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MIXING AND IGNITION IN SUPERCHARGED ENGINES

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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MIXING AND IGNITION IN SUPERCHARGED ENGINES.*

Mixing

For carburetor engines which work with a preliminary compression of the charging mixture, there are two principal methods of mixing: 1, with a suction carburetor; 2, with a pressure carburetor.

The employment of a suction carburetor on a supercharged engine (Fig. 1) necessitates no change in the normal fuel-delivery and atomization mechanism. The supercharger draws the finished mixture from an ordinary carburetor and forces it, previously compressed, into the working cylinder. The longer intake pipe hereby necessitated and its considerable enlargement by the intervening supercharger impair the homogeneity of the mixture and tend to cause precipitation of the fuel, especially at low revolution speeds, due to the smaller gas velocity and the lack of compression heat (since the preliminary compression is low).

In single-stage turbo-compressors, the homogeneity of the mixture is undoubtedly increased at higher revolution speeds. It has, indeed, been proposed to effect a further diminution in the size of the larger fuel drops after leaving the carburetor

* From "Der Motorwagen," December 10, 1925, pp. 773-782.

by means of a rapidly rotating centrifugal blower. One English inventor even goes so far in using a single-stage turbo-compressor as to omit the carburetor altogether and to leave the atomization of the fuel injected into the intake pipe of the compressor entirely to the centrifugal blower.

Hence the suction carburetor is universally used on all American racing cars with single-stage turbo-compressors. It is also used on the Mercedes (an 8-cylinder 2-liter engine with a Roots supercharger), the Guyot (with a Cozette rotary supercharger), the Delage (a 12-cylinder V engine with two Roots superchargers), Bignan (with a Roots supercharger) and the Sunbeam (a 6-cylinder 2-liter engine with a Roots supercharger). It must be remembered that these are all on racing cars, which are not often run at low revolution speeds.

The disadvantages of this system seem to be so small, however, that many constructors prefer to put up with them rather than with the greater complexity of the pressure carburetor.

A pressure carburetor must be used when the supercharger is a turbo-compressor with two or more stages. In such a supercharger the larger fuel drops, thrown off by centrifugal force, collect in the by-pass channels which connect the separate pressure stages, so that on the one hand, no homogeneous mixture is formed and, on the other hand, in the event of backfiring through the carburetor, these fuel deposits easily ignite and may cause dangerous explosions.

For this reason there must be provided, between the supercharger and the engine, a sufficiently large safety valve, which is held by springs and opens into the free air when a certain pressure is exceeded. Such a safety valve is advisable, even on engines with pressure carburetors, only here it must be inserted between the supercharger and the carburetor.

A pressure carburetor is, moreover, the simplest device when the supercharger does not run all the time (Mercedes touring car) or when it does run all the time, but is not continuously discharging into the engine (Fiat, Alfa Romeo). When the compressor is not running, or is discharging into the open air, the engine then draws the mixture through the carburetor. With the supercharger in use, however, the carburetor intake opening is closed and the carburetor receives the compressed air from the supercharger. This, however, necessitates some changes in the normal carburetor.

In a normal carburetor, due to the negative pressure in the intake pipe, the fuel is sprayed from the nozzle, since the float chamber is under atmospheric pressure. There must be a sufficient pressure difference between the float chamber and the intake pipe to enable the spraying process, whereby the quantity of fuel sprayed is approximately proportional to the pressure difference.

If, however, a positive pressure is produced in the intake pipe, the fuel does not flow out of the nozzle but is forced back into the float chamber, and the engine receives no fuel mixture. The carburetor functions again, only when the former relation in the barometric pressure between the intake pipe and the float chamber is restored, which can be accomplished by also subjecting the float chamber to the compression pressure. In order to prevent the escape of the compressed air, the cover of the float chamber, as also the passage of the valve needle, must be made air-tight, which does not, however, affect the principle of the carburetor. The fuel tank must also be subjected to the pressure of the supercharger, if the fuel is to flow to the carburetor under the influence of gravity.

Fig. 2 is a section through a "Zenith" pressure carburetor, the arrows indicating the course of the compressed air in the pressure-equalization channels. The very simple "Zenith" supercharger, as now used by several German firms, is represented diagrammatically in Fig. 3, and is easy to understand from what has preceded. Fuel delivery by gravity is not always possible, however, and a special fuel pump is necessary for a low fuel tank.

On an airplane engine the fuel pump is driven by the engine or by a wind-vane propeller. If the engine is equipped with a supercharger, a pressure-regulating valve with an overflow tank is introduced into the fuel circulation between the pump and the carburetor, as also a stop valve operated by a float, in order to enable the excess fuel, as delivered by the pump, to flow back into the main tank, without the need of subjecting the latter to the pressure of the supercharger. Fig. 4 shows such a fuel delivery system as worked out by Benz for a supercharged airplane engine (Noack, "Flugzeuggebläse," V.D.I., 1919, p. 995).

On racing cars with supercharged engines, pump fuel-delivery is employed by Fiat and Alfa Romeo and was formerly employed also by Mercedes.

Fuel pumps are troublesome devices, however. In piston pumps the cylinder-lubricating oil is dissolved, especially by gasoline but also by benzol, so that the piston runs dry. This disadvantage can, indeed, be avoided with rotary pumps, but their delivery power varies approximately as the third power of their revolution speed (Fig. 5). This is especially disturbing on automobile engines, which run at greatly varying revolution speeds. Moreover, they constitute a structurally undesirable loading of the engine.

It has therefore been attempted to put low fuel tanks under pressure. The pressure must, moreover, be higher than the compression pressure in order to offset the maximum difference of level in the tank and in the carburetor, the inclined position of the vehicle in hill climbing and the frictional resistance of the fuel-delivery pipe.

On a motor car equipped with a multi-stage turbo-compresor, it was so arranged that a portion of the compressed air furnished by the turbo-compressor was still further compressed in an auxiliary chamber on the compressor and then delivered to the main tank. This arrangement has the disadvantage that, at high compression pressures, the tank has to be specially reinforced in order to avoid deformation and that a certain time elapses in the transition from suction drive to pressure drive. The Pallas Apparatus Company overcomes these difficulties by making their successful negative-pressure fuel-delivery system also serve for compressor drive.

The Pallas pressure carburetor (Fig. 6) works both as a suction carburetor and as a pressure carburetor without the need of any alteration in shifting from suction to pressure drive or vice versa. The float chamber V is closed air-tight by the gaskets V_1 and V_2 and is put under the compression pressure through the channels S. The fuel, which is also under compression pressure, flows to the carburetor through the filter A and is kept at a constant level by the float C and a short valve needle B. To the air-inlet connection G, there is fitted an intermediate piece which, by means of a slide valve or a clack valve (with a three-way cock), makes optional the supplying of the carburetor with compressed or atmospheric air.

