REPORT No. 23

IN THREE PARTS

AERONAUTIC POWER PLANT INVESTIGATIONS

By THE SUBCOMMITTEE ON POWER PLANTS

Part 1.—PERFORMANCE OF AERONAUTIC ENGINES AT HIGH ALTITUDES
Part 2.—RADIATOR DESIGN
Part 3.—SPARK PLUGS

By H. C. DICKINSON
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REPORT No. 23.

PART 1.

PERFORMANCE OF AERONAUTIC ENGINES AT HIGH ALTITUDES.

By H. C. Dickinson.

INTRODUCTION.

This investigation was originally undertaken as a continuation of the work on carburetion reported on by Prof. Lucke in the second annual report of the committee. The intention was to undertake a study of carburetion and carburetor performance in connection with several types of aeronautic engines under varying conditions of temperature and pressure.

While this program was under development members of the French War Mission and others urged upon the committee the importance of making a special study of the problem of engine performance at high altitudes. The original carburetion program was, therefore, modified and made a part of a somewhat more comprehensive undertaking, viz, the design, construction, and equipment of a special laboratory for the study of engine performance in general, including carburetion, under conditions corresponding to the highest altitudes reached by aviators.

Such a laboratory has been designed, built, and fully equipped. Preliminary runs have been made for developing test procedure and the plant is in such condition that the following operations and measurements can now be made:

(*a*) A test chamber in which the engines are mounted can be reduced to any air pressure as low as one-third of an atmosphere. The air in this chamber can be maintained at a low temperature and circulated about the engine by means of fans at a high velocity. The engine is controlled and all measurements are made from outside this chamber.

(*b*) The temperature of the cylinder-jacket water is controlled by means of a thermostat, the amount circulated is metered, and its rise in temperature measured. Thus the heat taken away by the circulating water can be calculated.

(*c*) Provision is made to weigh the fuel supplied to the engine.

(*d*) The air supplied to the carburetor is metered and its temperature measured.

(*e*) The exhaust is water-cooled. This water is also metered and its rise in temperature measured so that the heat given out in the exhaust can be calculated.

(*f*) The pressures in the intake, the exhaust chambers, and the main test chamber can be measured, and there is provision for partial automatic control. Provision is also made for measuring such other pressures as may be desired.

(*g*) The temperature of the air in the test chamber and such other temperatures as may be of interest in various parts of the engine or elsewhere can be measured.

(*h*) Provision is also made for such other incidental measurements as may be necessary for special purposes.

Experimental work is now in progress to determine the effect of different fuels on the performance of typical aeronautic engines, particularly at very low air pressures and temperatures. This immediate program was laid out to assist in the specification for aircraft engine fuels to be supplied to the Army for service in Europe.

DESCRIPTION OF LABORATORY AND EQUIPMENT.

In designing the laboratory it was decided that results could be best obtained in a test chamber in which the entire engine in operation could be surrounded by conditions of air pressure, air temperature, and air velocity substantially duplicating actual flying conditions. To accomplish this result required a practically air-tight chamber of sufficient strength to withstand an excess of air pressure of 10 pounds per square inch or more on the outside and large enough to contain an engine, a large bank of direct-expansion ammonia cooling coils, and the necessary fans for producing the air blast, with space left for working around the engine. The essential auxiliaries outside the chamber consist of an electrical dynamometer for absorbing and measuring the power, an ammonia refrigerating plant for cooling the air circulating in the chamber and for cooling and drying the air taken to the carburetor, an exhaust blower of sufficient capacity to withdraw the exhaust from the engine and discharge it at atmospheric pressure, auxiliary chambers in which the exhaust gases can be cooled before reaching the blower, tanks for supplying and weighing the gasoline, water supply controlled by a thermostat for cylinder-jacket cooling, water supply for cooling the exhaust gases, a gravity vacuum drain pipe for removing the exhaust cooling water, and the experimental measuring equipment demanded by the various problems to be undertaken.

