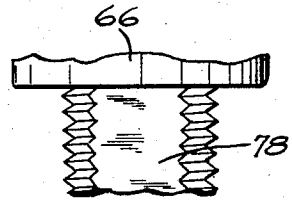


Fig. 12.



INVENTOR
BERNARD C. FISHER
BY
Robert Harding Jr.
ATTORNEY

July 28, 1953 B. C. FISHER 2,646,782

APPARATUS FOR CONTROLLING FLAME PROPAGATION IN INTERNAL-COMBUSTION ENGINES

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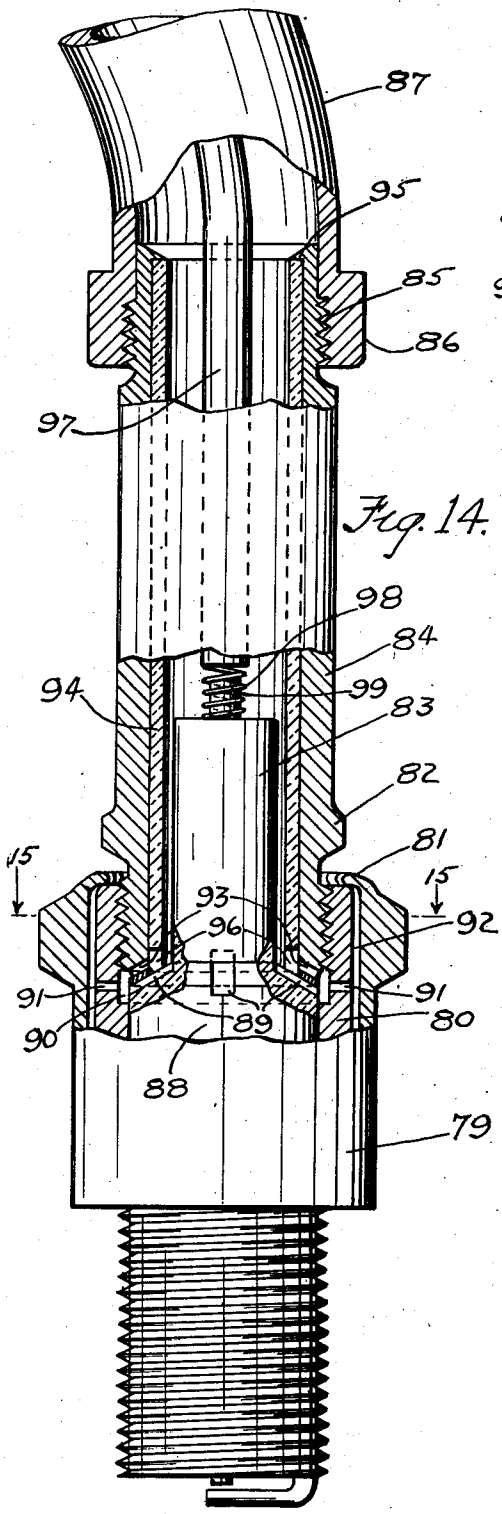

Fig. 14.

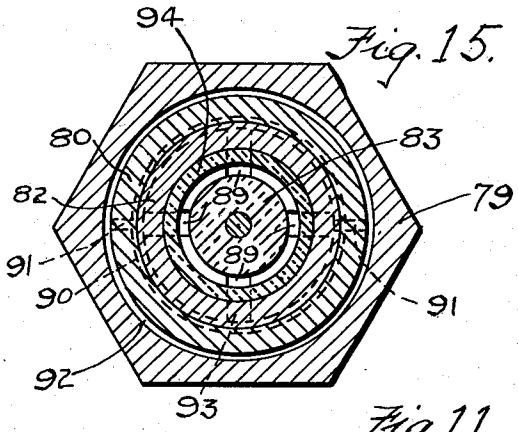

Fig. 15.

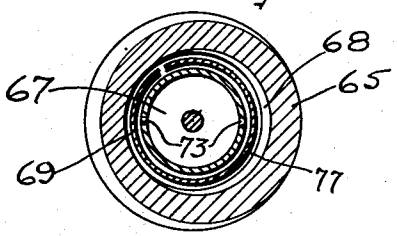

Fig. 11.

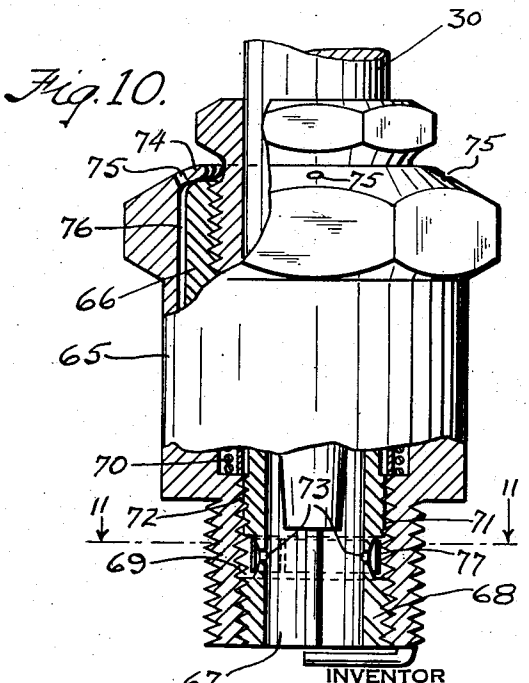

Fig. 10.

