March 7, 1944. K. W. MILLER ET AL 2,343,314

AIRPLANE IGNITION HARNESS

Filed May 24, 1941

Fig. 1

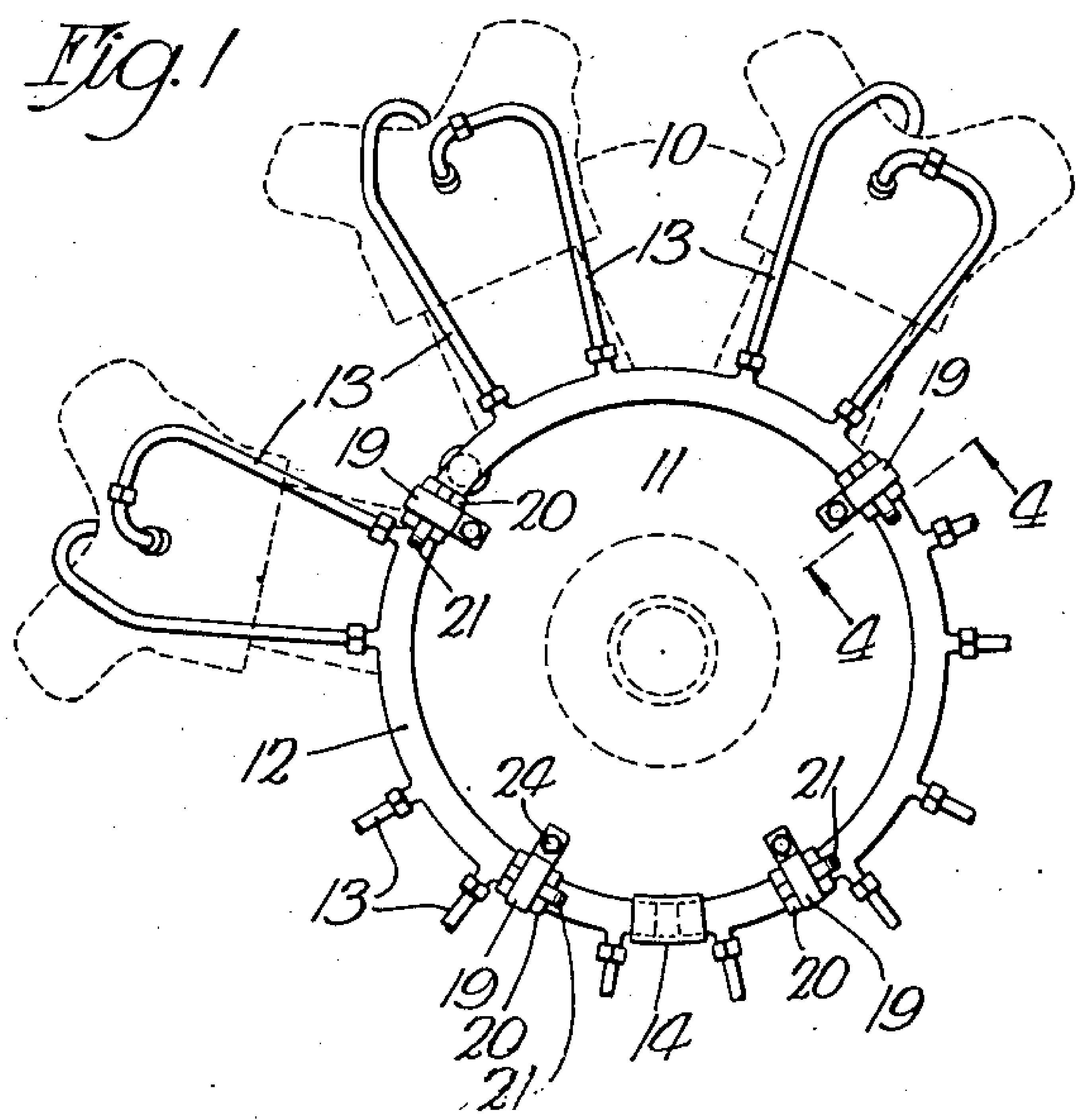


Fig. 4

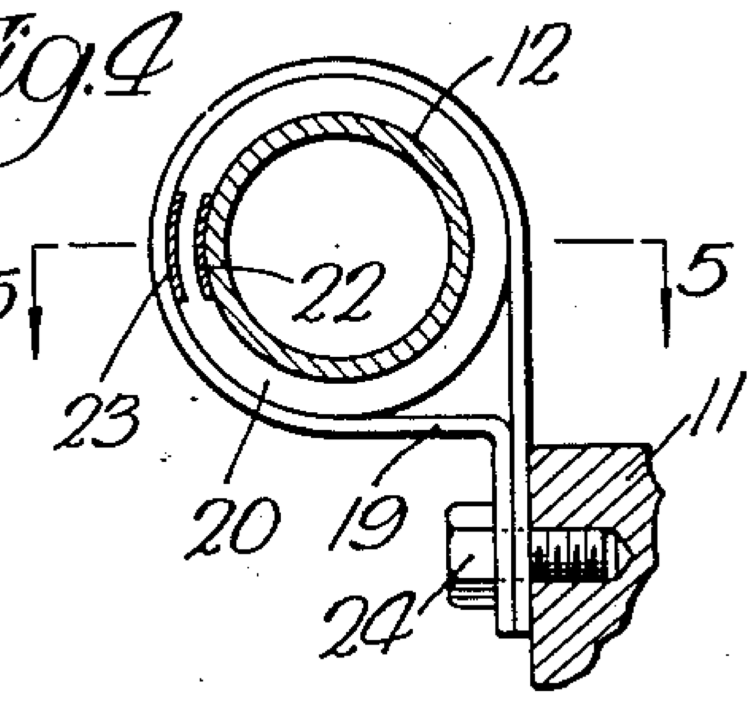


Fig. 5

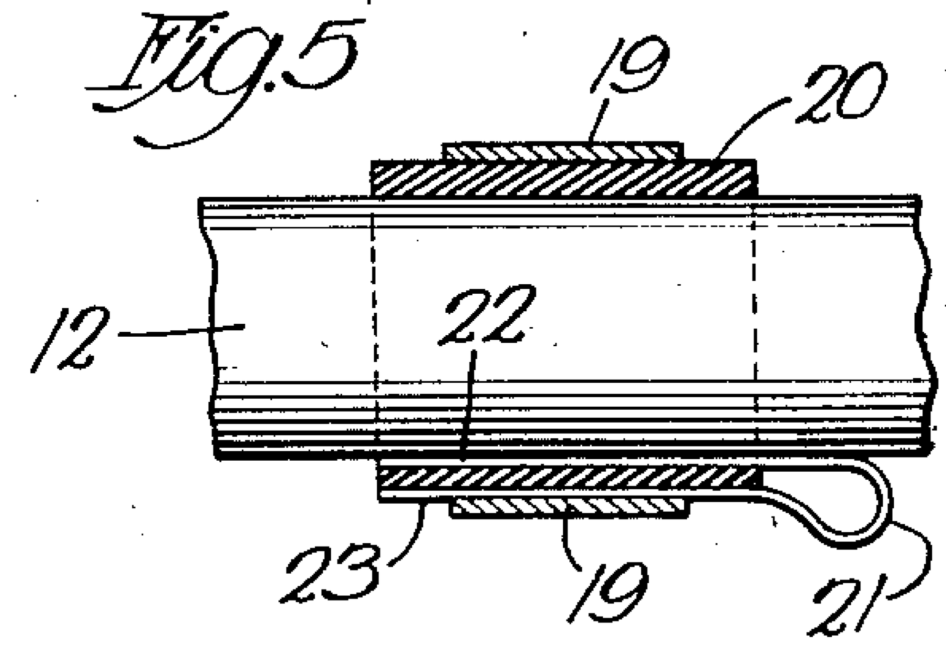


Fig. 2

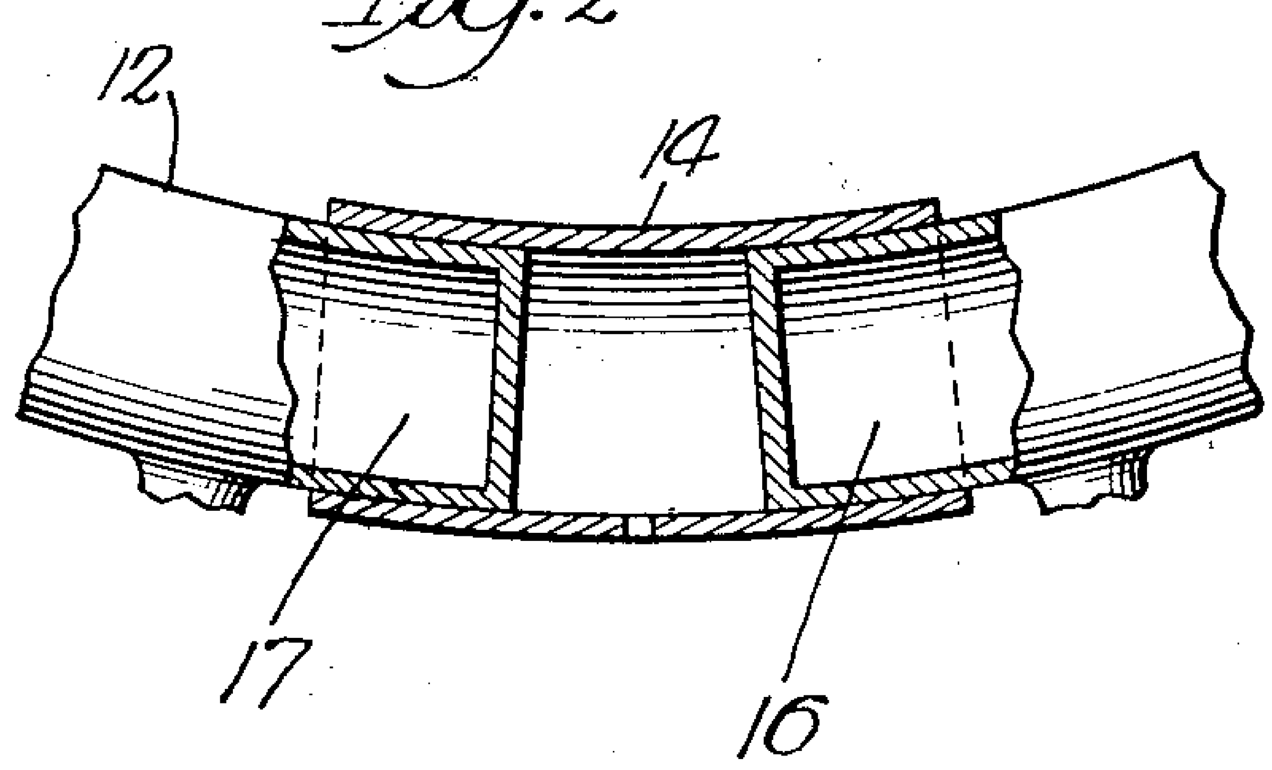


Fig. 6

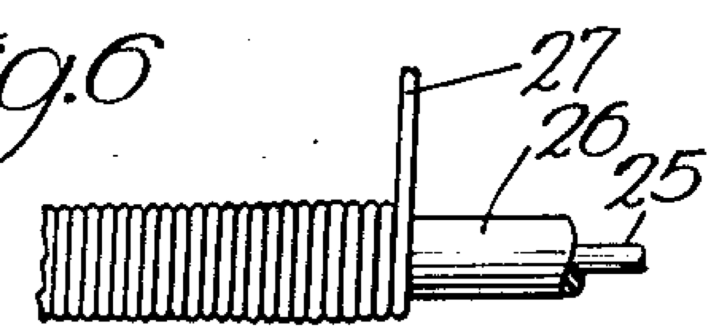


Fig. 7

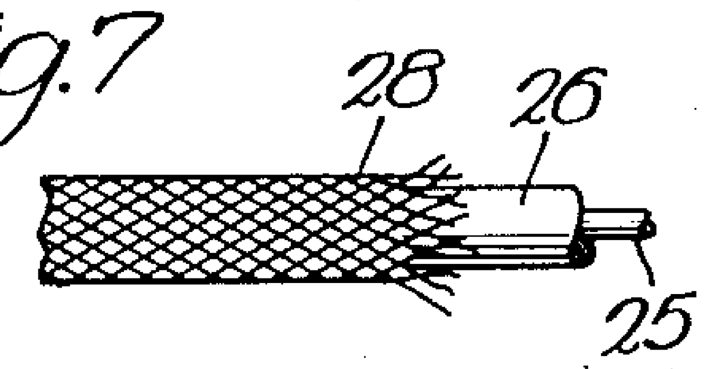


Fig. 3

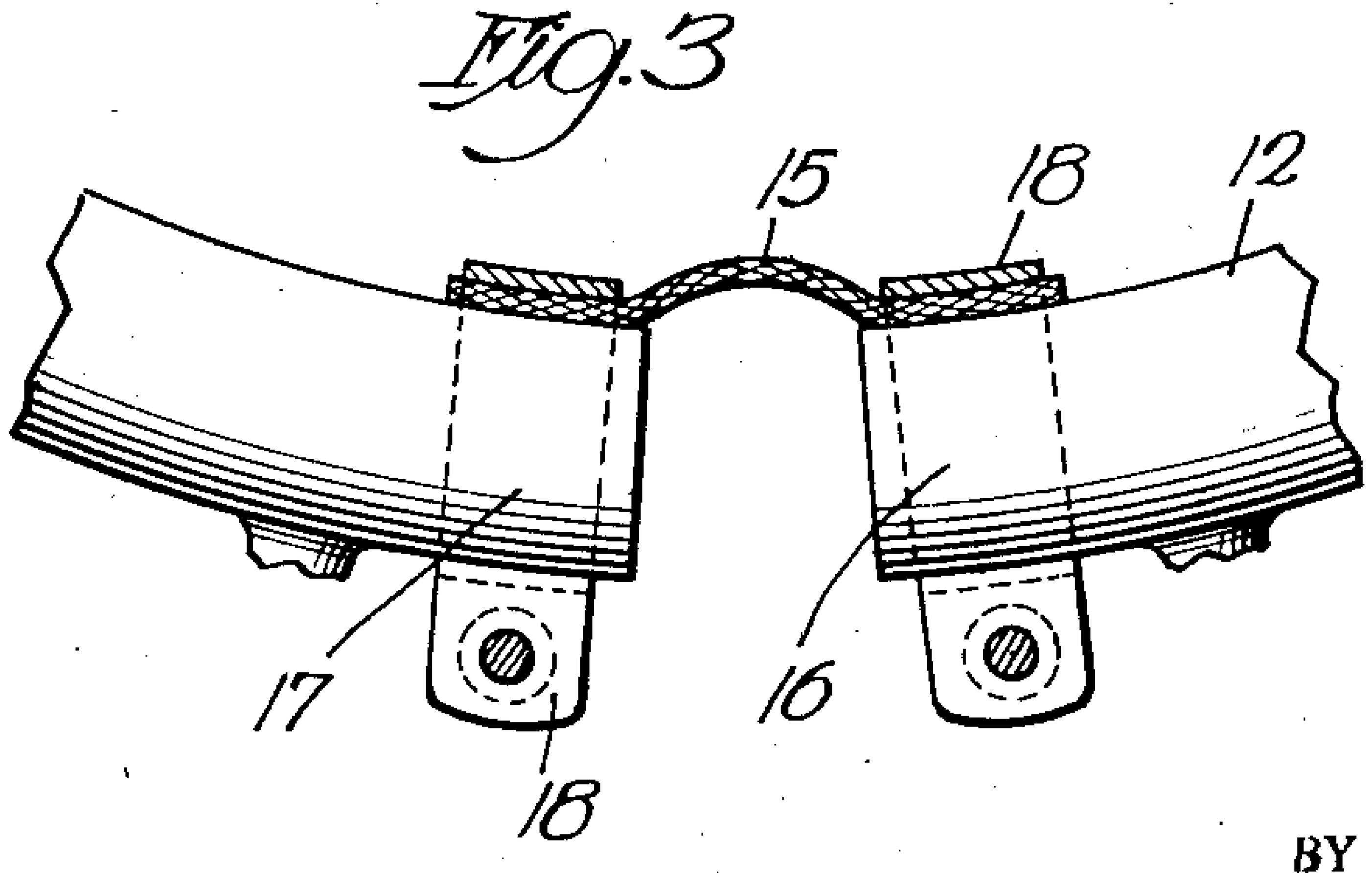


Fig. 8

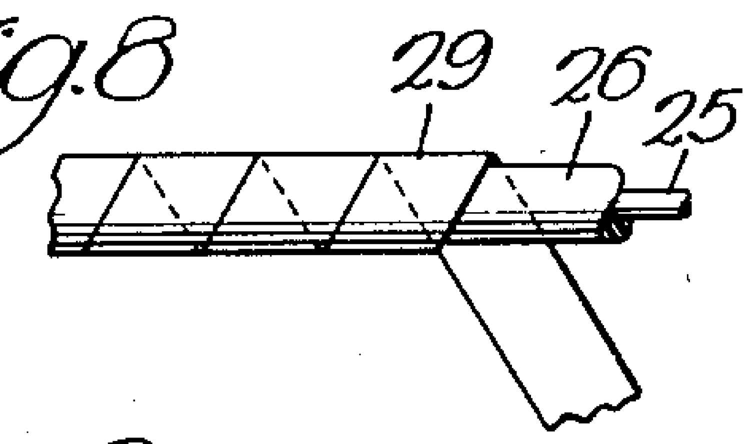
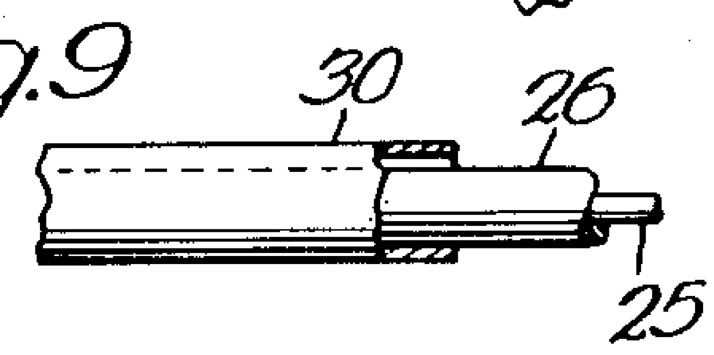


Fig. 9



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AIRPLANE IGNITION HARNESS

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12 Claims. (Cl. 123—148)

Serious, and at times disastrous, consequences may result in airplane flight with either commercial or military planes by engine stoppages which occur in electrical rainstorms. Such engine stoppages usually occur in the highly electrically charged