The equipment has all been designed for use with engines up to 300 horsepower and any attainable speed, with liberal allowances so that considerably higher powers can probably be handled, particularly as the power available at low pressures will be correspondingly less than normal. The Sprague dynamometer is rated at 300 horsepower with considerable overload capacity. The Nash blower has a volumetric capacity about twice the displacement of a 300-horsepower engine at a pressure of one-half atmosphere, and the York refrigerating machine is of 25-ton refrigeration capacity, which should prove ample.

The refrigerating apparatus, exhaust blower, and dynamometer equipment are conventional units purchased for the purpose in hand. Hence the only portions of the equipment specially designed are the building, low-pressure chamber, the air-cooling system, the engine support, and the apparatus for measurements of air intake, fuel, temperatures, and pressures.

Of the above the building offers no unusual features, being a temporary structure of frame and stucco, designed to accommodate the vacuum chamber and auxiliary machinery.

The low-pressure chamber shown in figure 1 is of concrete, 1 foot in thickness, heavily reinforced with ¾-inch steel bars to provide against pressure from without. The two door openings, the front one being shown in the figure, are on opposite sides of the test chamber and are 4 feet by 6½ feet in size. The doors swing on hinges and are built up of 2 by 7 inch oak beams 4½ feet long and spaced 7 inches between centers, the outside being covered with ½-inch soft wood loosely held with headless nails and covered over with air-proof roofing paper. This construction was adopted as a safeguard against possible explosion inside the chamber. The very light covering of the doors might be blown off without danger to the concrete walls. To guard against excessive air leaks the outside of the chamber is covered with a very heavy coating of asphalt paint and the doors close against heavy rubber gaskets.

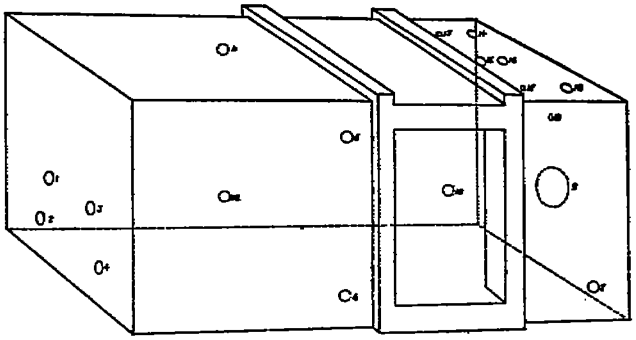

FIGURE 1

The engine is mounted at the right end of the test chamber, figure 1. The walls of the chamber are pierced by a number of holes appropriately placed, each being provided with a flange and gasket through which the various connections are made. The flexible coupling of the engine to the dynamometer is made through 9. The engine is controlled through 8 by means of a system of pull rods and bell cranks. The gasoline is supplied from overhead tanks through 17. These tanks rest on platform scales so that the weighing is done at the right of the front door. The pressure tubes are brought through 18 to appropriate manometers while an oil-gauge lead and necessary thermometer leads are brought through 13. All this apparatus, together with the manometers for the venturis of the two water-cooling systems, is mounted near the engine controls. Likewise the dynamometer control board and the auxiliary switch board for the blower and refrigerating compressor motors is near by. Thus the chief operator not only has complete control of the engine but also of all the auxiliary equipment. At the same time he can see at a glance everything that is happening. Electrical leads used in making the necessary heat measurements are brought through 5 and 6 to an instrument table. The cylinder jacket water enters through 15 and returns through 16 to an overhead mixing tank supplied with a thermostat to regulate the temperature.

The air-cooling system consists of two parts. A series of direct-expansion ammonia coils mounted on top of the chamber is provided for cooling the carburetor air. These coils consist of about 2,000 feet of 1¼-inch piping inclosed in a box insulated with 4 inches of sawdust. The air is made to pass through this coil box in a tortuous path and is then led through an insulated pipe provided with a regulating valve to the bottom of the test chamber at 7. From this inlet the air passes through a box in which it is metered directly to the carburetor, thus supplying cold air to the intake when desired.