INVENTOR
BERNARD C. FISHER
BY
Robert Harding Jr
ATTORNEY

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UNITED STATES PATENT OFFICE

2,646,782

APPARATUS FOR CONTROLLING FLAME PROPAGATION IN INTERNAL-COMBUSTION ENGINES

Bernard C. Fisher, Jersey City, N. J.

Application September 21, 1948, Serial No. 50,348

8 Claims. (Cl. 123—169)

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This invention relates to internal combustion engines and especially to a means and a method for controlling the flame propagation in the combustion chambers of such engines.

This application is a continuation in part of my prior filed applications, Serial No. 644,859, filed February 1, 1946, now Patent No. 2,534,860, issued December 19, 1950, and Serial No. 752,165, filed June 3, 1947, now Patent No. 2,545,546, issued March 20, 1951.

It has always been extremely difficult in the operation of internal combustion engines to control the flame propagation in the combustion chambers thereof so as to get the maximum driving force against the pistons during the proper portion of the power cycle. Many attempts have been made to solve this problem without great success. Among these has been the practice of providing special fuel mixtures which act to delay the burning of the mixture, so as to distribute the explosive force over a larger portion of the pistons' power stroke. Up to the present time these special fuel mixtures appear to give the best results.

I have discovered, however, that by a different proportioning, manipulation, and arrangement of the fuel and oxygen supply for the engine during the time the fuel is introduced into the combustion space and compressed therein, I can control the flame propagation of the fuel mixture in a manner far better than has ever been done before and without the use of any special fuel mixtures, and I can accomplish this by the application to the engine of a simple inexpensive device. In fact my invention permits the use of fuels hitherto thought unsuitable for use in an internal combustion engine.

It is, therefore, the principal object of the invention to provide a method and a means for automatically controlling flame propagation in an internal combustion engine, so as to obtain maximum efficiency of the engine throughout wide ranges of speed and load variations.

Another object of the invention is to provide a method and means for admitting auxiliary oxygen into the combustion chamber and confining this oxygen adjacent the sparking electrodes in a predetermined manner during compression, so as to form a time delay in the initiation of the explosion but at the same time much more rapid if not instantaneous propagation of the flame during the actual explosion.

A still further object of the invention is to provide a spark plug which when applied to an engine will permit the accomplishments of the objects in the last two paragraphs above.

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A further object of the invention is to provide a means and a method for operating an internal combustion engine whereby the engine may be operated with the ignition distributor at a fixed position or with any desired arrangement of ignition control.

The invention has been illustrated in the accompanying drawings in which:

Figure 1 is a sectional side elevation of a portion of a high compression engine designed for carrying out the invention.

Figure 2 is an enlarged sectional side elevation of a portion of the spark plug of the engine of Figure 1 showing the construction of the valve therein.

Figure 3 is a bottom plan view of the inner barrel of the spark plug of Figure 1, showing the valve seat and ducts leading to the air filter.

Figure 4 is an enlarged fragmentary perspective view of the air filter used in the plug shown in Figures 1 to 3.

Figures 5, 6, and 7 are schematic sectional views of the firing space in the inner or electrode end of the spark plug of Figure 1 which may be used to illustrate the principles of the invention.

Figures 8 and 9 are a fragmentary sectional side elevation and a bottom plan view, respectively, of a modified form of spark plug incorporating the invention.

Figures 10 and 11 are a sectional side elevational view and a sectional plan view, respectively, of a modified form of spark plug from that shown in Figure 1, by means of which mechanical ignition adjusting devices may be eliminated, Figure 11 being taken on the line 11—11 of Figure 10.

Figures 12 and 13 are a sectional elevation and bottom plan view, respectively, of a modified form of certain parts of the spark plug of Figure 10.

Figure 14 is a side elevation, partly in section, of another modified form of the invention; and Figure 15 is a sectional plan view of the plug of Figure 14, taken on the line 15—15 of Figure 14.

In carrying out the invention I admit oxygen to the combustion space of an internal combustion engine at the same time that the fuel mixture is introduced therein and confine the oxygen during the compression stroke to a space adjacent the sparking electrodes, anad I control the flame propagation of the explosive mixture in the cylinder by the proper relation between the amount of oxygen admitted and the configuration

and size of the space in which it is confined. I have found that a convenient way to admit the oxygen is through a suitable duct in the spark plug of the engine, the inner end of which also provides a convenient means for defining the above-mentioned space adjacent the electrodes. I have, therefore, illustrated the invention in connection with an engine having a specially designed spark plug for carrying out the objects of the invention, although I wish it to be understood that the features for admitting and controlling the auxiliary oxygen need not be incorporated in the spark plug, but may, if desired, be a part of the engine head or may be furnished by means of an attachment thereto.

