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NEW PRINCIPLE OF IGNITION AND COMBUSTION IN ENGINES

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NEW PRINCIPLE OF IGNITION AND COMBUSTION IN ENGINES

L. A. Gussak

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NEW PRINCIPLE OF IGNITION AND COMBUSTION IN ENGINES

L. A. Gussak[1]

ABSTRACT

The article considers the shortcomings of internal combustion engines associated with the combustion process taking place in them. It also describes a new principle of ignition and combustion of the working mixture (precombustion chamber jet ignition) and presents data on the improvement of performance in precombustion chamber engines compared with spark ignition engines. These data have been obtained during numerous testings of these engines on trucks and light automobiles. /98

Problems associated with effective transportation are important for the national economy. In this connection prime interest is in increasing the economy of the large number of automobiles, most of which are equipped with gasoline carburetor-type engines with spark ignition. Efforts to solve this important problem frequently encounter insurmountable difficulties, explained by the combustion process in such engines.

A combustion process during spark ignition develops slowly and unstably, which places severe limitations on the engine and makes its exploitation difficult. As shown in Figure 1, when such engines are used with maximum loads, even with mixtures close to theoretical composition ($\alpha \approx 1$) the combustion rate u_g is still quite small. When an automobile engine operates in these modes utilizing the maximum filling of the cylinder with a mixture charge of theoretical composition and with a wide open throttle, detonation frequently occurs. It limits the maximum power achievable in an engine and its economy.

Detonation occurs because the turbulent motion of the combustible mixture is of low intensity and because the flame front propagates very

[1]Moscow.

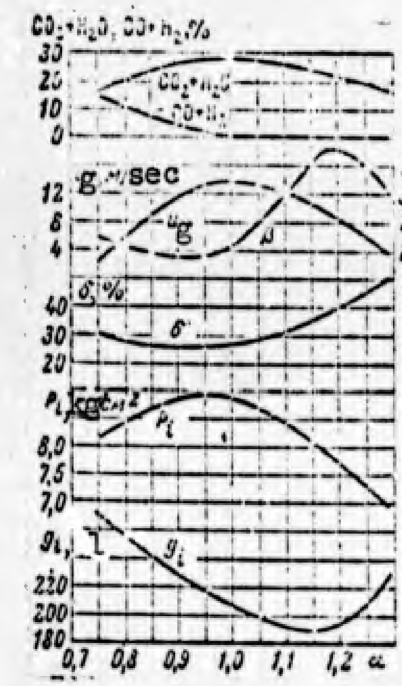

Figure 1. Rate effectiveness and combustion stability as a function of mixture composition during spark ignition: OTsU—GAZ—51f engine; $\epsilon = 6.2$; n = 1200 rpm; complete throttling; automotive gas with 53.6 octane rating; 1, g/hp hr.

slowly in it. As a result, ahead of the flame front in the last part of the charge, large sources of fuel-air mixture are formed. In these sources the prolonged action of high pressures and temperatures from compression and combustion produces chemical chain reactions. They ignite the combustible mixture in these sources, forming a shock wave resulting in detonation (explosive) combustion of the mixture ahead of the flame front.

In addition, the low combustion rate in engines is further shortened rapidly when the mixture is made lean. The stability of engine operation becomes entirely unsatisfactory. This is manifested, for example, in a ±20 percent spread in the maximum value of the combustion pressure on the indicator diagrams which is noted on the stability curve of the engine δ while the mixture is still only slightly lean, about 20 percent ($\alpha = 1.2$). The instability in the combustion process with a further leaning of the mixture reduces the specific power of the engine; expressed by the average indicator pressure P_1, and increases the specific fuel consumption g_1. No increase in ignition advance β can prevent the drop in the combustion rate u_g and establish the stable operation of the engine δ at normal level. /99

As is well known, the automobile is operated most of the time at 20 to 40 percent of maximum engine power. For this purpose the amount of combustible mixture is reduced by the throttle in the carburetor. In this connection, as throttling is increased the quantity of combustible mixture is decreased while the concentration of exhaust gases from the preceding cycle increases.

Thus it would appear that at low loads it would be more advantageous to utilize lean mixtures, thereby decreasing fuel consumption. However, throttling is accompanied by an even greater decrease in the combustion rate as well as a decrease in the stability of the engine which is poor to start with. This is explained by the detrimental effect of certain products of complete combustion of a lean mixture (CO_2) in exhaust gases on the combustion process. Therefore, it becomes necessary to enrich the mixture substantially and to maintain the normally stable operation of the engine at all levels of power at the expense of fuel consumption. The forced enrichment of the working mixture produces incomplete combustion and the ejection of a substantial quantity of poisonous and harmful products of incomplete combustion into the atmosphere. The requirement for the uniform distribution of the rich mixture in the cylinders to achieve the normal operation of the engine requires that it be heated intensely in the intake manifold, which causes an extensive scale formation on the walls of the intake manifold. As a result, the intake cross sections are gradually constricted, producing increased throttling and a substantial decrease in power and economy.

Thus, to limit detonation ignition at maximum loads and to extend the range for the effective utilization of lean air-fuel mixtures during partial loading it is necessary to increase substantially the combustion rate and to improve combustion stability.

It is known that an effective method of increasing the combustion rate is to intensify the random formation of vortices and turbulent motion in the operating mixture. This produces an increase in the turbulent propagation of the flame front (Ref. 1) and the sources which form ahead of the flame front break up and mix with the fresh mixture. Due to this effect of turbulence it is possible to limit the occurrence of detonation, to increase the combustion rate of the rich (for maximum loads) and lean (for partial loading) mixture and, consequently, to in- /100
crease effectiveness of the operating process. Such a method of increasing the combustion rate is already used in automobile engines whose combustion chamber has a turbulent shape. However, a further increase in the turbulence of the working mixture at the beginning of the combustion process produces an intense removal of heat from the ignition source, and the breaking up and extinguishing of the flame front, which has not had time to develop sufficiently. The conflicting effect of turbulence on the combustion process during its different stages limits the possibility of increasing the effectiveness of this process in spark ignition engines.