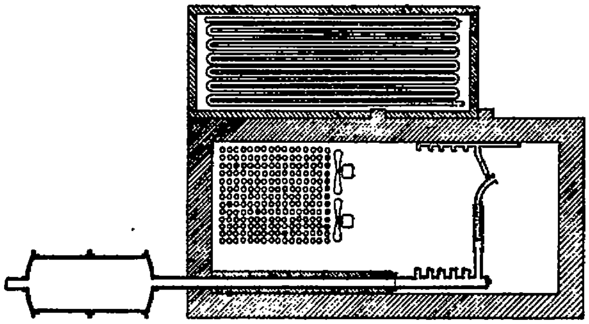

FIGURE 2.

The second part of the cooling system consists of about 800 feet of ammonia expansion coils mounted in the left end of the test chamber as shown in the sectional diagram, figure 2. Four fans are furnished to force air over the coils at high velocity. The object of these coils is to absorb the heat given out by the exposed surface of the engine. A fan is also provided for producing a high air velocity past the engine itself, if so desired.

The engine exhaust cooling system is shown diagrammatically in figure 2. The exhaust pipes connected to the engine are water-jacketed, the inner pipe extending about 3 feet from the engine, while the water jacket is continued from the exhaust elbow to the main exhaust manifold in the form of a flexible rubber hose. In this way the whole connection is made flexible and the water from the jacket enters the exhaust pipe at a considerable distance from the engine. The water enters the test chamber through 14 and is distributed to the exhaust pipes as shown in the figure.

The mixture of exhaust gases and water passes through a 5-inch pipe to the auxiliary exhaust chamber where the water is drained off through the gravity drain pipe and the gases pass to the exhaust blower. Two exhaust manifolds and chambers are provided, one for each set of cylinders in a V-type engine. Each side is provided with six inlets for pipes from the engine.

The engine support was designed for the purpose of duplicating as nearly as possible the flexibility and the inertia of the typical fuselage mounting. The design developed makes possible an accurate adjustment of stiffness as regards transverse and vertical vibration and rotation about each of the three principle axes of the engine, but as no data were at hand as to the corresponding characteristics of any fuselage mountings, the support was constructed on the basis of estimates of these constants, and appears to possess nearly the desired characteristics for the engines mounted on it up to the present time.

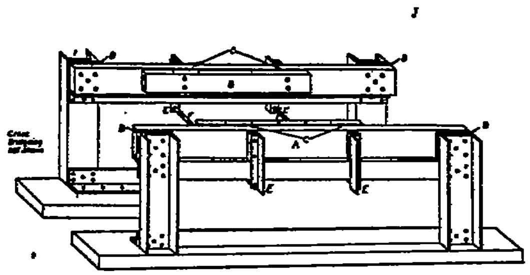

FIGURE 3

The design of this support is illustrated in figure 3. Two oak beams, *A*, in this case 2 by 6 inches by 6 feet 3 inches supported at the ends form the basis of the mounting. The engine is mounted directly on two supplementary beams, *B*, of 2 by 4 inch section and of the length required for the particular engine under test. These supplementary beams are free from the main beams except at two points where they are bolted together through a thin separating block, *C*. Two yokes, *E*, are provided to prevent torsion of the individual beams, but have no other effect as they are free from contact with any other part of the structure.

Selection of the dimensions of the main beams and adjustment of the spacing between the points of suoport of the secondary beams permits of adjustment of vertical and lateral stiffness and approximate adjustment of resistance about a vertical axis and a horizontal axis at right angles to the axis of the crank shaft. Stiffness as regards rotation about the latter axis can be adjusted by a third beam of proper dimensions rigidly connected at the ends and to the yoke rods, *F*.

The experimental program laid out in connection with the altitude laboratory, including a general study of the performance of aeronautic engines under high-altitude conditions, is in progress and much valuable information is in prospect. The subject of precompression engines and the development of precompression blowers or pumps is to be given special attention.

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PART 2.

RADIATOR DESIGN.

By H. C. Dickinson.

In this country, cooling radiators for aeronautical engines have been mainly adaptations of those developed for the cooling of automobile engines where air speeds are very much slower and where weight and particularly head resistance are of minor importance.