In Figure 1 I have shown an engine of the four cycle type having a cylinder 1 in which a piston 2 is mounted for reciprocation in the usual manner. The head 3 is provided with the usual compartments 4 for the cooling fluid 5, and in the top of the head is provided the usual tapped hole 6 for the specially constructed spark plug 7 which is provided with a cylindrical end 8 threaded to screw into the hole 6.

The spark plug 7 has a shell 9 formed of two different outer diameters, the smaller diameter portion forming the cylindrical end 8 and the remainder forming an open-ended housing 10 for the components of the plug. A shoulder 11 is formed between these two portions and seats upon a gasket 12 when the plug is screwed into place for making a gas-tight connection with the engine. The other end of the housing 10 is thickened and has its outer circumference formed into a hexagon nut 13 to which a wrench may be applied for screwing the plug into position.

The inner wall of the shell 9 has three portions of different diameters. The first portion 14 of largest diameter has a diameter only slightly smaller than the outside diameter of the housing 10 to form a thin wall for the housing. This first portion of the inner wall terminates in a shoulder 15 at the inner edge of which the second portion 16 of intermediate diameter commences. This portion 16 defines a portion of the valve chamber, (to be later described) and is relatively short, terminating in a shoulder 17 at the inner edge of which the third portion 18 of the inner wall commences. This portion is enough smaller in diameter than the threaded end 8 of the shell 9 to provide sufficient strength for the cylindrical end 8 of the plug.

The end of the inner portion 18 adjacent the shoulder 17 is threaded to receive a barrel 19 the outer surface of which has portions of two different diameters 20 and 21, to conform generally in length and size to the portions 14 and 16 and 18, respectively, of the shell 9, the portion 21 being threaded to screw into the portion 18 of the shell 9.

Between the two portions 20 and 21 of the barrel 19 is a shoulder 23 the outer circumference of which has a rim 24 which extends axially of the barrel and bites into the metal of the shoulder 15 in the shell 9 to form a gas-tight joint therebetween when the barrel is screwed into place.

The barrel 19 has a bore of two diameters: an outer end portion 25 and an inner end portion 26 of reduced diameter. Between these two portions is provided a sloping shoulder 27 against which is seated the enlarged central portion 28 of the spark plug insulator 29 which may be of the usual design and may be made of porcelain or other suitable ceramic, having an elongated post 30 extending outwardly of the plug from

the enlarged portion 28 and tapering to a smaller diameter from the enlarged portion towards the inner end of the plug, terminating at a point somewhat within the inner end of the barrel 19.

The insulator 29 has the usual small diameter bore extending through it from end to end in which is cemented the central electrode 31 of the spark plug. This electrode terminates at its inner end just about even with the inner end of the shell 9, in the example illustrated, and cooperates with a grounded electrode 32 which is welded to the end 8 of the shell 9 and extends diametrically towards the center of the plug with its end spaced slightly from the end of the electrode 31, so as to provide a gap for a spark to jump.

The other end of the central electrode 31 terminates in a cap 33 which may be of the usual design for attaching the wire to the plug from the distributor of the engine.

A gland nut 34 is threaded into the open outer end of the barrel 19, the outer end of the portion 25 of the bore being threaded for that purpose. The inner end 35 of the gland nut is tapered to conform to the tapered surface of the enlarged portion 28 of the insulator 29, so as to hold the insulator in place when the nut is screwed into place, suitable soft metal washers 36 and 37 being provided adjacent the shoulder 27 and the tapered end 35 of the nut 34, to make a gas-tight joint.

The rim 24 on the shoulder 23 of the barrel 19 is designed to separate the shoulders 23 and 15 a distance just sufficient to form a valve chamber 38 in which operates a valve 39, which is preferably a flat ring of stainless steel.

The portion 16 of the inner wall of the shell 9 is enough larger in diameter than the outer diameter of the portion 21 of the barrel 19 to provide space for a light coil spring 40 which may preferably be of stainless steel to resist rust and heat and which is under slight compression between the valve ring 39 and the shoulder 17 of the shell 9 and tends to maintain the valve ring against the shoulder 23 of the barrel 19.

In the portion 20 of the barrel 19, a short distance from the rim 24, I provide a groove 41 which may extend completely around the circumference of the barrel and in which is positioned a filter 42 formed of a suitable material having many interstices to permit the passage of a gas but preventing the passage of foreign particles which might otherwise pass into the engine cylinder.

I prefer to make the filter out of wire mesh and I have found that a suitable number of fine braided Phosphor bronze or inconel wires may be compressed into a cross-section to conform with the groove, cut off at the proper length and wrapped around the groove with the ends abutting. A fragment of such a filter is shown in Figure 4.