regions, and once initiated the stoppage may persist for several minutes. When a second engine becomes so affected, the results may obviously be tragic.

Corollary to the engine stoppages, difficulties are experienced with the ignition wires which lead to the several spark plugs. Often, even on recently installed wires, the insulation will be found to be punctured in many places, the multiple punctures in some cases numbering as many as a hundred or more on a single wire, and, therefore, only short distances exist between individual punctures.

These two phenomena are closely related. Engine stoppages and multiple punctures of ignition wire are both due to high frequency electrical oscillations produced on the airplane with frequencies much higher than hitherto suspected or considered possible.

It is well known that several factors may contribute to producing electrical charges on an airplane. The atmosphere is always more or less ionized and usually unevenly so. In storm clouds highly ionized regions may develop with extremely high voltage gradients between them (and the earth) which break down electrically in the form of well known lightning strokes. Potentials of such ionized regions may reach values of several millions of volts, and the potential gradients between them at incipient break down several thousands of volts per inch.

A rapidly moving air plane, therefore, finds itself immersed in "ionic clouds" of ever changing potential and also, since it is a metallic structure, it bridges or short circuits portions of the potential gradient which would otherwise exist in the region.

In addition to these effects, there is a well known dynamic factor. As the plane passes through air containing dust or ice particles, separations of electrical charges are produced, causing the airplane to become charged. This effect is particularly pronounced for water droplets such as rain which are shattered on the forward surfaces of the airplane and especially by the propellers.