The rational design of radiators to meet the requirements of maximum cooling capacity with minimum head resistance and minimum weight under the velocity, pressure, and temperature conditions met with in flight requires considerable fundamental information regarding the laws of air flow and of heat dissipation in the honeycomb air-tube and vertical flat water-tube types of radiator construction used to-day. At the start of the investigation practically none of this information was available although recently received reports of the British and French commissions have added much that is of value.

A radiator when mounted on any particular airplane will have a definite figure of merit depending upon the type and speed of the plane, the location of radiator, the temperatures of the air and water, the barometric pressure, and the rate of circulation of the cooling water. The figure of merit as used herein is defined as the ratio of the power (i. e., in the form of heat) abstracted from the cooling water to the power absorbed in carrying the radiator. Part of this power absorbed in carrying the radiator is used in overcoming head resistance and part in supporting its weight. If the ratio of lift to drift for the plane is known, or assumed, these two factors can be combined into a single figure for equivalent head resistance and therefore of power absorbed in carrying the radiator.

The problem suggested above is too complex to permit of a complete general solution, hence it was necessary to lay out a program which could be completed in a reasonable time and which would give results of most immediate importance.

The questions of more immediate importance appear to be somewhat as follows: What are the effects on the figure of merit and its component factors of (*a*) changes in air velocity through the radiator, (*b*) changes in head velocity, (*c*) changes in ratio of depth to diameter of radiator cells or air passages with changing diameter and width of air passages, (*d*) addition or omission of secondary cooling surface (i. e., metallic surface not in direct contact with cooled water), (*e*) addition of devices or changes of design to increase turbulence of the air stream, (*f*) changes in velocity of cooling water, (*g*) changes in turbulence of water streams as affected by design of water passages.

These questions could be best answered by the study of a sufficient number of special models designed and constructed specifically for the purpose of observing each factor separately, but the practical difficulty of constructing such a series of models in point of time made it advisable to limit the initial experiments at least to specimen radiators of types already in use with such modifications of dimensions as could be devised and built by the various makers, thus extending as far as possible the experimental range.

In pursuance of this program, two experimental wind channels were designed and constructed to accommodate specimen radiators with an exposed frontal area of 8 by 8 inches of typical air cells or passages, the necessary water connections not being included in this area.

The first wind channel shown diagrammatically in figure 1 is constructed inside a steel chamber in which the air pressure can be reduced to a fraction of an atmosphere. Air velocities in this channel at atmospheric pressure up to about 70 m. p. h. can be obtained without the specimen in place, or from 50 to 65 m. p. h. through the air cells of some of the types of specimen radiators when placed in the channel. Provision is made for measurement of velocities, pressure differences, and temperature differences in both the air and water streams; for metering the air and the water and for close control over the temperatures and rates of flow of both water and air.

The velocities obtainable in this channel, while reasonably adequate for calorimetric measurements, were not deemed sufficient for a study of head resistance at very high speeds. Therefore, the second channel was constructed in which velocities of about 120 m. p. h. are attained in the open channel and up to 90 m. p. h. with certain radiators in place. In this channel, measurements of air velocity and resistance to air flow are made, but it has been impracticable to duplicate the calorimetric equipment which is elaborate and complicated, requiring numerous instruments which could not be purchased or built without much delay.

In order to correlate the figure of merit as determined in these experiments with the performance of the radiator in an open air stream, measurements of the head resistance and tube velocities in a wind tunnel of large size, at least 4 feet in diameter, are necessary. The necessary equipment for these measurements will be available at the Bureau of Standards by February 1.