Fig. 7 is a diagram of a fuel-delivery system made by the Pallas Apparatus Company for supercharged engines. An ordinary negative-pressure system receives the fuel from the main fuel tank and conducts it to the carburetor. With the negative-pressure system, which consists of the suction tank a_1 and the collecting tank a_2, the following pipes are connected: pipe 1, as a negative-pressure pipe from a suction source; pipes 6 and 7, connected with a common pipe 5, for supplying air; pipe 4, for supplying fuel from the main tank; pipe 8, for conducting fuel to the carburetor. The system works as follows:

1. By ordinary suction.- The supercharger is shut off and the butterfly valve 18 is open. The negative pressure in the engine intake pipe causes the fuel to flow from the main tank through pipe 4 to the delivery apparatus. The non-return valve 16 is open; 15 and 19 are closed; 20 is closed by the float. As soon as a certain amount of fuel has flowed into the suction tank a_1, the float rises and closes 20 and opens 19, so that a_1 is also supplied with atmospheric air and the fuel can flow through valve 21 into the collecting tank a_2. The float sinks with the level of the fuel and again closes 19 and opens 20 and the process begins anew.

2. By preliminary compression.- On reconnecting the supercharger, valve 18 is closed. Since there is now a positive pressure in the intake pipe, the negative pressure required for the fuel delivery must be generated by the injector shown in Fig. 8. The injector is situated in a pipe 11-12 which connects

the pressure pipe 9 with the suction pipe 10 of the supercharger. The powerful air current, formed in the pipe 11-12, generates in pipe 14, opening into the narrowest part of the injector, a negative pressure, which is communicated through the pipe 3-1 to the suction tank of the delivery system. The non-return valve 15 is open and 16 is closed. The air pipes 5, 6, 7 of the delivery apparatus are now under pressure. The non-return valve 17 in the fuel pipe 4 is intended to prevent the positive pressure, required in a_1 for driving the fuel into a_2, from being communicated to the main fuel tank. Otherwise the system works just the same as in the suction method and has given satisfactory results, both on the test bench and on an automobile at positive pressures, up to 0.7 atm. (0.7 kg/cm² = 9.96 lb./sq.in.). No difficulty was experienced at the transition point from suction to pressure drive with either the Zenith or the Pallas supercharger.

The Mercedes supercharged engines for touring cars likewise use a combination suction and pressure carburetor with a Pallas negative-pressure delivery system, which, however, is shut off from the main fuel tank while the supercharger is in use and, like the carburetor, is put under the compression pressure. The large collecting tank supplies the carburetor with fuel until it is exhausted, after a run of about 18 km (11.2 miles) with the supercharger, whereupon the engine must again run awhile as a suction engine in order to refill the collecting tank of the negative-pressure delivery system. This system should answer the practical demands now made on a supercharged engine.

In a Fiat supercharged engine the air, after being so compressed by a Roots supercharger, passes through a cooler situated under the engine radiator and then enters two pipes, the larger one passing by the carburetor to the engine and the smaller one by an atomizer to the carburetor. The atomizer is supplied with fuel from the main tank by means of a pump and the rich mixture, thus obtained, joins the main air stream in the carburetor. A manometer on the dashboard indicates the compression pressure, which can be regulated at will.

The effect of cooling the charge on its weight and the reduction of the mean temperature in the cylinder is very important with gasoline or benzol, on account of the low heat of vaporization of these fuels (about 120 kcal/kg = 13.72 B.t.u./lb.). With alcohol mixtures, on the contrary, no intermediate cooling is either necessary or useful, due to the tendency of alcohol to condense in the intake pipes and to its relatively high heat of vaporization (270 kcal/kg = 30.86 B.t.u./lb.).

As regards fuels suitable for supercharged engines, it is obvious that all those with a strong tendency to spontaneous combustion and detonation (including unmixed gasoline) must be excluded at the outset.

Benzol can be subjected to considerably higher compression pressures without igniting and is said to be usable in the Delage supercharged engine ($\epsilon = 1 : 5.5$). It is said that the "Sunbeam" supercharged engine ($\epsilon = 1 : 7$) uses a mixture containing 60% gasoline (by volume) and 40% benzol. These data are probably correct, however, only when some substance is added for automatically retarding the ignition, although high-speed engines stand higher compression ratios (See note at end of article).

The special fuel used in the Alfa Romeo ($\epsilon = 1 : 7$) is kept secret, but it is probably an alcohol, benzol or gasoline mixture with the addition of some ignition agent such as ether. It is noticeable that the Alfa Romeo engines never fail to start promptly and, even in the severest endurance tests, give no indication of overheating, so that the firm probably owes its success in racing mainly to the kind of fuel used.

Alcohol has, for racing engines, the very important properties of lower combustion temperature and greater cooling effect on the inner walls of the cylinder, due to its greater heat of vaporization, so that the engine does not get so hot. It enables, moreover, a considerably higher compression ratio as compared with benzol and especially with gasoline, which increases its thermal efficiency and gives, notwithstanding its somewhat smaller heating power, a mean pressure at least equal to that obtained in engines using benzol or gasoline, because the fresh charge is heated less in the working cylinder (due to its greater heat of vaporization) than a gasoline or benzol mixture (Fig. 9). The main disadvantage of alcohol, that it requires a specially good atomization and (when possible) a preliminary heating of the mixture, is not very great for supercharged engines, with which it is not necessary to give any special attention to good filling at high revolution speeds and therefore, even at lower revolution speeds, sufficiently high gas velocities can be generated to assure good atomization. The mechanical atomization work of the supercharger and the heating of the mixture by the preliminary compression are additional. The further disadvantage, that the engine is hard to start when cold, can be overcome by the admixture of some ignition agent. Alcohol mixtures seem to have been used successfully even in American racing cars.

Some entertain great hopes for the combination of fuels with so-called "anti-knock" compounds, including metal (especially lead) compounds, which, when mixed with gasoline in very small proportions, greatly lessen its tendency to spontaneous ignition and hence have a retarding effect on the tendency of the fuel molecules to disintegrate. Thus even gasoline engines are enabled to attain a higher degree of compression and greater specific engine performances.

Whatever results these experiments (which, like all fuel chemistry, are only in their initial stage) may yet produce, they cannot change the low heat of vaporization and the high combustion temperatures of benzol and gasoline as compared with alcohol, wherein resides the chief importance of this fuel for high-powered engines.

I g n i t i o n

In all high-compression engines and especially in supercharged engines, the spark-plugs are subjected to great heat. Glowing spark plugs cause preignition of the mixture, sometimes even during the inflow, so that the reason for the back-firing through the carburetor is often due to this fact.

It has recently been demonstrated in automobile races in other countries that it is entirely possible to make spark plugs which will meet the severe demands of modern supercharged racing engines. Such spark plugs are not suitable, however, for ordinary use with small loads, as they then easily become coated with oil and soot. It is impossible to combine in the same spark plug great resistivity to heat and safety from incrustation, since these properties are structurally opposed to each other. Great heat resistivity requires rapid transmission of the heat received, especially for the middle electrode, which can be attained by a suitable shape and by cooling fins. Great safety against incrustation requires a high temperature, so that oil vapors will not condense on them and oil drops thrown on them will easily drip off.

A spark plug with a strongly-cooled middle electrode, suitable for use in a heavily loaded engine, may, under a small load, have a great tendency to become coated with oil, especially if the engine is abundantly lubricated, or if the piston rings let oil through. Spark plugs with protecting caps over the electrodes can only be used for slow-running, well-oiled engines, since such caps must necessarily delay the ignition.

It is therefore a mistake for a driver who has been vexed with continual spark-plug troubles, to buy the most expensive plugs in the hope of thereby getting rid of these troubles. The question of the best spark plug must be solved for each engine. Engine and spark-plug makers should assist the purchaser by publishing instructive, easily understood pamphlets, just as is done by some conscientious carburetor makers by publishing tabulated statements of the possible carburetor troubles and their remedies.