In 1935 at the Institute of Chemical Physics of the USSR Academy of Sciences, A. S. Sokolik, N. A. Rivin and V. G. Voronkov investigated the combustion process in tubes with various constrictions placed in the path of the propagating flame at various distances from the source of spark ignition. It was shown that the flame propagation velocity increases after it passes through the opening in the crosspiece. This increase depends on the tube volume before the crosspiece and on the cross section of the hole in the crosspiece.

The results of this investigation made it possible for A. S. Sokolik to propose the idea of increasing the combustion rate in a gasoline engine by a turbulent flame jet. To carry out this idea, they provided a small volume auxiliary combustion chamber (precombustion chamber) near the main combustion chamber, where a preliminary spark ignition of an auxiliary mixture took place and the flame jet was ejected through a small nozzle opening into the basic combustion chamber. According to the originator of this idea the products of combustion in the precombustion chamber jet must have a maximum temperature achievable by the complete combustion of the auxiliary mixture. For this purpose, in 1936 it was proposed to burn an auxiliary fuel-air mixture in a precombustion chamber. The mixture was to be close to a theoretical one "with a coefficient of air excess approximately equal to 0.9" (Ref. 2) in which there were fifteen parts of air for each part of fuel.

The application of this ignition method in various types of engines showed that it could be used for combatting detonation and for the effective burning of lean mixtures. Although the theory of turbulent flame propagation then being developed confirmed the correctness of this idea, the positive results of its application were achieved only after extensive refinement of precombustion chamber design. During these and similar works conducted by other organizations there were also cases on record when the precombustion chamber ignition by flame jet did not produce satisfactory results.

As was established subsequently, this method of precombustion chamber ignition does not differ in principle from the method well known at the very beginning of the 20th Century. We refer to the method of ignition by means of the so-called "intermediate flame" (Ref. 3). There are also many similar later designs recorded in patents and authors' certificates in which the ignition of the combustible mixture is achieved by ejecting flames or enflamed gas jets into the combustion chamber from the precombustion chamber at a maximum temperature, etc. However, none of these "flame" methods of ignition have been adopted in practice. All this pointed to the fact that the ideas of the turbulent acceleration of combustion by the precombustion chamber flame jet were not sufficiently well founded and that methods of this type were not very reliable. It was established that ignition produced by the precombustion chamber flame jet is in principle identical to the ignition produced by the flame formed during the spark ignition close to the spark plug electrodes. If there is any difference between the two methods then it consists merely of the fact that the flame volume in the case of the precombustion chamber flame may be much greater while its temperature is much less than that of the spark. /101

After many years of experimental investigations associated with the kinetics of branched chemical chain reactions, the ignition and combustion of the gaseous mixture and the process of spark and flame ignition in internal combustion engines, a theory for a new principle of flame ignition and turbulent combustion was formulated at the Institute of Chemical Physics of the USSR Academy of Sciences. The application of this principle, which produces a radical change in the form of the combustion process, provides for a substantial increase in the combustion rate and produces a significant and reliable improvement in the effectiveness of the process. According to this principle, the mixture must not be ignited by a flame jet but rather by a jet of chemically active products of incomplete combustion rich in an auxiliary mixture with a substantial concentration of free radicals and atoms. The chemical activity of these substances which initiate a rapid development of branched reactions with the formation of an avalanche of the natural active free radicals and atoms in the mixture, is very high. As shown in Reference 4, the maximum concentration of chemically active particles is formed when heat liberation is incomplete. This occurs when the mixture does not burn completely.

The proposed generator of the initial active centers was a precombustion system with a precombustion chamber of small volume equal to 2-3 percent of the main combustion chamber volume. It must be of compact construction and have a minimum ratio of surface to volume and must also be situated near the main combustion chamber and connected to it by means of one or more passageways. The shape and cross section of these passageways must provide for a reliable formation of the turbulent breakaway of the flame flowing from the precombustion chamber. This breakaway must occur with minimum possible pressure drop produced by burning of the precombustion chamber mixture and must occur with a low discharge velocity of combustion products and with a short-range ejection of this flame into the main combustion chamber. In the volume of the principal combustible mass, the precombustion chamber flame must produce a rational intensity of turbulence with a vortex formation of a large number of small independent combustion sources. To achieve this, the discharge openings must have a sharply defined form and their edges must not be smoothly rounded. Openings of the Venturi and Laval type are not permissible. The total cross section of the discharge holes referring to the volume of the precombustion chamber must lie within the limits 0.03-0.04 cm^2/cm^3 while the ratio of their length to the reduced diameter of these openings must not exceed 2.

A simple and reliable method was developed for forming the chemically active products for the precombustion chamber flame by carrying out an incomplete combustion of a rich auxiliary mixture. For this purpose the auxiliary mixture filling the precombustion chamber at the instant of spark ignition must have a high deficiency of air oxygen--the quantity of air in this mixture must equal 10.5-6.0 parts instead of the 15 parts necessary for the complete combustion of one batch of fuel. The combustion of such a rich mixture in the precombustion chamber when the coefficient of air excess equals $\alpha = 0.4\text{-}0.7$ takes place slowly and is easily subjected to any type disruptions. To provide for normal operation, the precombustion chamber must be heated to approximately 160-180°C, it must be cleared of exhaust gases which have completed the cycle, and any excess intensity of turbulent motion within this precombustion chamber must be eliminated.