A series of some 45 or more specimen radiators have been secured representing practically all the radiator designs now in use on airplanes or automobiles, together with a number of modified designs to cover more fully the desired experimental range of cell dimensions. Measurements for determining the figure of merit of a number of these specimens have already been completed, observations having been made in both of the 8-inch wind channels. The immediate program calls for the detailed study of about 20 of the radiators in hand, so selected as to give the necessary data for a preliminary report on the several questions outlined above. Until the observations on these specimens are completed, none of the results can be put in final form, although the following tentative conclusions may be drawn from the results already obtained:

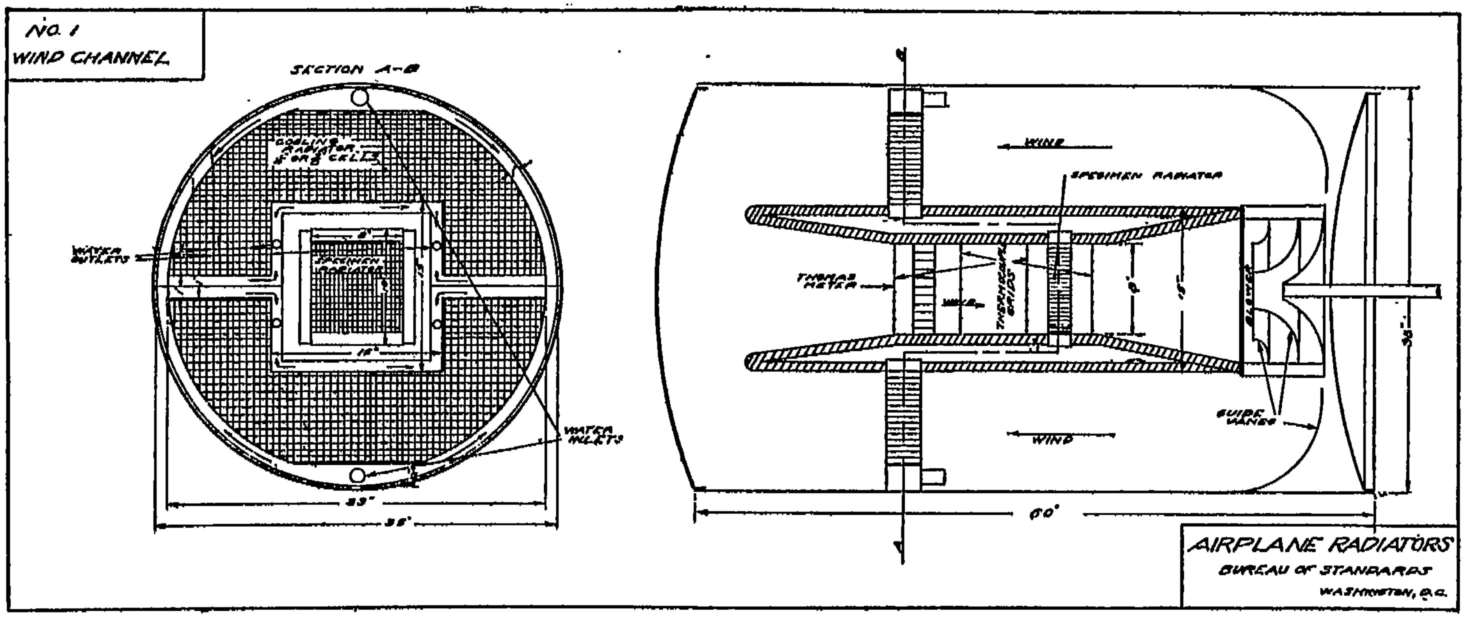
NO. 1
WIND CHANNEL
SECTION A-B
COOLING RADIATOR ¼" OR ⅜" CELLS
WATER OUTLETS
SPECIMEN RADIATOR
8"
12"
16"
WATER INLETS
33"
36"
WIND
SPECIMEN RADIATOR
THERMOMETER
THERMOCOUPLE GRIDS
WIND
8"
15"
BLOWER
GUIDE VANES
WIND
36"
60"
A
B
AIRPLANE RADIATORS
BUREAU OF STANDARDS
WASHINGTON, D.C.

FIG. 1.

(1) The amount of heat transferred is nearly proportional to the velocity through tubes when the ratio of the length of the air cells to their diameters is greater than about 8. This relation holds for velocities up to about 60 m. p. h. through the tubes.