Fig. 10 is a Bosch spark plug known to the public by the name "compressor spark plug." It is designed for high-powered engines, which run only for short spells at the maximum load (e.g., the supercharged Mercedes for urban and short-distance traffic). For high-powered and supercharged racing engines, the company recommends another spark plug, which differs essentially from the first only in that its middle electrode has copper cooling fins.

The Champion spark plug is much used in foreign racing engines, such as the Alfa Romeo, Duesenberg, Delage, Fiat, etc. It has, like nearly all spark plugs of foreign manufacture, only one auxiliary electrode, while the German public prefers two. The number of auxiliary electrodes is unimportant, since the spark always passes to only one electrode and indeed to the one offering the least resistance, which is generally the fouler one. For the same reason, the use of two spark plugs for each cylinder is senseless, unless two separate ignition-current sources are provided. The burning out of the spark-plug electrodes is generally very slight and hardly affects the length of life of the spark plugs. It is greatest at the middle electrode.

A promising possibility of overcoming the antagonism of the heat-proof and carbon-proof spark plugs lies in the Lepel high-frequency-current transformer (Fig. 11). Mostly erroneous information has been circulated concerning this invention, since on the one hand, the explanations of the electrical processes in the magneto are incorrect and obviously opposed to the action of the current transformer, and since on the other hand, even an approximately correct and popular presentation of the processes in the magneto is very difficult to make in a few words. It is intended to take this matter up at another time, but only the action of the current transformer will be discussed here.

Fig. 12 is the diagram of the electric tension at the spark plug for the ignition current generated by each half-turn of the magneto armature. A high-tension wave is first produced, which is necessary for the passage of the spark and which has, according to the compression ratio of the engine, a voltage of 3000-5000, with a current strength of 2-5 amperes. Immediately after the spark passes, the tension falls to the so-called "arc-voltage" of 30-50 and the ensuing current, with a strength of only 30-50 milliamperes, can regain its equilibrium through the slight resistance of the ionized spark gap. This continuous-current "tail" (or after-flow) does not aid the ignition in any way, but is exceedingly harmful, since it maintains a magnetic field in the soft-iron armature of the magneto, thus preventing the armature from promptly receiving the lines of force in the opposite direction, which it requires for generating the next spark. The latter is thereby considerably weakened, because there are not enough lines of force in the armature.

An ordinary motor-truck magneto at n = 3000 to 4000 gives (for example) at each revolution only one spark capable of causing ignition. The intermediate sparks (after each half-turn) grow continually weaker, as the revolution speed increases, and finally drop out altogether. This is due to the fact that the current generated by the magneto and, consequently, the duration of the discharge increase with the revolution speed, whereby the magnetic fields of the previously-generated ignition impulse or surge is retained much too long in the armature and there is too little time left to saturate the armature with new lines of force, in the opposite direction, required for the generation of the next spark (Fig. 13, curve C).

It is an absolutely wrong, though prevalent idea of the generation of the high-tension secondary current in the magneto, that the ignition current is generated directly by the induction effect of the interrupted primary current.

In the process of ignition, the primary current plays only the subordinate role of a carrier which holds together the lines of force, taken in by the armature in its passage through the horizontal position between the poles of the magneto, and carries them to the vertical middle position, the so-called "neutral zone," in order to make them disappear in a violent plunge by the interruption of the primary current (Fig. 13, curve B). This sudden collapse of the armature field (cutting of the lines of force) generates the high-tension ignition current in the secondary winding (Figs. 12 and 14). The primary current is therefore only indirectly connected with the generation of the secondary current. It is only an energy-consuming, necessary evil, though the least of the evils which could result from a sudden collapse of the armature field.

If the magneto is to be adapted to high-speed engines, in order to get sufficiently powerful sparks at higher revolution speeds, a portion of the greater electrical energy, corresponding to the higher revolution speeds, must be uselessly dissipated in resistances, in order to prevent any overlapping of the opposing magnetic impulses of the field and armature. The energy of the ignition spark increases up to about n = 1000 and then remains nearly constant, although the electrical energy furnished by the armature increases in proportion to the revolution speed. Hence the exceedingly harmful effect of a slow discharge is easily understood.

If an interrupter is now introduced into the high-tension circuit, which interrupts the ignition current when its tension falls to a certain minimum (say 300-500 volts), then the harmful continuous-current "tail" cannot arise to maintain a harmful magnetic field in the armature. The lines of force, after performing their duty, can vanish much more quickly from the armature and make way for the new lines in the opposite direction, which are needed to generate the next spark (Fig. 13, curve D). With the increased vanishing speed of the armature magnetic field, there is a proportional increase in the momentary value of the electromotive force induced in the secondary winding, which is freed at the spark plug during a portion of the ordinary ignition process (Fig. 13, curve D).

The Lepel current transformer is based on this consideration, which is therefore only a current interrupter in the high-tension winding and indeed an unsurpassably simple one, which, without any movable part, interrupts the discharging process about 100,000 times per second (Fig. 15). The current transformer consists of a number of aluminum plates, insulated from one another by perforated mica sheets, the spark being compelled to jump across the intervening spaces between the aluminum plates before jumping to the spark plug. The formation of an electric arc between the aluminum plates is prevented by the thin coating of aluminum oxide with which they are covered. This tendency of certain metals to become coated is also made use of in wireless telegraphy, in the well-known spark-extinguishing gap, which was likewise invented by Lepel and the similar principles of which were embodied in the Lepel current transformer. This property of a spark-extinguishing gap is therefore especially important, because it renders possible the oscillatory character of the ignition-spark discharges. Even in the normal discharge, the spark is oscillating at first and then changes to a continuous-current discharge, while by employing a current transformer, only high-frequency partial discharges occur with a frequency of 20 to 30 million per second.

The diagram of the tension on a spark plug with a current transformer (Fig. 14) shows that the harmful continuous-current "tail" has made place for a series of high-frequency heavy-current ignition impulses, whose total discharge time is, however, only about one-third of the normal ignition process. The strange phenomenon of several ignition impulses, instead of one, is explained by the alternating action between the magnetic field and the current. So long as a current is flowing in the secondary (or primary) winding, the magnetic field of the armature cannot collapse, but as soon as the current is interrupted by the current transformer, the armature field collapses and, by cutting the lines of force, generates a new electric impulse, which prevents any further collapse of the field until the current transformer again interrupts the flow, which causes the armature field to collapse again, thereby generating another electric impulse, etc., until the whole armature field is exhausted (Fig. 13 D and Fig. 14). Since these partial discharges follow one another at the rate of about 100,000 per second, the whole discharging process is completed in but a fraction of the time consumed by a normal ignition spark. The resistance of the current transformer corresponds to that of a spark gap of about 0.2 mm (0.008 in.) in atmospheric air and means, in contrast with the 0.4 mm (0.016 in.) spark-plug gap in the compression chamber at 5-7 atm. (71-99.6 lb./sq.in.), an additional load of only 5-10% for the magneto, which it can easily stand, so that there is no danger of discharges through the insulation in the high-tension winding of the armature. It is possible, moreover, by increasing the number of the spark gaps in the current transformer, to vary the duration of the discharge within quite broad limits and consequently the momentary value of the ignition-spark energy and the security against spark-plug troubles. Increasing the resistance of the current transformer also increases the small revolution speed at which just one more spark jumps to the spark plug, because the spark gap of the current transformer is added to the spark-plug gap, which may increase the difficulty of cranking the engine. The normal type of current transformer renders it possible to obtain ignition sparks at an engine revolution speed of n = 50-60 and is therefore suitable even for difficultly starting motor trucks.