Small holes or ducts 43 are formed in the barrel 19 and extend between the shoulder 23 and the groove 41, these holes being preferably two in number and being diametrically positioned with respect to the barrel. The arrangement is such that the valve ring 39 covers the holes 43 when seated against the shoulder 23.

The diameter of the portion 20 of the barrel 19 is slightly smaller than that of the portion 14 of the shell 9 so as to provide a space or duct 44 through which air may pass into the groove 41, and the filter 42 may have a radial dimension sufficient to provide a press fit within

the shell 9, when the barrel 19 is inserted therein.

With the arrangement shown, it will be seen that air may pass through the duct 44, through the filter 42, and through the holes 43 into the valve chamber 38 when the pressure in the valve chamber is sufficiently less than that in the duct 44 (which is under atmospheric pressure) to permit the valve 39 to be displaced from its seat against the pressure of the spring 40.

In the example shown in Figures 1 to 4, the passage or duct leading from the valve chamber 38 to the combustion space of the engine is formed by the normal clearance between the threaded portions of the barrel and the shell. These threads are standard U. S. threads with normal clearance for a running fit, but there is enough clearance between the outside diameter of the thread on one part and the root diameter of the thread on the other part to provide a helical duct (indicated at 45 in Figure 2), of sufficient cross-section for my purpose. How the cross-section of this duct may be increased and in what instances it should be increased will be described later.

In general the operation of the engine and plug assembly shown in Figures 1 to 4 is as follows:

During the suction stroke a mixture of gasoline and air is drawn into the cylinder in the usual manner. At the same time, since the pressure in the cylinder is substantially less than that of the outside air, air will be drawn through the duct 44, through the filter 42, and the holes 43, displacing the valve 39, through the valve chamber 38, and through the helical duct 45 into the space or cavity 46 formed by the cylindrical end 8 of the shell 9, which space may be called the "firing space."

Air passing thus at this stage through the ducts of the spark plug has two important effects. First, it cools the several parts of the plug. The space 44 between the barrel 19 and the shell 9 being relatively small, air passes through here at high velocity, and, since this high velocity air is exposed to a relatively large metal surface, an efficient cooling action of both shell and barrel takes place in a well-known manner. The same effect is produced in the helical duct 45 between the barrel 19 and the shell 9, cooling both parts, and the air passing over the electrodes 31 and 32 cools them also. Second, the air passing into the firing space 46 adjacent the electrodes, when admitted to this space in the proper amount, provides the means for controlling the flame propagation when the charge is fired.

In order to explain what I believe takes place during the compression and power strokes, the firing space 46, defined by the cylindrical end 8 of the shell 9 and the inner end of the insulator 29, has been represented diagrammatically in Figures 5, 6 and 7. The following theory of operation has been developed after many experiments and careful study of the results obtained:

At the end of the intake stroke fresh air surrounds the electrodes including the firing space 46. Just before the end of the intake stroke, when the pressure inside the combustion chamber approaches atmospheric, the valve 39 closes under control of the spring 40. As the compression stroke starts, the air surrounding the electrodes is forced back into the space 46. Since the valve is closed, this air cannot get out of the spark plug and continues to compress in the valve chamber 38, the duct 45, and in the space 46. At the end of the compression stroke the arrangement of air and fuel mixture in the space 46 is

somewhat as indicated in Figure 5. Pure air has been forced into the innermost portion of the space 46 and various gradation of a mixture of air and the normal fuel mixture will be arranged between that point and the point where the spark occurs at the tips of the electrodes. Thus, pure air may exist in the space between the inner end of the space 46 and the dot-and-dash line 47; a lean gas mixture varying from pure air to 60 parts of air to 1 of the normal mixture, may extend from that line to the dot-and-dash line 48; a mixture varying from 60 to 1 to 30 to 1 may extend between the dot-and-dash line 48 and 49; a mixture varying from 30 to 1 to 25 to 1 may extend between the lines 49 and 50; a mixture varying from 25 to 1 to 20 to 1 may extend between the lines 50 and 51; a mixture from 20 to 1 to 15 to 1 may extend between lines 51 and 52; and from line 52 to the end of the center electrode there may be a mixture varying from 15 to 1 to the normal mixture.

The spark, occurring a little after the end of the compression stroke, finds the stratification of air and gas somewhat as thus outlined. It ignites the mixture at the electrodes and the flame begins to spread away from the electrodes in all directions. This burning of the mixture is relatively slow and an increment of time elapses before the edge of the flame reaches the line 52 in the space 46, but as the flame approaches this line the rate of burning increases and the flame front then moves faster and faster. As the flame front passes beyond the line 52 into regions of leaner and leaner mixtures, it will finally reach a point where the rate of burning becomes substantially instantaneous. While I do not know exactly where this point is, it may be assumed for the purpose of this explanation to be at the line 49. At this point then, the lean mixture, supplied by the oxygen immediately adjacent to it in the still leaner mixture, is instantaneously consumed, creating such a sudden expansion of the gases that the flame, with no other place to go, is forced out of the firing space 46 like the flame of a blow-torch and into every corner of the combustion chamber, igniting the mixture therein at points which would normally not have been reached at this time by the expanding flame front. The blow-torch effect thus causes substantially instantaneous burning of the rest of the mixture in the combustion chamber, and when the stratification of the air and gas mixture is correct, a smooth pressure is applied to the piston during the most effective part of its power stroke and the combustion of fuel is substantially complete, with resulting increase in engine efficiency.