(2) The pressure difference necessary to force air through the tubes is in nearly all cases proportional to V^n where V is the velocity through the tubes and varies from 1.5 to 2.5, depending on the air cells construction.

(3) Various features added for the purpose of producing turbulent flow in the air passages are by no means equally efficient. Some types introduce resistance that is not compensated for by a corresponding increased cooling capacity.

(4) When properly designed, indirect cooling surface, i. e., metal not in direct contact with the water, appears from the present data to be good practice.

(5) Increasing the water velocity in different types of radiator construction in general results in increasing the rate of heat transfer, but by no means in like proportion in all radiators.

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PART 3.

SPARK PLUGS.

By H. C. Dickinson.

In December, 1916, the National Advisory Committee for Aeronautics requested the Bureau of Standards to undertake a laboratory study of the spark-plug problem which had arisen because of the very severe conditions of temperature and pressure existing in modern aviation engines. The work has proved to be of much wider scope than was originally anticipated. It includes an investigation of the various properties of materials entering into the construction of spark plugs with a view to improving their construction and design, and a study of various related problems in ignition systems. In connection with this work, tests have been devised for specifications, and routine acceptance tests made on plugs purchased by the Government.

The work has also involved numerous conferences with representatives of all the more important manufacturers of airplane spark plugs, and also with members of the foreign scientific missions.

As a result of these conferences, it appears that the sources of trouble in spark plugs may be roughly grouped as follows:

1. "Cut-out," or failure of the spark, due to short circuit resulting from the electrical conductivity of the body or the surface of the insulating material of the plug at high temperature.
2. Preignition due to excessive heating of parts of the plug.
3. Fouling of the insulating parts by carbon.
4. Cracking due to differential thermal expansion.
5. Excessive gas leakage.
6. Minor causes, such as warping of electrodes, bridging of the gap with oxides, carbon, or oil, direct puncture of the material, and mechanical breakage.

Some of these troubles, such as mechanical breakage, bridging, etc., are essentially accidental and can be studied satisfactorily only from statistical data. Others, such as "cut-out," fouling, and preignition, lend themselves more readily to experimental study and most of the work thus far has been aimed at these troubles. An understanding of the causes of these failures requires primarily a knowledge of the conditions existing in the cylinders and spark plugs of a modern aviation engine. The first two also require a knowledge of the ability of ignition apparatus to deliver a spark from an imperfectly insulated plug, and the first is intimately connected with the electrical resistance of the insulating material at high temperatures.

The gas leakage through a spark plug, though not in itself enough to affect the operation of the engine, is exceedingly detrimental since it rapidly heats the body of the insulator and brings on other types of failure frequently causing the complete destruction of the plug. The work thus far accomplished will, therefore, be discussed under the headings of "Engine conditions," "Ignition systems," "Gas tightness," and "Electrical conductivity at high temperatures."

ENGINE CONDITIONS.

To indicate the conditions under which spark plugs operate, a study of the sparking voltage and temperature conditions in a gasoline-engine cylinder has been undertaken. Using a pressure bomb which could be heated in an electric furnace, measurements have been made of the sparking voltage at 60 cycles across each of three different air gaps. This was done at temperatures up to 430° C. and at pressures up to 7.5 atmospheres. The data confirm the conclusions of other observers at lower temperatures, that the breakdown voltage is proportional to the density of the gas and is independent of pressure or temperature at constant density. It was noted that when the electrodes are heated, as is the case in a plug firing steadily from a magneto, the gas in the gap is thereby warmed and the density diminished so that the sparking voltage is consequently reduced.

By using a Kenotron vacuum tube in series with a static voltmeter, it was found possible to measure the maximum voltage on an ignition circuit. The voltage across a plug with a gap adjusted to 0.020 inch in a Hall-Scott aviation engine running at full load was found to be about 6,000 volts. This value can be reconciled with that computed from the density of the gas in the cylinder at the instant of firing by making reasonable allowance for the heating effect of the hot electrodes on the gas near them.