The effect of the current transformer on the process of discharging consists therefore:

First.- in a temporary concentration of the discharge to 1/3 - 1/10 of the normal discharging period to which the electric momentary output is inversely proportional, since according to the principles of mechanics, the engine output (in HP.) equals the work divided by the time (electric impulse or surge);

Second.- In an absolute additional output of the ignition magnet, especially at high revolution speeds, because as a consequence of the shortened discharging process, more time is allowed the armature to pick up the lines of force, than without the current transformer, and the electromotive force delivered by the armature is proportional to the density of the lines of force included in the armature.

This fact can be easily demonstrated by a rotating glass tube connected with the magnet armature, there being at one end of the glass tube a spark gap for showing the current strength and, at the other end, a neon-gas filling for showing the tension (Fig. 16).

The ignition current now traverses the spark gap and the neon-gas filling and is separated in its direction of rotation by the rapid revolution of the tube, so that the discharging process appears as under a "time lens." Fig. 13 compares a discharge with and without the current transformer for the same magneto and a revolution speed of $n = 2000$ for the armature and tube.

The considerably higher momentary value of the ignition impulse is further demonstrated by an ammeter introduced into the high-tension circuit, which shows a two to threefold higher mean value with than without the current transformer.

This is of special importance, since the heating effect of the electric current increases as the square of its strength, so that the use of a current transformer produces a disproportionately hotter spark, which greatly facilitates ignition.

The more intensive ignition effect is further strengthened by the so-called "blow-out effect" of an alternating-current arc, which likewise increases as the square of the current strength. Every alternating circuit has the tendency to broaden out (horn-shaped lightning conductors in high-tension technics), which means for the electric arc between the spark-plug electrodes a widening in the inside of the cylinder and a consequent enlargement of the core of the flame.

Mixtures, otherwise very difficult to ignite, as when too poor, too rich, too cold or poorly vaporized, are more easily ignited, because a greater number of the particles are embraced in the electric arc.

The chief advantage of the current transformer resides, however, in the considerable lessening of the ignition troubles caused by the fouling of the spark plugs. Any deposit of oil or carbon impairs the insulation, so that the spark, instead of jumping across the spark gap between the spark-plug electrodes, flows, to a greater or less extent, through the better-conducting soot, oil or fuel deposits, thus heating the latter and making them still better conductors. The portion of the current which goes the wrong way constantly increases, and the ignitions miss occasionally at first until finally, due to the increasing thickness of the deposits, the whole current follows this more convenient route. This fouling is especially promoted, in normal ignition, by the gradual increase in the tension in the spark plug and by the detrimental continuous-current "tail" (Fig. 12).

The case is quite different when a current transformer is employed. Due to the interrupter inserted before the spark plug, the high tension does not continue permanently in the plug and, consequently, the first ignition impulse sets in with a greater tension and current strength than in normal ignition, while each of the succeeding current impulses has about the value of the first impulse in normal ignition. Since, moreover, the current in the intervals between the individual high-frequency impulses stores up electrical energy in the capacity of the ignition cable, the current strength of each impulse is so high that an electric current capable of causing ignition is immediately formed, notwithstanding the loss of some of the current by being shunted through the fouling deposits.

If, however, the spark gap is first ionized by the passage of sparks, its resistance as compared with the soot gap, is so diminished that most of the succeeding current impulses pass across the spark gap, and only a small proportion of them follow the soot route. Small soot particles on the electrodes, if not solidly burned on, are charged electrically, thrown off and consumed in the electric arc, so that the spark plug is automatically cleaned to a certain degree.

The current transformer is neither a condenser nor a series spark gap, whose effects it surpasses many fold without any attendant disadvantage (Schwager, "Wert und Wirkungsweise eines Kondensators und Vorschaftfunkenstrecke," Motorwagen, 1921, pp. 235, 399 and 523). The designation "spark intensifier" (wrongly applied to the above devices) is justifiable for the current transformer, both with relation to the momentary value of the ignition spark due to its temporary concentration and as absolute with reference to the greater total electric output of the ignition magneto at high revolution speeds. The current transformer can increase the engine power, however, only by eliminating misfires.

There is still some uncertainty as to whether a certain increase in the output of an engine is produced by the stronger ignition effect of the hotter spark as, for example, by the double ignition in aviation engines. Fig. 17 shows the effect of rapid ignition on the pressure increase in the cylinder, according to the experiments of the Englishman, T. David, the capacity of the cylinder used being 27 liters (1847 cu.in.).

Quick combustion means not only increased engine power, but also improvement in thermal efficiency; because the effect of the wall-cooling on the gas is less. In this connection, the normal indicator diagram (Fig. 18) of the Rolls-Royce aviation engine "Condor," at $n = 1900$, $N = 640$ HP., is interesting. This engine has 12 cylinders of 140 mm (5.51 in.) bore, a stroke of 190.5 mm (7.5 in.), and $\epsilon = 5.1$.

The life of a current transformer is not exactly unlimited, but it is nevertheless given as 30,000 - 50,000 km (18,641 - 31,069 miles) of flight. There is no increase in the burning out of the spark-plug electrodes, since high-frequency alternating-current discharges are employed.

With Lepel current transformers, it is therefore possible to use high-heat-resisting spark plugs, without danger of fouling with oil under partial loading, since the spark itself, at the maximum revolution speeds is unusually hot and powerful and compels good ignition, even in cases where the oil film on the electrodes would cause an ordinary spark plug to misfire. These effects find their natural limits in pronounced structural faults or in defects in the piston rings. Special note should be made of the fact that the current transformer is used constantly on the engines of the largest German air-traffic companies. The prompt starting of all the cylinders, even after long glides with the engine stopped, make the current transformer specially valuable for aviators. The experiments by American aviators with the current transformer on the Liberty engine are said to have given such good results that its general introduction is contemplated.

The same firm (Lepel) has recently made a spark plug designed by Barenyi, of which the longitudinal section and parts are shown in Fig. 19. It is novel and noteworthy that the explosion pressure of the engine does not act, as in ordinary spark plugs, as a suction force on the packing, but presses against it, thus increasing its tightness. Leakage of spark plugs (which easily occurs in much-worn engines as a result of the unlike heat-expansion coefficients of the insulating materials and of the metal) is thus rendered impossible. The middle electrode has a large cross section for the purpose of good heat conduction. The spark plug can be easily taken apart, and each part is exchangeable, so that an injury to one of the parts does not render the whole spark plug useless. This spark plug has been thoroughly tested and has been used successfully in combination with the current transformer, even in engines which had previously always had trouble with the spark plugs, including one high-powered two-stroke-cycle engine which had a mixed lubrication system and in a new type of aviation engine.

Note.- The deplorable accident to the Mercedes 8-cylinder, 2-liter car in the race at Monza in September, 1924, was not due to spark-plug trouble, but to unsuitable fuel. The engines (ϵ = about 3.5; excess load = about 100% at n = about 6000) had been run with benzol without trouble, but had to be run in Monza with a mixture of gasoline and benzol, in which there was much more gasoline than benzol, because benzol could not be obtained in Italy. This resulted in the overheating of the engine and the premature ignition of the mixture, heated to about 100°C (212°F) by the preliminary compression, on coming in contact with the glowing spark plugs.