Due to the substantial deficiency of air oxygen, products of incomplete combustion are rejected from the precombustion chamber and these are mixed with the main mixture by a turbulent flame. On the basis of theoretical and experimental investigations, it was established that /1 these products contain peroxides, aldehydes and other unstable intermediate products of chemical reactions, as well as a substantial concentration of chemically highly active free radicals and atoms. Investigation of the luminescence of the products of incomplete combustion of the precombustion chamber flame jet during their afterburning in the air has shown that the intensity of luminescence is apparently due to the luminescence of the radicals C_2, CH and atoms H which increase rapidly as the auxiliary mixture is enriched to $\alpha_r = 0.6$ and below. In this case the delay period for the burnout of products of incomplete combustion is radically reduced and reaches a value of 0.2-0.3 msec.

Measurements were made of the heat of re-combination of the chemically active parts of incomplete combustion products in the precombustion chamber flame by wires made of different materials. These measurements show that when the auxiliary mixture is enriched the temperature of the platinum wire is much higher than the temperature of the products of combustion flowing around it. On the other hand, the temperature of the molybdenum or tungsten wires is substantially lower. This points to the high chemical reaction capability of the products of incomplete combustion associated with the precombustion chamber flame. This is due to a substantial concentration of free radicals and atoms and apparently primarily of atomic hydrogen. It follows from analysis of results of this investigation that when there is an increase in the time spent by incomplete combustion products in the precombustion chamber system their chemical activity is reduced and completely eliminated, although the composition of the stable products of incomplete combustion and their temperature remained fixed. Products of incomplete combustion also have a substantial concentration of molecular hydrogen and carbon monoxide, which have a high combustion temperature. Since they are added to the mixture with a large number of combustion sources and since they accelerate the development of branched chain reactions and since they increase the temperature, these chemically active products substantially reduce the delay period of flame jet ignition and increase the rate and completeness of combustion of the working mixture.

By using a precombustion chamber jet flame of active products from the incomplete combustion of a rich mixture it is possible to achieve much higher intensities of ignition and combustion rates as well as greater stability in the effectiveness of the combustion process in the operating mixture than in the case of spark ignition, ignition by the precombustion chamber flame jet or ignition by a flame jet containing the products of complete combustion. This is so in spite of the fact that the temperature of the precombustion chamber flame jet containing active products of incomplete combustion is approximately 1,000°C whereas the temperature of the precombustion chamber jet flame containing products of complete combustion is 2,000°C. With this method of flame jet ignition, the combustion rate increases compared with spark ignition by a factor of 3-4. Also, it increases not only for mixtures with a composition close to the theoretical but also for very lean mixtures, for example, those in which the coefficient of air excess is equal to $\alpha = 2$. In this mixture the ignition of one part of fuel is accomplished by adding 30 or more parts of air. During a spark ignition and also during ignition by a flame jet, such mixtures neither ignite nor burn. /102

This is the essence of the new principle for the forced initiation of ignition and turbulent combustion which serves as the basic method of the precombustion chamber--flame jet ignition of the operating mixture by the flame of chemically active products formed in the precombustion chamber generator as a result of incomplete combustion of a rich auxiliary mixture (Ref. 5). A schematic diagram of this method is shown in Figure 2 where numbers show successive stages of the process.

This method of intensive ignition and effective combustion may be applied to combustion chambers of various engines, heating plants and other thermotechnical devices with various precombustion chamber designs. /103
A most steady configuration of the precombustion chamber--flame jet ignition--is a system with a combustion chamber permanently separated from the main combustion chamber. The precombustion chamber in this case is fed with an auxiliary mixture by an independent system through auxiliary intake valves and through a separate intake manifold from the precombustion chamber part of the carburetor. The mixture is supplied under the action of vacuum developed during the suction process simultaneously with the feeding of the principal combustion chamber. As a result of extensive experimental investigations of the design elements associated with a precombustion chamber and the control system for the