A number of spark plugs have been drilled so that thermo couples can be inserted in the center electrode or in the porcelain inside the shell. Determinations of the temperature at these points have been made in several engines. Temperatures as high as 800° C. in the electrode and 400° C. in the porcelain have been obtained. It is highly desirable that further measurements of this kind be made on other types of plugs and engines, particularly on engines which are known to be severe on plugs, such as the Hispano-Suiza.

IGNITION SYSTEMS.

As an aid in studying the behavior of ignition systems a number of instruments have been devised including a thermocouple cross for measuring the current, the peak voltmeter mentioned above, and a copper calorimeter for measuring the entire heat energy of the spark.

A collection of magnetos of different makes have been submitted by the Signal Corps for an exhaustive series of tests. The energy per spark from each of these has been measured at several speeds and found to vary from 0.05 to 0.12 joule per spark. Also a determination has been made of the resistance which, put in parallel with the magneto, will draw so much current that the magneto fails to give a spark at about 6,000 volts. The value of this resistance has been found to be of the order of 80,000 ohms. Further measurements with an oscillograph will be taken up as soon as more assistants can be obtained.

ELECTRICAL CONDUCTIVITY.

One very important property of the insulating material of a spark plug is its ability to maintain a high electrical resistance at the high temperatures at which a spark plug operates and a very considerable amount of work has been done in studying this property. Over 100 complete curves of resistivity vs. temperature have been obtained on specimens of various insulating materials. The ceramic laboratory of the Bureau has made up a large number of specimens of porcelain covering the whole quartz-kaolin-feldspar field, in the form of cups which are convenient for resistivity measurements. Several porcelain manufacturers have also submitted samples of their material in this shape. It is also possible, though with much less accuracy, to determine the resistivity of material in completed spark plugs and a number have been measured, including not only the principal American porcelain plugs but also German and French porcelains, mica, "lava," steatite, glass, and quartz specimens.

In all these substances the resistivity drops very rapidly with increase of temperature and roughly follows the exponential law.

$$\log_{10}\rho = c - bt.$$

Where ρ is the volume resistivity (ohm-centimeters) and t is the temperature in degrees C.

In the following table are given the values of b and c for various materials, applicable in the range from 250° to 600° C.; also in the column headed $\rho\sqrt{500}$ the resistivity of the material at 500° C. in megohm-centimeters, and in the column headed T_e the temperature at which the resistivity is 1 megohm-centimeter.

Electrical conductivity of some insulating materials, between 250° and 600° C.

[$\log_{10}\rho = c - bt$.]

Material.	b	c	$\rho\sqrt{500}$	T_e
Quartz	0.0094	14.	2,500	830
Mica	.0143	15.	63	630
Special porcelains	.0070	10.	3.2	590
Steatite	.0098	10.	.2	400
"Pyrex" glass	.0094	9.5	.06	380
Ordinary porcelain	.0095	9.	.05	350
Soda glass	.0015	11.	.006	350

In making these measurements it was found that if direct current were used the specimens showed a very considerable "polarization" effect. This caused the apparent resistance to increase considerably with the time of application of the measuring voltage, even for impressed voltages of several hundred volts. It was therefore found necessary to use alternating current in these measurements, and with this method the resistance was found to be independent of the voltage, frequency, and previous applications. At the higher temperatures the resistance is so low that the heating of the specimen by the measuring current becomes appreciable. Most of the data given in the table were obtained with 500 volts at 60 cycles impressed on the specimen.

GAS LEAKAGE.

The volume of air leaking through the body of the plug has been measured for a number of types of plug. This was done by screwing the plug into a container and applying an air pressure of 150 pounds per square inch. The entire container was then immersed in a tank of oil heated to 200° C. This heating develops any leaks which result from differential thermal expansion and is very severe since the outer parts become heated first. A graduated glass tube, originally filled with oil, can be placed over the plug and the volume of air escaping thus collected and measured. The amount of this varies from zero up to several cubic centimeters per second, but a good plug should not show more than 0.2 c. c. per second.

SPECIFICATIONS.