Translation by Dwight M. Miner,
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for Aeronautics.

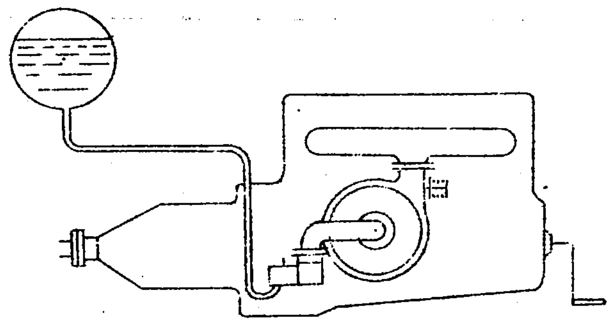


Fig.1 Suction carburetor in a supercharged engine.

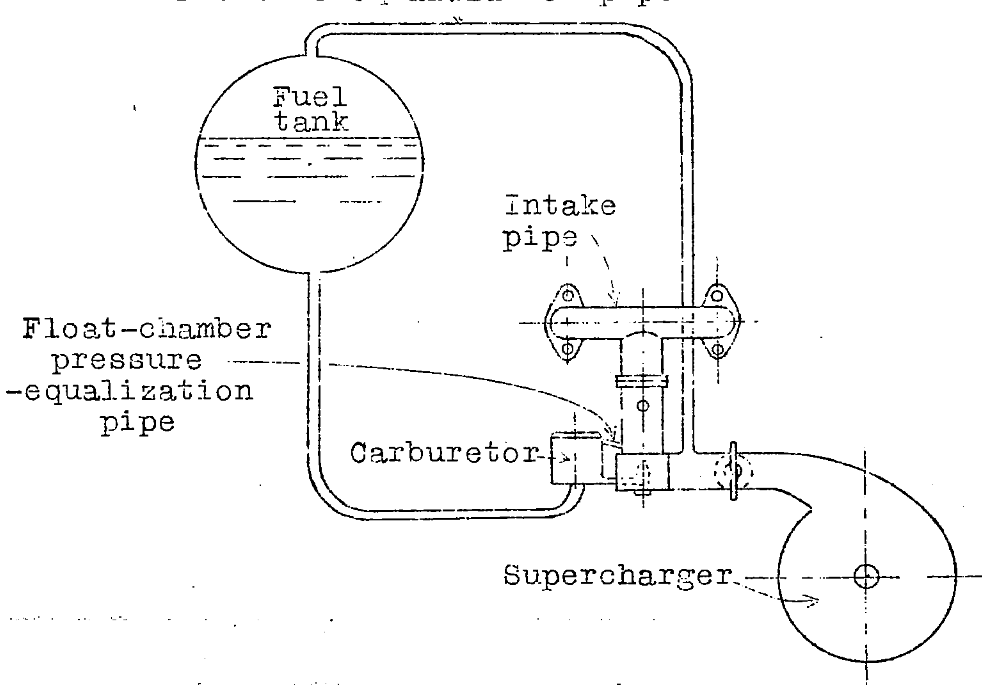


Fig.3 "Zenith" supercharger with pressure carburetor.

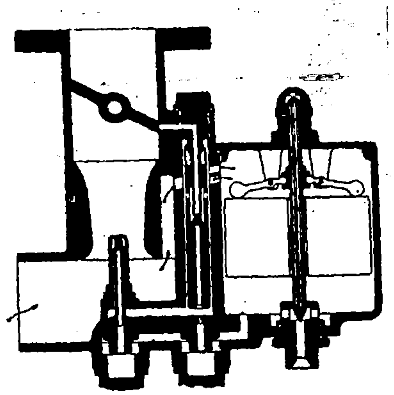


Fig.2 "Zenith" pressure carburetor

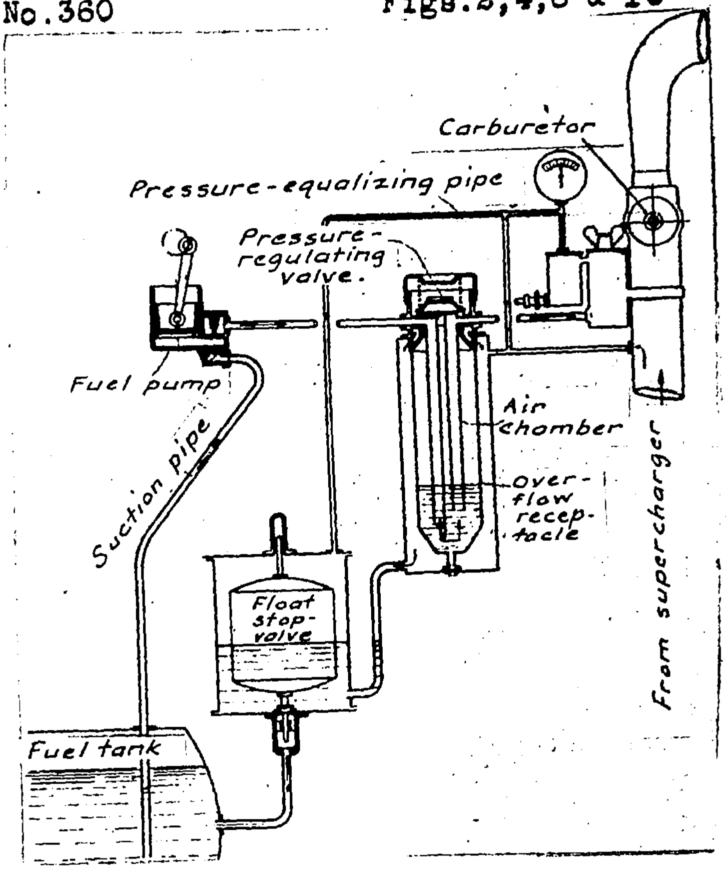


Fig.4 Benz fuel-delivery system for supercharged engines.

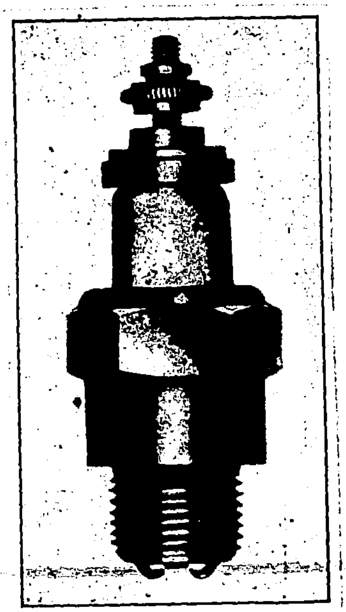


Fig.10 " Bosh " spark-plug for high-powered engines.