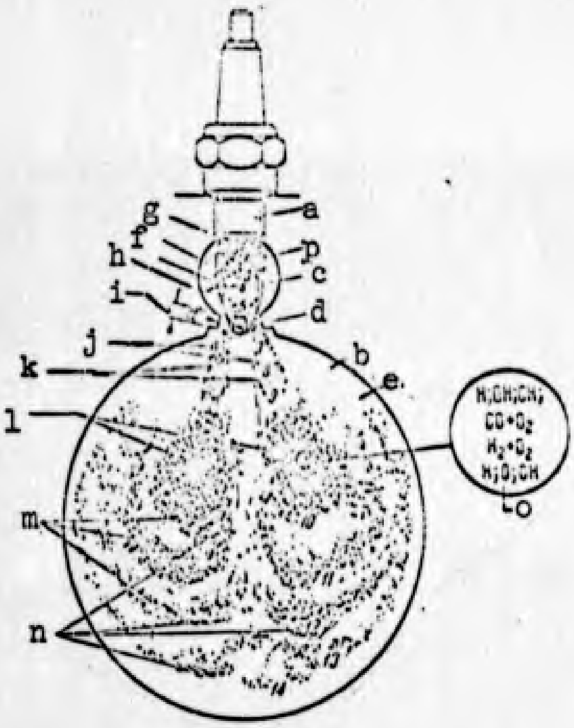

Figure 2. Schematic diagram showing development of ignition and combustion process during precombustion chamber--flame jet ignition: 1, 2, 3, 4, ..., 14 successive positions of flame fronts in precombustion chamber and zone of source combustion in the main combustion chamber; a - spark plugs; b - combustion chamber with a volume V_k; c - precombustion chamber with a volume $V_f/V_K = 0.02\text{-}0.03$; d - passageways with a cross section $F_p/V_f = 0.03\text{-}0.04$ cm^2/cm^3 and a length of $l/d = 1\text{-}2$; e - combustible mixture in combustion chamber with $\alpha_1' = 0.95\text{-}2.0$; f - precombustion chamber mixture with $\alpha_f = 0.4\text{-}0.7$; g - spark discharge in the precombustion chamber; h - zone of initial flame front formation; i - flame propagation in precombustion chamber; j - flow of turbulent breakoff and destruction of flame tongue; k - flame tongue of chemically active products of incomplete combustion; l - vortex formation of sources, their induced ignition and turbulent combustion; m - propagation of turbulent combustions zone and flame front; n - turbulence of charge ahead of combustion zone, of flame front and in the last part of charge; o - branching of chain-thermal ignition of a source with burnout of the products of incomplete combustion utilizing the air oxygen of the mixture; p - screen for spark plug electrodes.

fuel supply, a design was proposed for the precombustion chamber of an internal combustion engine with a carburetor (Ref. 6) (Fig. 3).

A carburetor engine contains a precombustion chamber with a spark plug containing a screen to limit the intensity of the turbulent motion of the auxiliary mixture near the spark plug electrodes and to protect the electrodes from overheating. It also has a valve for taking in the auxiliary mixture and a carburetor for feeding the engine with the fuel-air mixture containing a cylindrical part and the precombustion chamber part. The precombustion chamber is situated beside the main chamber and has passageways with axes directed at an angle with respect to each other in the diametric plane of the cylinder at the middle level of the combustion chamber height.

The mixture control and the control of the amount of fuel-air mixture by overenriching the precombustion chamber mixture and the variation of the cylinder mixture as dictated by load conditions is accomplished by throttling. For maximum loads the possibility of enriching the operating mixture below the theoretical composition is limited. For this purpose the precombustion chamber and the cylinder part of the carburetor are equipped with a system of throttles, with air and fuel jet tubes containing automatic feedback so that when there is a decrease in the quantity of the cylinder mixture or when it is leaned out there is a decrease in the quantity of the precombustion chamber mixture as well as its enrichment. Fuel supplied the engine during forced idling is turned /104
off by a winder valve. The engine uses a separate water cooling with forced cooling of the head and with a thermosiphon cooling of the block. As a result, regardless of engine speed and loading, the water temperature in the cylinder block is maintained at a rationally high level (approximately 90°C), and the crankcase oil temperature is approximately 85°C while the temperature of the cylinder head is only 65-70°C. This decreases the heat transfer to the cooling medium and at the same time, when lean mixtures are used, it limits the possibility of scale, carbon and resin formation as well as formation of a condensate with the subsequent removal of oil from cylinder walls. This improves the quality of lubrication and decreases wear, thereby increasing the useful life of the engine.

In this design there is a simultaneous intake of the operating mix- /105
ture into the cylinder and of the auxiliary mixture into the precombustion chamber. The precombustion chamber valve is driven by the rocker arm for the main intake valve. As shown above, this is achieved under the action of vacuum produced in both chambers during the piston intake motion. During compression, part of the cylinder mixture with an air excess coefficient of α_1 is displaced into the precombustion chamber through the passageway valves. There it is mixed with the rich mixture with α_2 which has entered the precombustion chamber from the precombustion chamber part of the carburetor through the auxiliary valve during