In the ideal timing of the flame propagation the force of the expanding gases against the piston should start from zero as the piston leaves the innermost dead-center position, increase sinusoidally to a maximum as the piston passes its half-way position, and decrease sinusoidally to zero again at the outermost dead-center position. By means of my invention I approach much nearer to this ideal condition than has been done before with any engine of which I am aware.

The force of the explosion creates an extremely high pressure in the combustion chamber which forces unused air or burned gasses back into the farthermost crevices of the space 46, including the duct 45 and the valve chamber 38. The valve chamber contains mostly air because I have

found that burned gasses pass only about one-third of the way through the duct **45**.

At the proper time, at the end of the proper stroke, the exhaust valve opens and the burned gasses rush out of the combustion chamber, aided by the piston which has begun to move into the cylinder again. When the exhaust valve opens, the pressure within the combustion chamber drops far below the extremely high pressure created therein by the explosion. Since the air in the valve chamber **38** is under this much greater pressure, some of it will be forced through the duct **45** and through the space **46** into the combustion chamber. Any air left compressed in the innermost portion of the space **46** joins this pure air in flushing the burned gasses out of the space **46** and away from the electrodes **31** and **32** and again producing a cooling effect upon the electrodes and associated parts. When the exhaust valve closes at the end of the exhaust stroke, the cycle is ready to be repeated again with another intake stroke.

Consider now what will happen when load and speed conditions of the engine change. Assume for a predetermined condition of load and speed that the region in the firing space **46** which the flame front has to reach before the "blow-torch" effect is obtained is represented by the line **49**. Suppose now that the load is increased as, for instance, in an automobile, when the automobile starts to climb a hill, and that this condition is met by opening the throttle for supplying more fuel to the engine. Since more fuel mixture enters the cylinder at the intake stroke, the compression in the cylinder will rise and it will be seen that the various gradations of the mixture of fuel and air will be squeezed farther into the space **46**, so that now the lines **47** and **52** may assume the positions indicated in Figure 6. Thus it will now take longer for the flame front from the spark to reach the region of line **49** and the ignition is effectively retarded, which is what is desired when the load is increased, as is well known.

If the load should decrease and a smaller amount of fuel be admitted by the throttle, the compression also decreases, thus permitting the stratified fuel mixture to spread out in the space **46** with the result that the line **49** may now be much closer to the spark, as indicated, for instance, in Figure 7, requiring less time for the flame front to reach it and thus effectively advancing the ignition, which is again what is desired for this condition.

Now assume again that the normal conditions prevail which produce the effect indicated in Figure 5 and that the speed of the engine increases. This will cause less fuel mixture to enter the cylinder, because the time for it to get in becomes less, and the compression will therefore decrease and the lines **47** and **52** will spread out bringing the line **49** nearer the electrodes, as indicated in Figure 7, and thus effectively advancing the ignition, which again is what is desired under this condition.

Decreasing the speed has the opposite effect, increasing the compression again and crowding the stratified mixture into the space, as indicated in Figure 6, thus effectively retarding the ignition.

It will be seen that the position of the critical region of stratified fuel mixture will be governed by a number of factors. These are: (1) the normal compression in the cylinder at the end of the compression stroke; (2) the normal engine speed; (3) the size of the firing space **46**; (4) the shape of the firing space **46**; and (5) the amount of oxygen (air) admitted to the firing space **46** prior to compression.

The shape and size of the space **46** and the amount of oxygen (air) admitted to the space may be controlled for any given engine. I have found that a convenient shape and size may be determined by the inner end of the spark plug, and I control the amount of air admitted by the size of the duct and the arrangement of the valve.

In variable speed, variable load, internal combustion engines now in use, the automatic advancing and retarding of the spark is usually accomplished by two automatic mechanical adjusting devices operating on the distributor, one under control of the suction in the carburetor or intake manifold and the other controlled by centrifugal force. I have found that the automatic effective adjustment of the spark which my invention provides may be used to replace entirely the mechanical adjusting devices referred to above, or the invention may be used in conjunction with these mechanical adjusting devices. In either case the added advantage is obtained of causing substantially instantaneous and complete combustion of the fuel mixture at a time when it will do the most good, so that the efficiency of the engine is greatly increased.