The airplane, then, is rarely in electrical equilibrium with its surroundings, and conditions are particularly aggravated in electrical rainstorms. This becomes manifest to the pilot by St. Elmo's "fire" often observed covering portions of his airplane, by electrical discharges to and from the plane (some of which punctured the rubber de-icing boots until the latter were made electrically conducting), by radio interference, by actual arc scars or burns found on propellers, and metal surfaces of the wings, etc.

It has not previously been appreciated, that the most serious effects are caused by electrical oscillations of extremely high frequency. Occasionally an airplane may be included as part of the discharge path of a full sized or complete lightning stroke. In such cases, aside from arc scars burned in the metal surfaces of the plane, no apparent disturbance is caused to the engines. This is consistent with the findings of very extensive lightning studies made on electrical transmission and distribution lines, on the Empire State Building in New York and elsewhere. In all such cases, the length of the discharge path is very long—measured in thousands of feet—and the objects struck of dimensions large or long compared to an airplane. Consequently, in such cases the electrical discharges are of comparatively low frequency or usually even unidirectional pulses.

The ordinary conditions of an airplane flying in an electrical rainstorm are quite different. Here the airplane is immersed in the very source of the trouble, and its own dimensions are relatively small. Charges are received by and discharged from the airplane in the form of "static discharges" or sparks only a few feet long often observed by the pilot and otherwise manifest by the puncturing of the de-icing boots before they were made conducting.