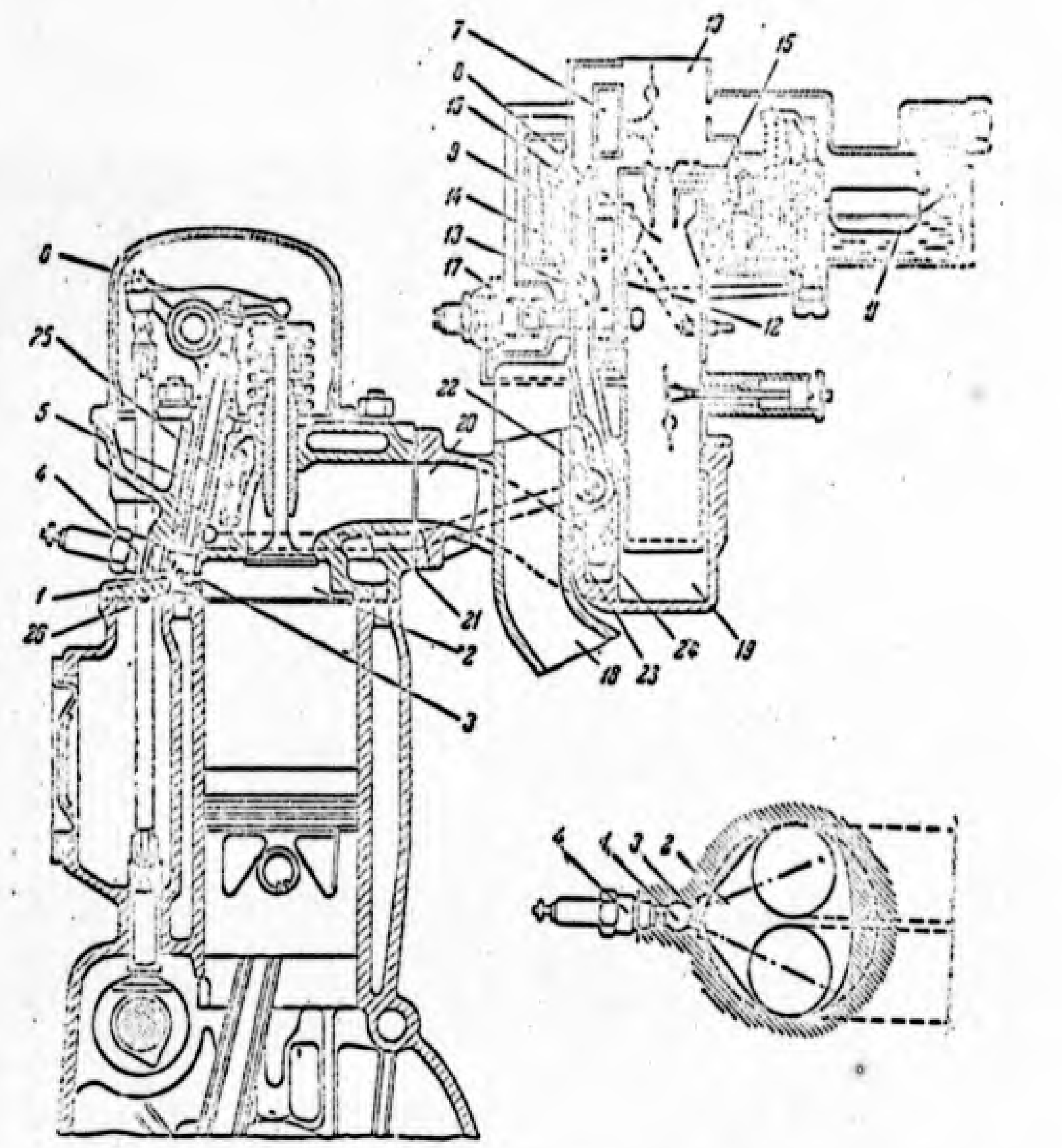

Figure 3. Design drawings of a precombustion chamber carburetor engine: 1 - precombustion chamber; 2 - main combustion chamber; 3 - passageway valves; 4 - spark plugs; 5 - precombustion chamber intake valve; 6 - intake valve rocker arm; 7 - common carburetor; 8 - cylinder part of carburetor; 9 - precombustion chamber part of carburetor; 10 - common air intake; 11 - common fuel chamber; 12 - throttle for cylinder mixture; 13 - valve for the precombustion chamber mixture; 14 - pull rod drive for throttle; 15 - jet tubes for cylinder mixture; 16, jet tubes for precombustion chamber mixture; 17 - winder valve; 18 - exhaust collector; 19 - intake collector; 20 - cylinder mixture channel; 21 - precombustion chamber mixture channel; 22 - heat receiving ribs; 23 - well for precombustion chamber mixture; 24 - well tubes; 25 - water distributing tube; 26 - spark plug electrode screen.

the intake cycle. At ignition the precombustion chamber contains a resulting mixture whose air excess coefficient is computed by

$$\alpha_{r} = \frac{\varepsilon \alpha_1 \alpha_2}{(\varepsilon - 1)\alpha_2 + \alpha_1}$$

where ε is the engine compression ratio. From this equation we establish the following relationship between compositions of the mixture in the precombustion chamber and in the cylinder parts of the carburetor (Fig. 4):

$$\alpha_2 = \frac{\alpha_1}{\frac{\varepsilon}{\alpha_r}\alpha_1 - (\varepsilon - 1)}$$

If we assume that for the resulting mixture composition in the precombustion chamber the air excess coefficient equals α_r = 0.4-0.7, recommended for the most effective application of the method of precombustion

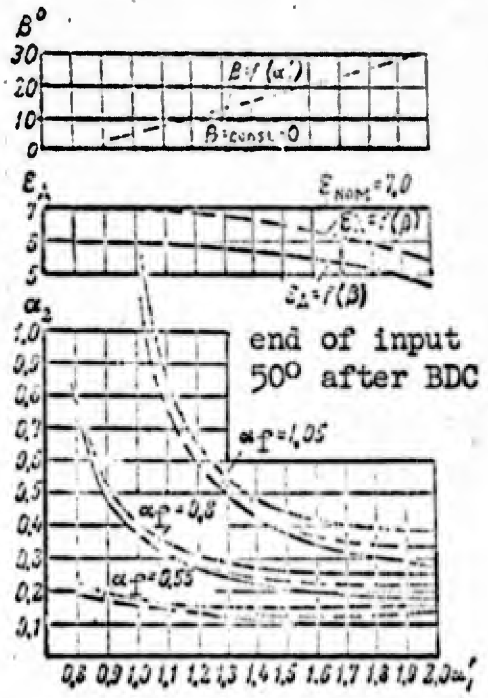

Figure 4. Control of precombustion chamber mixture composition as a function of cylinder mixture control: ——— $-\varepsilon = \varepsilon_{nom} \neq f(\beta)$, — — — — — $\varepsilon = \varepsilon_D' = f(\beta)$; ———·— $\varepsilon = \varepsilon_D = f(\beta)$ taking into consideration that the input ends at 50° after BDC (bottom dead center).

chamber-flame jet ignition in all precombustion chamber engine designs, then as we see from Figure 4 this provides for constant control of the mixture composition in the precombustion chamber part of the carburetor with α_2 remaining independent of the mixture composition control in the cylinder part of the carburetor with α_1. In this respect the new method of independent control differs radically from the old dependent control of the precombustion chamber mixture (Ref. 2) in which it is necessary to control the precombustion chamber mixture so that its composition is easily ignited by a spark when the air excess coefficient equals $\alpha_f = 0.8\text{-}1.0$. In addition to substantial simplification of the control system when the precombustion chamber is fed by a rich auxiliary mixture, there is an increase in reliability of the precombustion chamber elements due to substantial decrease in the combustion temperature of the precombustion chamber mixture. Experiments show that this method of feeding the precombustion chamber with a rich resultant mixture produces an effective, stable and reliable operation of a precombustion chamber engine over a wide range of loading. The indicator diagrams shown in Figure 5 for an engine with a precombustion chamber--flame jet ignition and spark ignition show substantial increase in combustion rate, decrease in duration and an improvement in stability of the combustion process in the precombustion chamber engine compared with a spark plug engine.