The embodiment of the invention illustrated in the figures thus far described is suitable for use in an automobile engine equipped with the usual controls for advancing and retarding the spark and having a normal compression of 110 pounds per square inch. Good results have been obtained when the various dimensions were as follows:

Threads on shell to fit engine	14 millimeters x 1¼ millimeters.
Internal diameter of end of shell 9	.2813 inch.
Internal diameter of shell 9 at portion 18	.355 to .360 inch.
Internal diameter of barrel at 26	.263 to .271 inch.
Diameter of inner end of insulator	.1625 inch
Diameter of inner end of insulator adjacent enlarged portion	.2188 inch.
Distance of electrode gap to end of barrel 19	.31 inch.
Threads on barrel forming duct 45	10 millimeters x 1 millimeter.
Pitch diameter of thread	.3675 to .3642 millimeter.
Distance from end of barrel to valve chamber	.1875 inch.
Thickness of valve ring	.015 inch.
Clearance between valve ring and shoulder 15	.010
Diameter of holes 43	.040 inch.
Width of space 44 between barrel 19 and shell 9	.004 to .008 inch.
Gap between electrodes	.018 to .025 inch.
Spacing of distributor points	.012 inch.

Although the duct **45** around the threads between the firing space **46** and the valve chamber **38** has a very small cross section, it allows enough air to pass through to obtain good results with an engine having dual mechanical spark controls at the distributor, as explained above. In addition, the burned gases are prevented by the cross section and length of the duct from being forced into the valve chamber by the explosion and thus the spring **40** is protected. In some instances, I may still further protect the spring against hot gases by providing a sleeve **53**, preferably of stainless steel to fit loosely over the threaded end of the barrel **19** within the spring **40**, this sleeve being provided with a hole or holes **54** for the passage of air.

The plug, as described, may be inserted in an engine cylinder in place of the ordinary plug, without any other change, resulting in much bet-

ter operation of the engine. However, I have found that because the fuel is used more efficiently, much less is needed under all conditions of engine operation. I may therefore obtain better mileage by reducing the size of the main jet by a larger metering rod to produce a leaner mixture when the main jet is in operation.

I have also found that in adjusting the engine for optimum operation, it is best to set the timing in accordance with standard practice and then advance the setting until the most power is obtained without pre-ignition. When properly adjusted, an automobile can start at ten miles an hour at the bottom of a thirty degree grade and with the throttle wide open pick up speed smoothly and without pre-ignition or detonation. If the car fails to pick up speed, the setting of the spark should be advanced; if pre-ignition occurs, the setting of the spark should be retarded.

Best results have been obtained with regular gasoline, that is gasoline which has not been treated with tetraethyl lead or the like.

The results obtained with the invention are startling. I have found after repeated tests that the mileage per gallon of any automobile can be increased by at least ten percent and with one standard automobile of a well known make, I have increased by 50% the mileage per gallon stated by the manufacturer to be the standard mileage of the car.

In addition to the increase of mileage which comes with the practice of the invention, other phenomenal results are obtained. These may be listed as: increased power and therefore increased acceleration; cooler operation of the engine, and especially cooler operation of the spark plugs with accompanying long life thereof; slower idling speed for the engine at much smoother operation than with ordinary engines; much less tendency for carbon to form in the cylinder or around the electrodes of the plug, since the combustion is substantially complete and therefore less fouling of plugs and valves.

In addition to these advantages the whole engine may be designed to incorporate the invention with the result that the compression may be raised; a longer stroke may be used with no loss in revolutions per minute; and there need be no limit to the bore of the cylinder. Heretofore, gasoline engines have been limited to a six inch diameter bore. Beyond that diameter the combustion becomes very inefficient. With the use of the invention, however, the efficiency of engines with bores larger than six inches can be increased several hundred per cent. Also an engine designed in accordance with the invention permits the use of a smaller cooling system than required with the ordinary engine and a lower powered ignition system.

The size of the duct leading from the valve chamber to the firing space forms an important control for the amount of oxygen admitted to the firing space during each cycle of the engine, but the amount of this oxygen may be additionally controlled by the pressure of the spring 40 against the valve 39. By increasing the tension of the spring, the time at which the valve will open during the suction stroke will be delayed, with the result that less air will be drawn into the firing space. The characteristics of the plug, therefore, may be easily altered for different engines by supplying springs of different tensions.

The size of the opening of the firing space into the combustion space of the engine may also be varied to vary the characteristics of the plug. By restricting this opening, less of the mixture can get into the firing space, with the result that the stratification as indicated in Figure 7 will be approached. One manner of restricting this opening has been illustrated in Figures 8 and 9. Here the shell 55 is provided with a disc 56 which is welded over the open end thereof. This disc serves as the grounded electrode of the plug and is provided with a hole 57 into which the center electrode 58 extends, the hole being sufficiently large to provide the desired spark gap between the disc and the center electrode. If less restriction is desired, the hole 57 may be elongated or additional holes may be provided in the disc.