Electrically considered, the airplane is a very complicated shape and will oscillate electrically in very complicated wave patterns. Thus, subject to a succession of abrupt electrical shocks by the sparks or short length discharges leaving it and the continuous electrical disturbances of the propellers and wings shattering raindrops, electrical oscillations and standing waves are established. The sparks are short and the metal surfaces, mostly aluminum, are highly conducting so that there is little damping effect from resistance, and these oscillations may persist through many cycles.

That extremely high frequency oscillations and standing waves of very high voltages—and hence high energy content—actually do exist on airplanes under these circumstances, we have observed in indisputable form. Arcs have been observed passing directly across the glass windshield of the cockpit instead of taking a path around the metal frame only a few inches longer. At times arc streams several inches long may be drawn from the fingers of the pilot to various metal objects in the cockpit even though his other hand is "grounded" by contact to other metal objects. Sometimes arc streams are observed playing over the instrument panel or will pass between the end of the "elephant trunk" metal defrosting tube to the wall, or from the control wheel across to the instrument panel, etc.

The inside of a metal airplane is ordinarily considered to be a "Faraday cage" and totally shielded from external electrical effects and so it is for slow or static phenomena. However, when the oscillations reach frequencies of wave length comparable to the size of the cage or smaller, then electromagnetic fields may exist inside the cage as is well illustrated by "resonating cavities" extensively used in short wave radio. The high frequency—several megacycles—is further verified by the fact that the pilot does not receive any sensation from the arcs drawn from his fingers—certainly not a distinct shock such as is felt upon touching a radiator, metal door knob, etc., after walking over a carpeted floor. That these arcs inside the cockpit are not frictional or static electricity in the ordinary sense is further evident from the relatively long time that they persist and the high humidity conditions existing in the cockpit during a rainstorm.

Although the above described discharges observed inside the cockpit are there harmless, or at worst a nuisance, they afford indisputable evidence of high frequency phenomena on the plane as a whole which may persist for considerable periods of time and have voltages and energy contents of very serious proportions in their effects on performance of engines and ignition wires. Recent changes in the design of the ignition "harness" and what in the industry is known as a Breeze ring, but which will herein be termed a manifold ring or ring-shaped manifold, have unwittingly increased the trouble as we have noted from a study of operating records and personal observation.

On airplane engines of present design, the ignition wires from the spark plugs are led over the end of the cylinders and radially inward to the manifold ring. The several wires are therein bunched together and led to two conduits or tubes disposed parallel to the shaft leading to the two magnetos and distributor heads at the rear of the engine. The portions of the wires external to the manifold ring and spark plug housings are electrostatically shielded with braided copper wire tubes. The manifold ring itself provides the electrostatic shielding for the wires therein. The manifold ring is not a complete circle but has a gap of a few inches length at the bottom, the ends of the tube ring being there closed or capped. This ring is attached at only a few points around its circumference to a few of the cylinders by clamps. To avoid damage to the ring from vibration, it is separated from the clamps by pads or cushions of a material which usually happens to be electrically nonconducting.

Such an ignition harness although apparently adequately shielded and grounded to the engine for ordinary external electrical disturbances is by no means so for very high frequency oscillations or standing or traveling waves of short wave length. Just as the unclosed circular tube shield of the conventional shielded loop radio antenna permits magnetic induction to affect the loop inside; so does the unclosed and imperfectly grounded manifold ring permit magnetic induction from the high frequency currents on the airplane surfaces to affect the ignition wires within. Moreover, just as the metal plane itself ceases to function as a Faraday cage and permits high frequency voltages and arcs to occur within the cockpit induced from external causes, so too does the manifold ring and copper braid shielding of the ignition wires external to the manifold ring fail to shield the ignition wires within from voltages induced by very high frequency disturbances external to the shielding.

The normal breakdown voltage of the insulation on ignition wire when in good condition is about 70 to 80 kv. The sparkover voltage of the spark plugs is ordinarily about 2 or 3 kv. and never more than 5 kv. The spark plug gaps, therefore, function as protective gaps shunted across the insulation of the ignition wires. If, then, under extreme conditions, high frequency high potential electrical oscillations are induced on the ignition wires through the inadequate shielding, they may spill over the spark plug gaps. Being persistent and obviously improperly timed, such discharges cause back firing and in extreme cases almost continuous prefiring of cylinders and consequent engine stoppage or failure.