This system for a precombustion chamber engine without a compressor turns out to be simpler from the standpoint of design and production than other systems, for example, those incorporating forced feeding of the precombustion chamber with a compressor supplying the auxiliary mixture at the end of the compression cycle (Ref. 10). /106

After long collaboration between the Institute of Chemical Physics of the USSR Academy of Sciences and the Design Department of the Gor'kovskiy Automobile Plant a new type of highly efficient automobile engine GAZ-51F (GAZ-52) was developed. Comparative investigations involving the single cylinder prototype of the engine OTs U-GAZ-51F with an engine using the spark ignition shown in Figure 6 have shown there is a substantial increase in rate and stability of combustion as the basic features of this precombustion chamber engine. This engine has the following important advantages over the standard engine with spark ignition.

An increase in combustion rate increases the compression ratio of the precombustion chamber engine by more than 0.8 units with standard automobile gasoline. When operating at the assigned compression ratio, the required octane number may be decreased by more than 10 units, due to the antidetonation effect realized as a result of accelerated combustion during precombustion chamber--flame jet ignition.

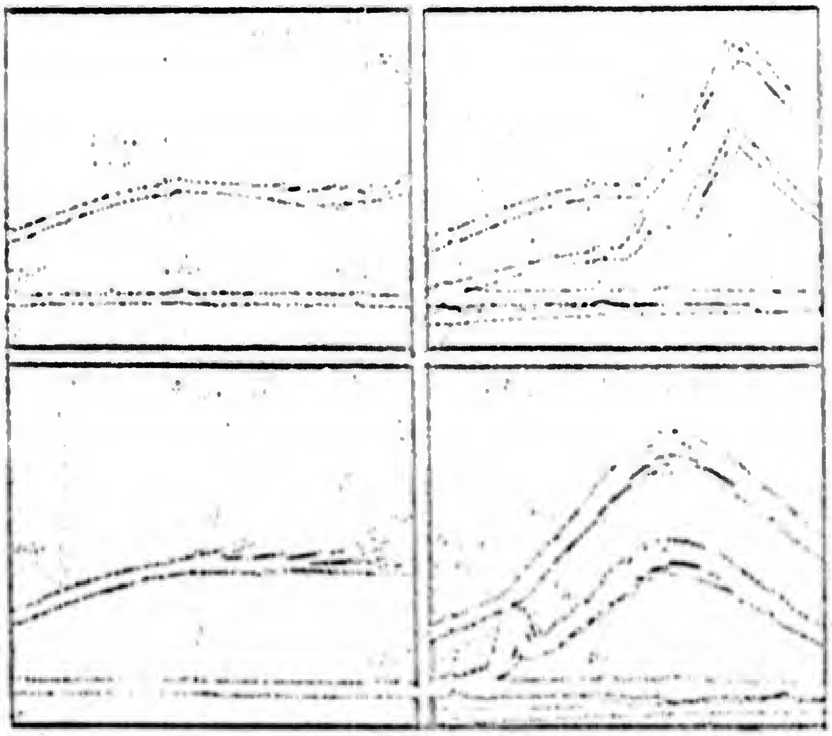

Figure 5. Indicator diagrams showing increase in combustion pressure, taken from single cylinder engine with spark ignition and precombustion chamber--flame jet ignition. Engine is OTs U-GAZ 51F; ϵ = 7.15; full throttle; n = 1200 rpm; η_v = 0.84; t_a = 25°C; gasoline is of secondary variety Ω = [illegible].6. Upper series, operating mode close to maximum power; left, spark ignition; α = 1.10; β = 2° pkv before TDC (top dead center); right, precombustion chamber-flame jet ignition: α = 1.07; α_1' = 1.14; α_f = 0.57; β = -1° pkv before TDC. Lower series, limiting lean mixture modes: left, spark ignition; α = 1.23; β = -23° pkv before TDC; right, precombustion chamber--flame jet ignition; α = 2.1; α_1' = 2.3; α_f = 0.52; β = -26 pkv before TDC.

The rapid and effective combustion of lean mixtures and the high stability of the combustion process in the precombustion chamber engine reduces specific fuel consumption along the load characteristic over a wide range of load fluctuations of this engine up to 190-200 g/hp, as compared with 230-260 g/hp for the same loads with a standard engine with spark ignition. As a result, there is more than a 15 percent decrease in fuel consumption for automobiles with precombustion chamber engines. /107

The increase in compression ratio, and filling and rapid and effective combustion increase the specific power of the precombustion chamber engine by more than 10 percent without the detonation effects associated with the use of secondary type automobile gasoline. This substantially improves the dynamic properties of the automobile and substantially increases the pick-up of the engine, etc.