As has been stated above, the variation in position of the stratified fuel mixture in the firing space 46, under control of the compression, provides an automatic adjustment of the effective timing of the spark. The embodiment already described may be used with engines provided with mechanical spark advance apparatus. An embodiment of the invention will now be described by means of which the mechanical spark adjusting devices on an engine may be entirely eliminated and the timing of the spark permanently set at about dead center position of the piston.

The arrangement is illustrated in Figures 10 and 11 in which the plug shown is generally the same as that already described, having a shell 65, much the same as the shell 9 of Figure 1, and a barrel 66 which corresponds to the barrel 19 of Figure 1. But the firing space 67 has been made longer and narrower than that of Figures 1 to 8.

The barrel 66 differs from that of Figure 1 in that the inner end 68 is extended to be flush with the inner end of the shell 65, and both parts have extending cooperating threads. A groove 69 is provided in the outer surface of barrel 66 midway between the end of the barrel and the valve chamber 70, this valve chamber being identical with that described in connection with the other figures. The threads between the groove 69 and the end of the barrel 66 are standard and engage in the normal way with the threads of the shell. The threads 71, however, between the groove 69 and the valve chamber 70 are flattened, as by machining off the peaks of the threads, so as to increase the clearance and provide a duct 72 of greater cross section than the duct 45 of Figures 1 and 2 for the air to pass between the groove 69 and the valve chamber 70. Holes 73 are provided through the barrel between the groove 69 and the interior space 67. Preferably two holes are provided diametrically opposite each other, although more may be provided if desired.

With the arrangement just described, it will be seen that there is much freer access of air from the valve chamber 70 to the space 67 than was provided in the structure of the other figures. Because of the groove 69 and the flattened threads on the barrel, the structure is somewhat weaker, and I overcome this by providing an extended rim 74 at the outer end of the shell 65 and spinning this rim over the outer end of the barrel when assembling. Holes 75 are drilled at spaced points around the circumference of the rim to give access for the air to the space 76 between the barrel and the shell.

In the operation of this plug, hot gases may pass into the groove 69 through the holes 73, and in order to prevent damage from heat to the spring and the valve in the valve chamber, which will be understood to be the same as those shown in connection with the other figures, I provide in

the groove 69 a sleeve 77 which may be a split ring of stainless steel and may snap loosely over the narrow portion of the groove and fit loosely therein. Gases impinge on the sleeve and are disbursed and cooled before entering the valve chamber.

Because the space 67 is longer and narrower than the space 46 of Figures 1 to 8, the stratification of the fuel mixture becomes more sensitive to changes in compression, and hence the automatic adjustment of the spark timing is obtained. A long narrow space will also produce a more violent blow-torch effect than a shorter wider space, causing a closer approach to instantaneous combustion in the main combustion space. By carefully designing the firing space for a particular engine the desired result can be obtained.

Where more air is needed in the space 46 or the space 67, in order to bring the critical region in the fuel-air mixture nearer to the point where the spark is produced, I may mill away a portion of the threads on the barrel, as shown at 78 in Figures 12 and 13, to increase the cross section of the air duct still further.

It is the oxygen in the firing spaces 46 and 67 which permits me to control the flame propagation, as explained above, and this oxygen is supplied by a pair in the embodiments already described. However, it will be apparent that in some instances it may be desirable to supply a gas more nearly approaching pure oxygen, or under pressure other than atmospheric. For instance, the engine of airplanes will require air or perhaps pure oxygen at a pressure higher than the surrounding atmosphere. To meet such a requirement, I may use the embodiment of the invention shown in Figures 14 and 15.

In Figure 14, the inner part of the spark plug towards the combustion space may take the form of either of the embodiments heretofore described, except that the end which screws into the engine is preferably longer, and this inner part is not shown in detail. In this figure, the shell 79 and the barrel 80 correspond to the shells and barrels of the other figures. The outer end of the shell 79 is provided with a rim 81 which is spun over the outer end of the barrel 80, not only to make a more rigid connection, but also to make a gas tight seal at the outer ends of the shell and barrel. The gland nut 82 which holds the central insulator 83 in place is extended in a sleeve 84 which is provided at its outer end with threads 85 to receive a suitable fitting 86 at the end of a flexible hose 87 leading from a supercharger, (not shown), or other source of the gas to be fed through the spark plug. The outer surface of the enlarged portion 88 of the insulator 83 is provided with a plurality of radial grooves 89 which align with a groove 90 formed circumferentially in the inner wall of the barrel 80. A plurality of radial holes 91 are provided through the wall of the barrel to connect the groove 90 with the cylindrical duct 92 formed between the barrel and the shell.

The inner end of the gland nut 82 may also be provided with radial grooves 93 so that when the nut is screwed down against the surface of the central insulator with the usual soft metal gasket, the grooves 89 and 93 provide passage into the groove 90 and holes 91.

A ceramic sleeve 94 is provided within the gland nut 82 which fits snugly against the inner wall of the sleeve 84 of the nut and is thin enough to provide an air passage between its inner wall and the central insulator 83. This ceramic sleeve may be held in place by spinning the outer end of the gland nut over it as indicated at 95 in the drawing. The inner end of the sleeve 94 may also be provided with a plurality of grooves 96 to insure a passage of gas from the inside of the sleeve into the groove 90 and thence to the duct 92.