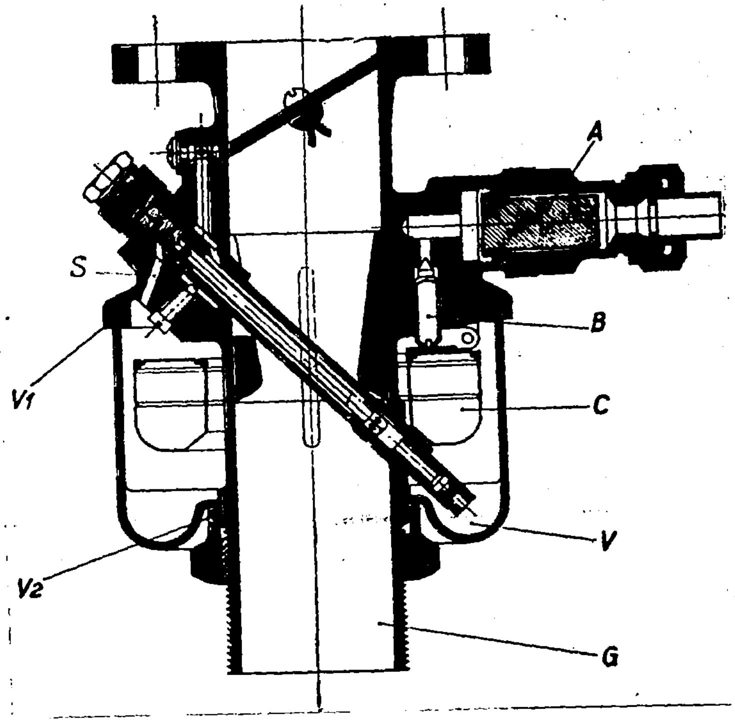
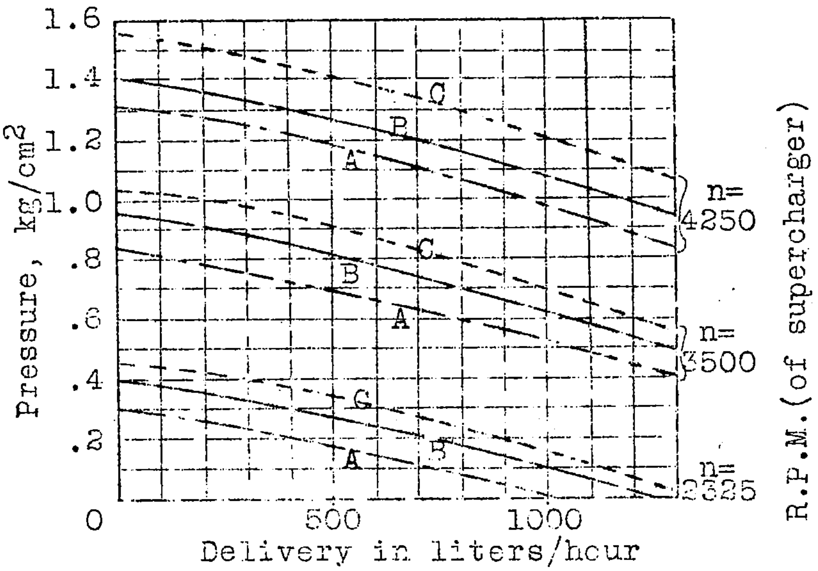


Fig.6 Pallas pressure carburetor



A = Intake pressure of pump = 1.8 m water column.
B = " " " " = 0.0 m " "
C = Discharge " " " = 1.8 m " "
Diameter of centrifugal wheel = 76 mm

Fig.5 Characteristics of a centrifugal fuel pump for Vickers airplane engines.

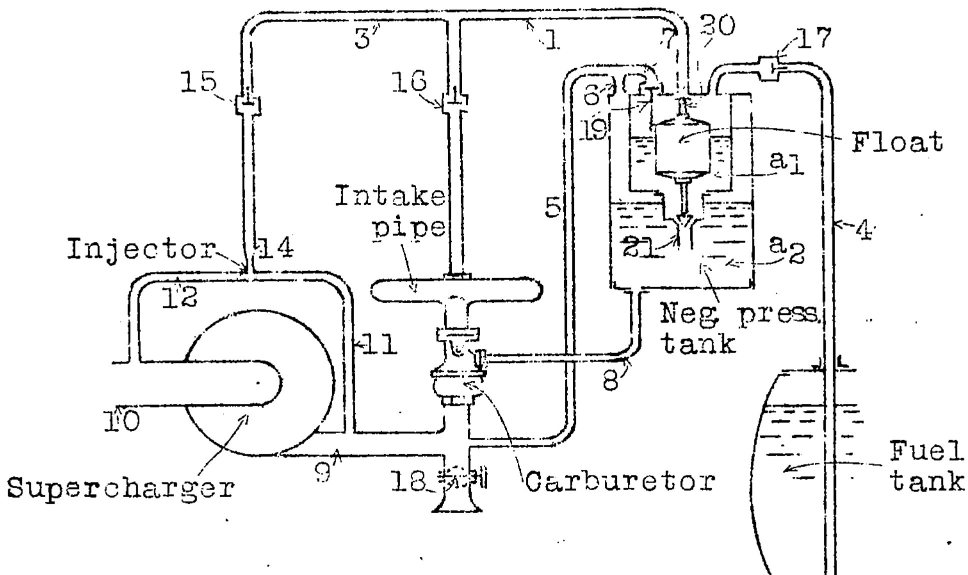


Fig.7 Pallas supercharging system.

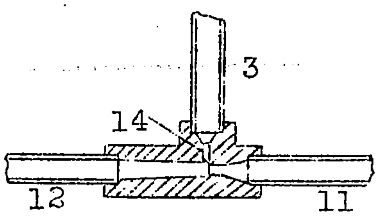


Fig.8 Pallas injector.

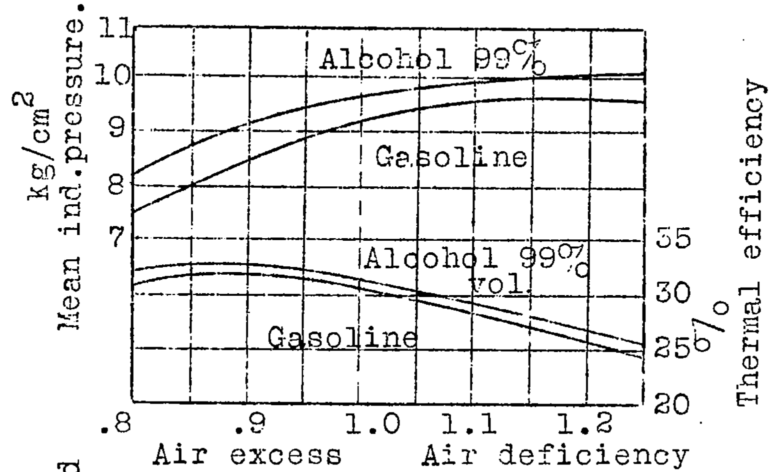


Fig.9 Comparison of gasoline and alcohol drive (Ricardo).