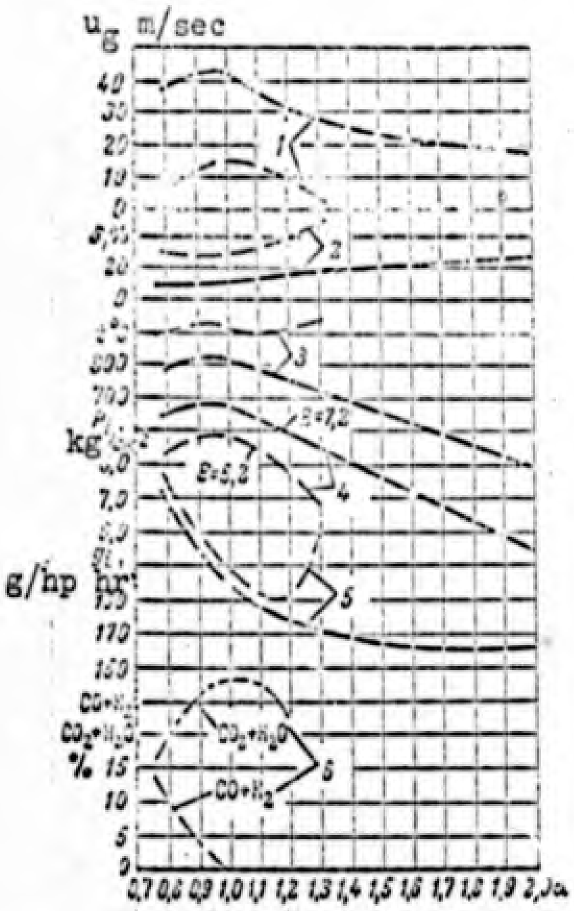

Figure 6. Characteristics showing variation in composition of mixture for one-cylinder engine with flame jet and with spark ignition. Engine is OTs U-GAZ-51f; full throttle; n = 1,200 rpm; automobile gasoline with an octane rating of 53.6; ——— — flame jet ignition with ϵ = 7.2; — — — — — — spark ignition with ϵ = 6.2; 1, flame velocity; 2, stability of operation; 3, temperature of exhaust gases; 4, specific power; 5, economy; 6, content of exhaust and residual gases.

When higher octane fuel becomes available for automobile transportation, the application of precombustion chamber-flame jet ignition will further increase the fuel economy of the precombustion chamber automobile engine. This follows from the analysis of the relationship showing the required number Ω, specific fuel consumption g_i, specific power P_i, optimum ignition advance angle β and limiting effective leaning α_{limit} as a function of the compression ratio taken for the case of spark ignition and for the case of precombustion chamber--jet flame ignition (Fig. 7). /108

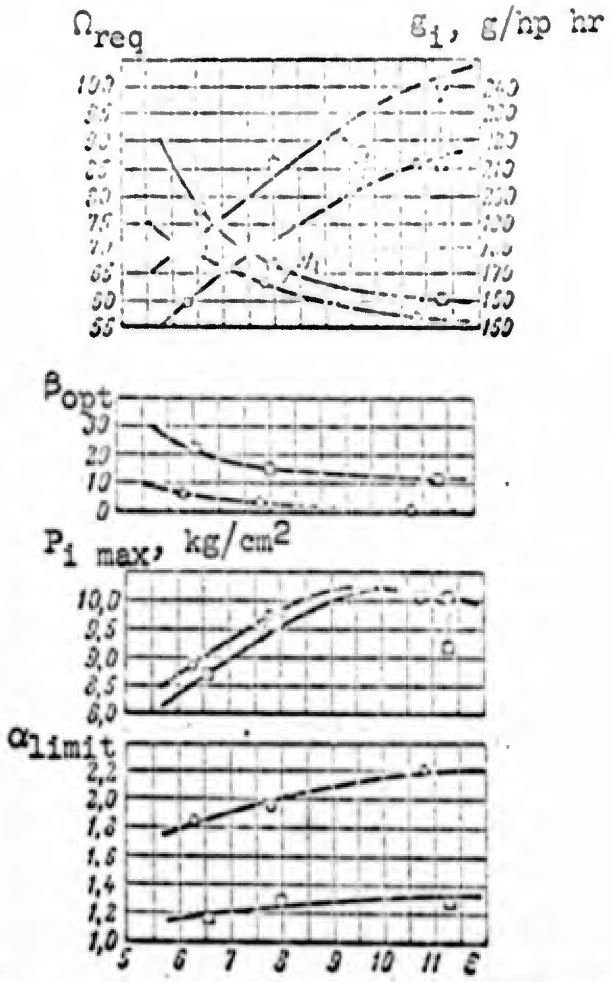

Figure 7. Variation in basic parameters of combustion process as function of compression ratio of engine with spark and with flame jet ignition. Engine OTs U-GAZ-21f; hemispherical combustion chamber with displacer; D_{ts} = 92 mm;

S_{ts} = 92 mm; full throttle; n = 1,500 rpm;

□, spark ignition; O, precombustion chamber jet flame ignition.

Due to the complete and effective combustion of lean working mixtures it is not necessary to use rich mixtures during any mode of operation. This means that there is no ejection of harmful and poisonous products of incomplete combustion into the atmosphere. Furthermore, there is a tenfold decrease in the concentration of carbon monoxide and /109 of the cancer-producing benzopyrene (Ref. 8).

In 1957 small series of precombustion chamber, carburetor, in-line, 6-cylinder engines GAZ-51f and ZIL-120fk were fabricated. Laboratory and road tests and operational tests of these confirmed the possibility of

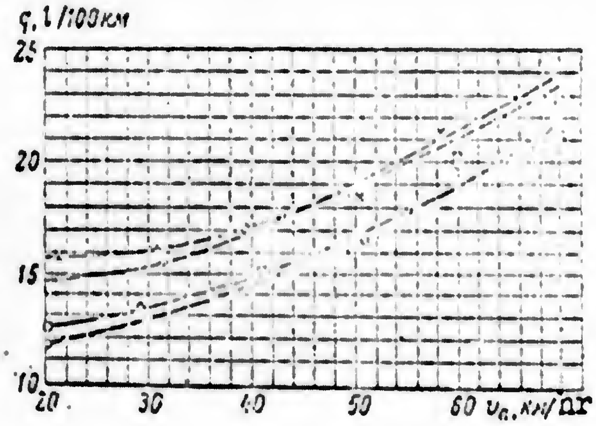

Figure 8. Gasoline consumption characteristics of automobile GAZ-51 with nominal load of 2.5 metric tons. O and □, automobiles Nos. 12 and 13 with precombustion chamber engines GAZ-51f; X, automobiles Nos. 14 and 15 with standard engine GAZ-51.

realizing high performance with these engines in automobile transportation. The gasoline consumption characteristics of these engines are compared with those of engines with spark ignitions of various types in Figures 8 and 9.