The electrical connection may be made to the plug by means of an ignition wire 97 extending down the center of the hose 87 into the sleeve 94. The ignition wire may have a spring 98 at its end which contacts with the outer end 99 of the center electrode at the outer end of the insulator.

Except for the fact that the gas (air or oxygen) is delivered to the plug from a desired source and may be under pressure, the plug of Figures 14 and 15 operates in the same manner as the other embodiments already described.

It will be noted that the insulator in the different embodiments illustrated ends some distance from the end of the central electrode where the spark is produced, this construction being different from that of the ordinary spark plug where the insulator is carried almost to the end of the electrode. This provides the necessary increased volume for the firing space, and I have found that the exposed portion of the electrode is unaffected by the burning gases because of the cooling effect of the incoming air. To decrease the size of the firing space, the insulator may be carried to the end of the shell.

In the embodiments shown, the gap between the electrodes is about flush with the inner wall of the engine head. It is to be understood, however, that with a given amount of air entering the plug, the timing of the flame movement from the gap to the critical region of the gas mixture may also be varied by moving the gap into or out of the firing space. The position of the gap will therefore be determined by the particular requirements.

While the use of the invention in connection with a four cycle engine has been described in detail, it will be understood that the invention is by no means limited to any particular type of engine, but may be used wherever a more accurate control of flame propagation is desired.

Modifications of what has been shown and described may be used without departing from the spirit of the invention and I do not wish to limit myself except by the appended claims.

What I desire to claim and secure by Letters Patent is:

1. A spark plug comprising a body member, means at one end of said member for attaching said member in the cylinder head of an internal combustion engine, electrodes at the same end of said member providing a spark gap, an insulator extending axially through said body member, a conductor extending through said insulator and forming one of said electrodes at its end, said body member having a cavity outside said insulator communicating with the space adjacent said gap and on the opposite side of said gap from the combustion chamber of said engine, a duct leading from said cavity to the outside of said plug through said member but outside of said insulator, and a one-way valve in said duct permitting gas to pass into said cavity through said duct but preventing passage in the other direction, the configuration and size of said cavity, the cross section of said duct, and the sensitiveness of said valve being such that stratification of the normal fuel mixture and the gas in-

troduced through said duct will occur in said cavity during the compression stroke of said engine, so as to control the flame propagation in the combustion chamber thereof for different speed and load conditions of said engine.

2. A spark plug, as defined in claim 1, in which the duct has an enlargement forming a valve chamber in which the valve operates.

3. A spark plug, as defined in claim 2, in which the valve chamber is annular, the valve is a thin, flat, annular plate, and a coil spring is provided for normally holding said valve against its seat, and in which shielding means is further provided in said valve chamber to protect said spring from hot combustion gases.

4. A spark plug, as defined in claim 1, in which the cavity has a restricted opening.

5. A spark plug, as defined in claim 1, in which the body member is formed of two telescoping parts having threaded engagement at the inner end of the plug, said parts being relatively displaced beyond said threaded portions to define a chamber for said valve and the threaded connection forming the duct between the cavity and the valve chamber and in which the threads on one of the parts are flattened to increase the cross section of the duct into the valve chamber.

6. A spark plug comprising a body member, means at one end of said member for attaching said member in the cylinder head of an internal combustion engine, electrodes at the same end of said member providing a spark gap, an insulating member extending axially through said body member, a conductor extending through said insulating member and forming one of said electrodes at its end, said body member having a cavity outside said insulating member communicating with the space adjacent said gap and on the opposite side of said gap from the combustion chamber of said engine, a duct leading from said cavity to the outside of said plug through said member but outside of said insulating member, and a one-way valve in said duct permitting gas to pass into said cavity through said duct but preventing passage in the other direction, the configuration and size of said cavity, the cross section of said duct, and the sensitiveness

of said valve being such that stratification of the normal fuel mixture and the gas introduced through said duct will occur in said cavity during the compression stroke of said engine, so as to control the flame propagation in the combustion chamber thereof, said body member being formed of two telescoping parts having threaded engagement at the inner end of the spark plug, said parts being relatively displaced beyond said threaded portions to define a chamber for said valve and the threaded connection between said parts providing a tortuous, restricted portion of said duct between said valve chamber and said cavity.

7. A spark plug, as defined in claim 6, in which the two telescoping parts extend outwardly of the plug a relativley long distance in closely spaced parallel relationship, forming an annular passage of small cross section between the valve chamber and the outer end of the plug.

8. A spark plug, as defined in claim 7, in which one of the telescoping parts has a groove in its wall opposing the other part, adjacent the valve chamber, a filter is provided in said groove, and a duct is provided in said part extending from said valve chamber to said groove and forming the inlet duct for said valve chamber.

BERNARD C. FISHER.

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