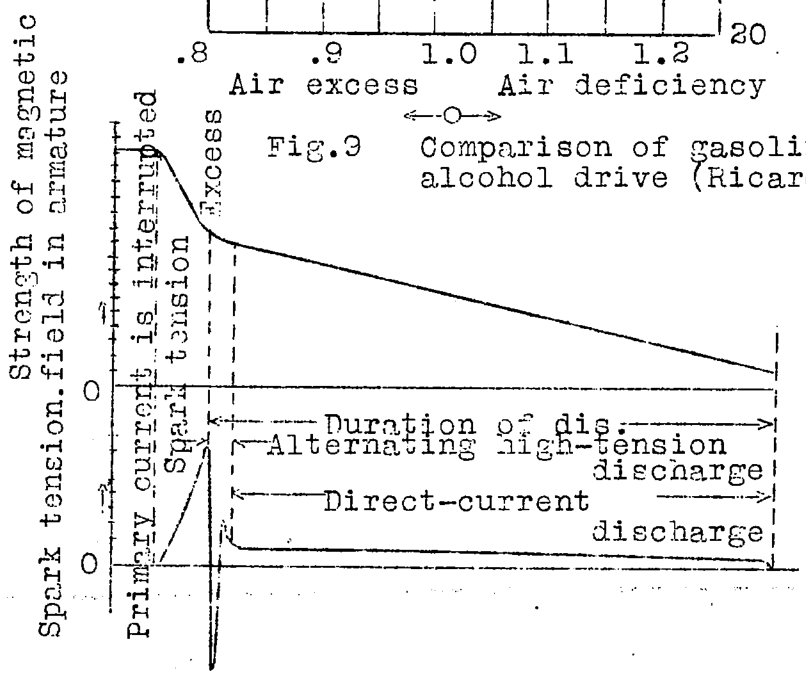


Fig.12 Normal tension diagram for a spark-plug.

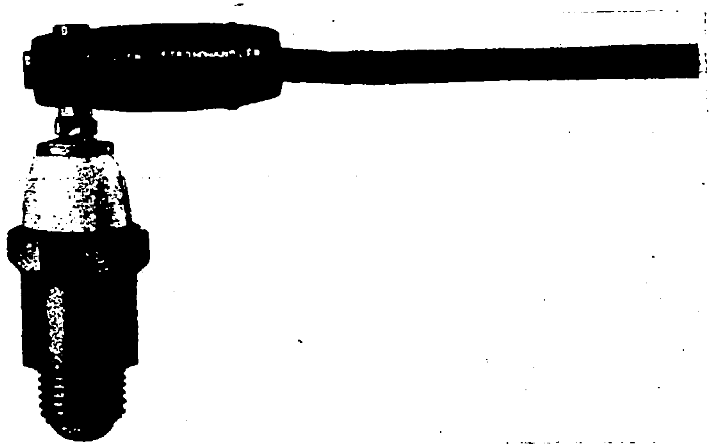
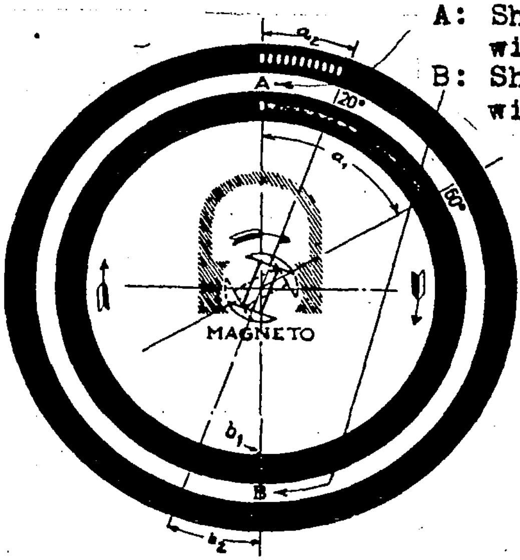


Fig.11 Lepel high-frequency-current transformer



A: Showing the spark-gap rotating with the armature .
B: Showing neon-gas tubes rotating with the armarure.

A
a_1 Current strength of normal spark.
a_2 Strength of spark with current transformer

B
b_1 Tension of normal spark
b_2 Tension of spark with current transformer

Fig.16 Discharge processes in a rotating spark-gap

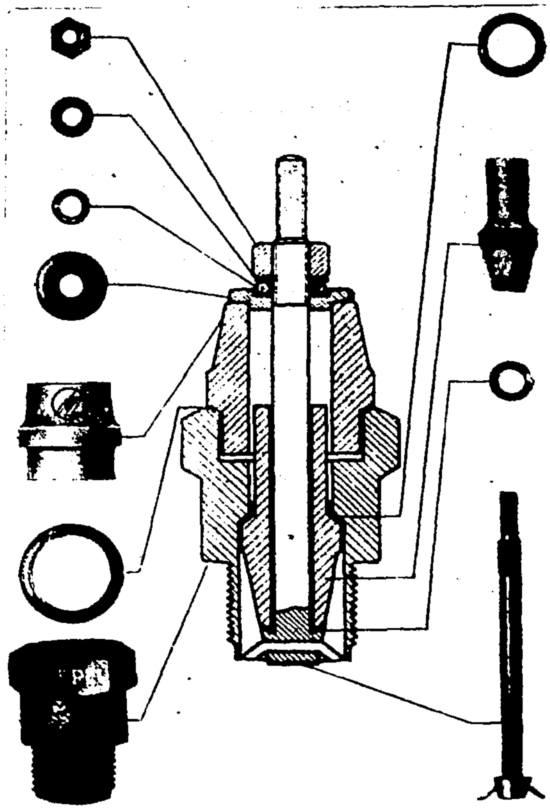


Fig.19 Lepel high-powered spark-plug.

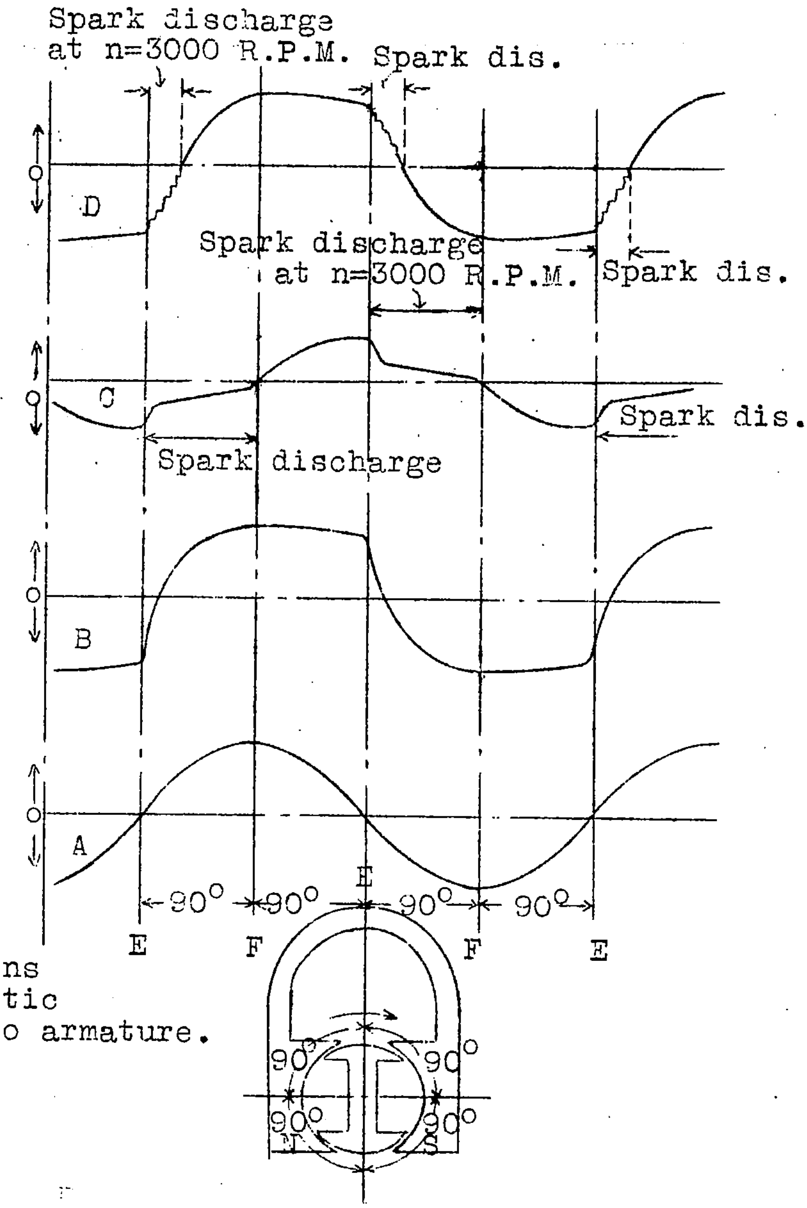


Fig.13 Pulsations in magnetic field of magneto armature.