In collaboration with the inspection division of the Signal Corps, their material specification No. 28004 was drawn up and is now being revised in several details. A copy of this specification is appended to this report. Some 25 different types of plug have been tested in accordance with these specifications. The principal tests so far developed are those for electrical resistance at high temperatures, gas leakage, dielectric strength and cracking under sudden changes in temperature.

The first two tests are based on the work described above, the limits set at present being that the resistance of the plug shall be greater than 500,000 ohms at 400° C. and that the gas leakage shall not exceed 0.2 c. c. per second of free air at 200° C. and 150 pounds per square inch.

The cold dielectric strength is measured by placing the insulators under oil and applying an alternating electromotive force, between the center electrode and a narrow metal strip around the center of the insulator. Good material should withstand 25 to 30 kilovolts, at which voltage flash over through the oil occurs.

The only test available for cracking consists in heating the porcelain insulators to 300° C. and then plunging them into water at room temperature. They are then subjected to an electrical breakdown test to detect any serious cracks. It has been found that soaking the porcelains in an alcoholic solution of eosin is a very sensitive test and will show cracks which would otherwise be entirely invisible. The quenching test at 300° followed by an application of voltage has been the subject of considerable adverse criticism and is admittedly very drastic; but since materials are available which will withstand it, it seems best to retain it until a better test is devised. An attempt has been made to duplicate engine conditions with respect to temperature gradients by heating one end of the plugs with a surface combustion burner while the shells are screwed into a water jacket. It has not as yet been found practicable to obtain sufficient temperature gradient by this method.

FURTHER WORK.

Since the element of accident enters into so many of the causes of failure of spark plugs, it is of the highest importance that accurate statistical data be accumulated concerning the average life and ultimate nature of failure of a large number of plugs of various types used in a variety of engines in actual service. Such data can, of course, be best obtained at the flying fields, and the committee is planning to secure systematic statistical data by cooperation with the Signal Corps.

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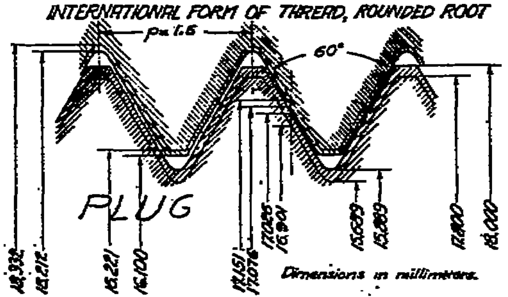
SCREW THREAD LIMITS—METRIC SPARK PLUG

INTERNATIONAL FORM OF THREAD, ROUNDED ROOT



Dimensions in millimeters.

INTERNATIONAL FORM OF THREAD, FLAT ROOF

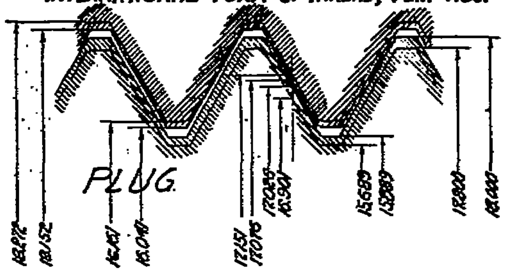


TABLE OF LIMITS, ROUNDED ROOT FORM

	PLUG		TAPPED HOLE.	
	MAX.	MIN.	MAX.	MIN.
PITCH DIAM.	17.026	16.901	17.151	17.076
OUTSIDE DIAM.	18.000	17.800	18.332	18.212
ROOT DIAM.	15.889	15.689	16.221	16.100

TABLE OF LIMITS, FLAT ROOT FORM

	PLUG		TAPPED HOLE	
	MAX.	MIN.	MAX.	MIN.
PITCH DIAM.	17.026	16.901	17.151	17.076
OUTSIDE DIAM.	18.000	17.800	18.272	18.152
ROOT DIAM.	15.889	15.689	16.161	16.041

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MAY 1, 1917 B.R.M. V.R.C.
SK 8214(003)-T-B611

Other work which should be undertaken as soon as possible includes a study of the mechanical strength of the plugs, a more intimate investigation of the deposition of carbon and of preignition, and of the characteristics of ignition systems.