The advantages of the precombustion chamber engine described in this article are of great importance for the national economy. The gasoline economy associated with an annual production of trucks GAZ and ZIL with precombustion chamber engines is expected to exceed 15 million rubles per year.

In 1963 samples of 4-cylinder, in-line engine GAZ-21f with a precombustion chamber were fabricated and tested on the light automobile "Volga." These tests also showed the high economy and good dynamic and operating characteristics. The gas consumption characteristics of the Volga automobile with precombustion chamber and spark ignition engine are shown in Figure 10.

Conclusions

1. Many experimental investigations on the combustion process have established the high chemical activity of products of incomplete combustion of a rich mixture. This was established as a result of a substantial decrease in temperature, decrease in the delay period of ignition and increase in combustion rate of the fuel-air mixture, by measuring the heat of catalytic recombination on the surface of the

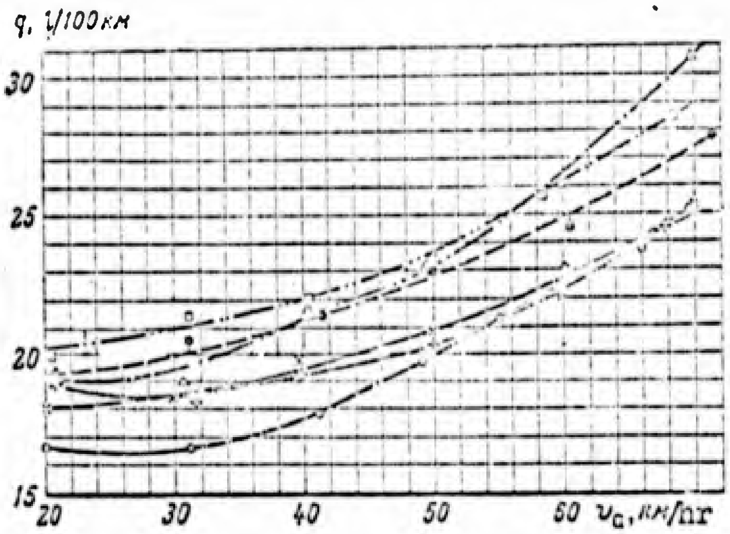

Figure 9. Gasoline consumption characteristics of automobiles ZIL-150 with nominal load of 4 metric tons: □, automobile No. 10 ZIL-150 with standard spark plug engine; O, automobile No. 7 ZIL-150 with overhead valve spark ignition engine; △, automobile No. 9, ZIL-164 model with forced spark plug engine; +, automobiles Nos. 2 and 3 ZIL-150 with precombustion chamber engine designed in accordance with compressor scheme MAMI, ZIL-120f B; O, automobile No. 5 ZIL-150 with precombustion chamber engine without compressor IKhF AN, ZIL-120f.

platinum, molybdenum, or tungsten wire over which products flow, and by recording the intensity of their luminescence. This high activity is explained by the presence of incompletely burned, unstable products of intermediate chemical reactions and apparently of free radicals and atoms which tend to decrease the energy of activation when the fuel-air mixture burns.

2. The high chemical activity of the products of incomplete combustion is utilized to increase ignition reliability and intensity of turbulent combustion in internal combustion engines. Ignition is /110 achieved by forced formation of many turbulent sources in a mixture of small dimensions and their forced initiation by the jet flame of chemically active particles ejected from the precombustion chamber into the combustion chamber. Under these conditions a substantial increase in combustion rate as well as an increase in the completeness of combustion is achieved. Combustion stability is also increased over a wide range of lean mixtures.

The application of the principle of induced initiated ignition and of the mechanism of turbulent combustion in the mixture of an engine with

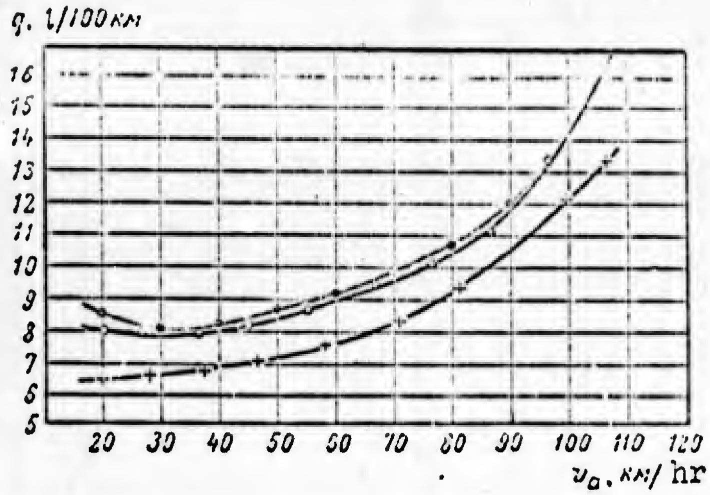

Figure 10. Gas consumption characteristics of the "Volga" automobile, operating with spark plug engine and with precombustion chamber-jet ignition engine. O, standard spark ignition engine GAZ-21 with carburetor K-124 on Volga automobile No. GV 00-01; O, engine having head with spark ignition; +, engine having head with precombustion chamber--flame jet ignition.

precombustion chamber--jet flame ignition permits lowering of the required octane rating by more than 10 points, permits decreasing average fuel consumption by more than 10 percent, increasing dynamic properties of the engine and eliminating almost all the toxic exhaust gases.

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