A: Field strength in armature with open primary and secondary winding.
B: " " " " " closed " " " "
C: " " with normal ignition winding.
D: " " for ignition with current transformer.
E: Armature in vertical position. Primary current with interrupter
F: " " horizontal position.

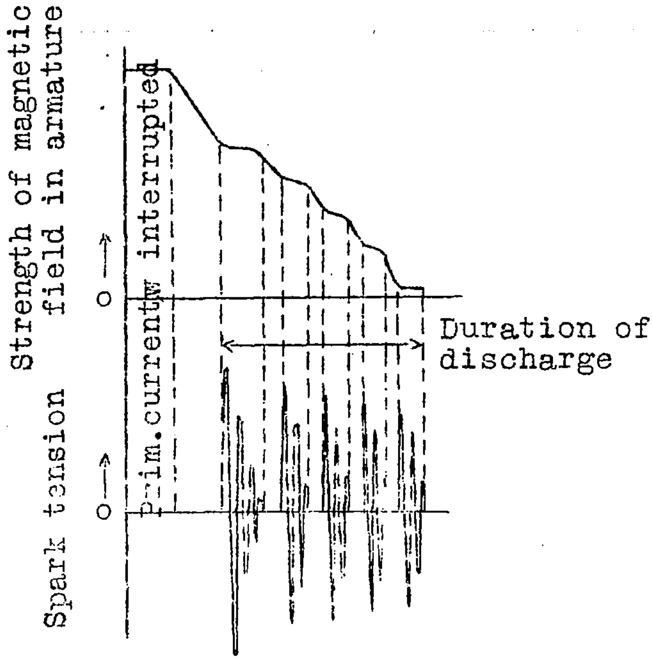


Fig.14 Diagram of spark tension with current transformer.

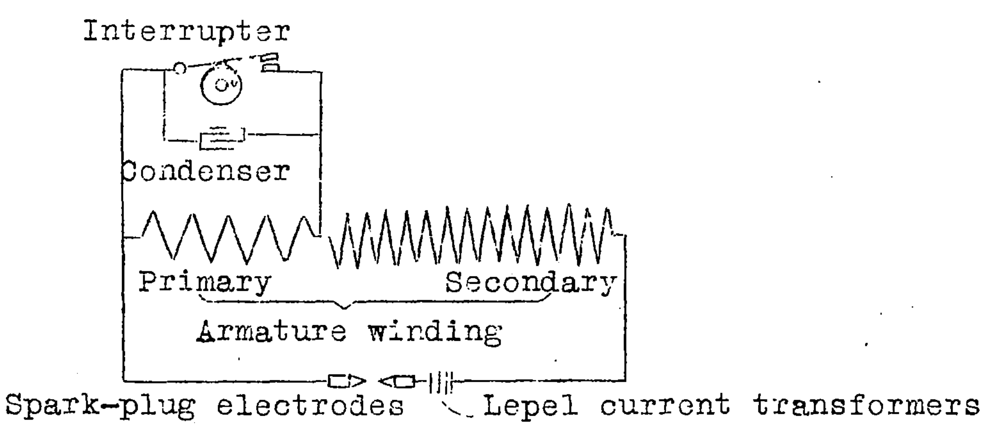


Fig.15 System comprising magneto and Lepel current transformer

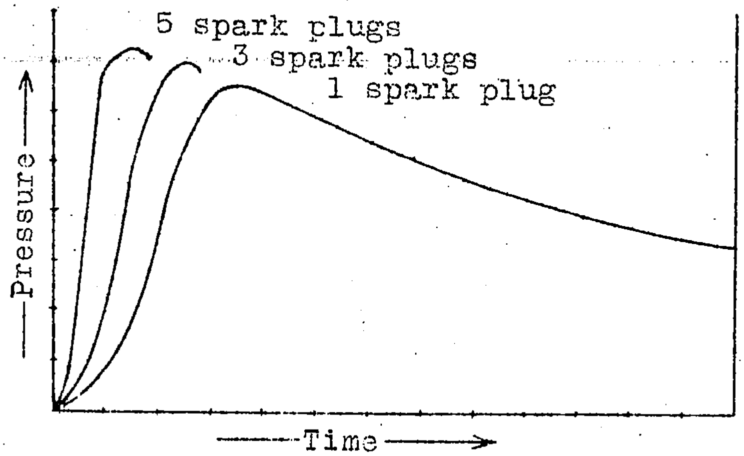


Fig.17 Effect of rapid combustion on cylinder pressure.

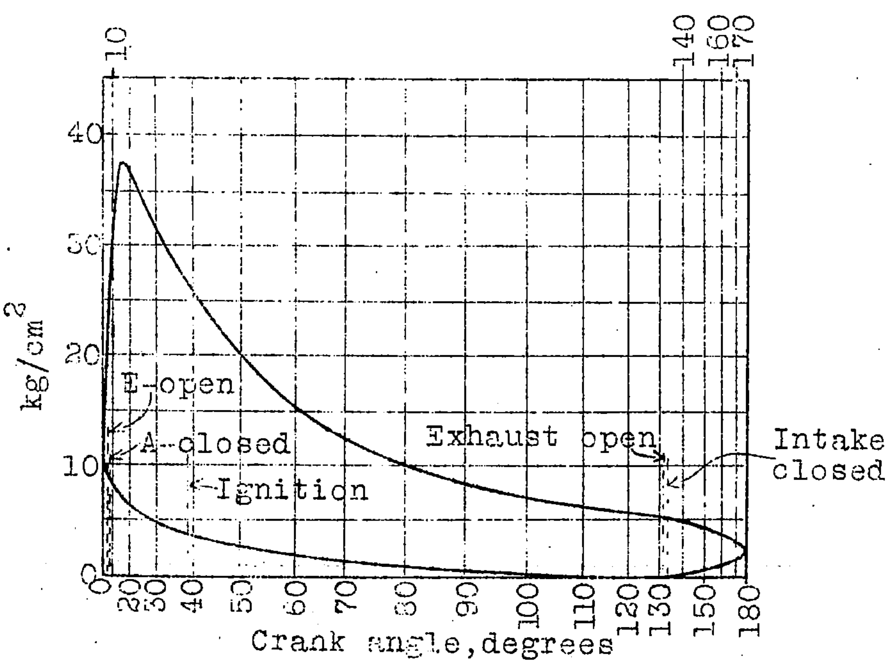


Fig.18 Norm. indicator diagram of Rolls-Royce "Condor" airplane engine.