It is a well known characteristic of very high frequency currents to arc across gaps or puncture through insulation rather than take a not much longer, easier, roundabout course. This is because wave length or wave fronts are so short or steep that breakdown potential can build up at such points before relieved by a reflected wave from an easier path a short distance away. In such manner, the 60 to 80 kv. insulation may be punctured, even though apparently protected by a 2 to 5 kv. spark plug gap a short distance away or multiply punctures at new places although previously formed punctures already exist.

Whether at any particular time random or persistent discharges will be produced across the spark plug gaps, thus directly causing the engine to malfunction, or whether ignition wires will be punctured with or without indirectly causing immediate engine trouble is a matter complicated by many factors such as nature of the high frequency discharge, barometric pressure, and moisture conditions surrounding the wires, etc.

The principal object of this invention is to prevent the troubles, and generally speaking this is accomplished by using one or more of the following expedients.

Voltages induced within the manifold ring may be reduced by electrically closing the present gap at the bottom either by an electrical jumper such as a braided copper wire strap or by providing a slipover tube which can be telescoped back over one end of the ring during assembly or when access is desired. Thoroughly grounding the manifold ring to the cylinders will improve the results. This may be done by providing more clamps to more cylinders at shorter intervals around the ring and making the vibration pads electrically conducting. Alternatively, a like result may be achieved by providing short, flexible, electrical jumpers from the manifold ring to every cylinder block independent of means for mechanical attachment and support.

The most effective protection from external high frequency electrical disturbances is to be had by enclosing the entire ignition cable or wire from the magneto to the spark plug within ferrous shielding,—woven, braided or wrapped—because the magnetic ferrous material having high electrical conductivity will serve as electrostatic shielding and also because of its high magnetic permeability will operate as a distributed choke coil for the entire length of the ignition cable or wire which it covers.

This result may be accomplished by using iron or any of its magnetic alloys—ferrous material—in a wide variety of forms either as wire helically wound about the ignition cable or braided about the cable, or as tape or flexible tubing formed about the cable, or in the form of pipe. The ignition cables thus individually enclosed within a shield that so acts both with respect to electrostatic and magnetic disturbances may pass through the usual manifold ring or a manifold ring of magnetic material or a ferrous alloy of the same general character as used for enclosing the cables.

In adopting this scheme, it is not difficult to avoid undue choking of the normal electrical pulses or spark discharges furnished by the magneto while at the same time furnishing high inductive reactance to high frequency oscillations on the wires internal to the shielding. This is because of the great difference in effective frequency or rate of current change between the two. In fact, a simple calculation shows that less than 100 volts reduction or choking effect of sparking voltage will be produced in an ignition wire 5 feet long providing the effective thickness of iron shielding does not exceed ⅕ inch. However, the same wire covered with magnetic iron shielding only 1/100 inch in effective thickness would consume over 100 kilovolts of a 50 megacycle current attempting to flow on the ignition wire inside. Therefore there is a wide latitude of choice available in selecting the type and effective thickness of the magnetic shielding. 1/100 inch thickness is sufficient to perform the required magnetic shielding function; ⅕ inch or twenty times as much will not appreciably affect the normal ignition service.

It is possible to design the shielding to perform another useful function, that of assisting in dissipating the energy of the high frequency currents. By applying the shielding in the form of fine iron wire either enameled, plated, or bare, and either wrapped or braided on, the resistance can be made high to the flow of currents in the shielding lengthwise to the ignition cable. This helps to damp out high frequency currents in and on the shielding. In this manner, a form of shielding may be achieved which is more effective in preventing penetration of induced high frequency voltages into the ignition wires by both electrostatic and magnetic shielding while at the same time acting to dissipate and damp out the offending cause at the point it is most hazardous—namely on the ignition harness.

In the drawing illustrating a selected embodiment of the invention:

Fig. 1 is a diagrammatic front view of an ignition harness with parts of the engine shown in the background in dotted lines,

Fig. 2 is a partial sectional view of the lower portion of the manifold ring illustrating one way of making it into a closed circuit,

Fig. 3 is a similar view showing an alternative way of making the manifold ring into a closed circuit,

Fig. 4 is a transverse section on the line 4—4 of Fig. 1, showing one way of mounting the manifold ring on the crank case,

Fig. 5 is a longitudinal section on the line 5—5 of Fig. 4, showing a metallic bridge across the anti-vibration cushioning within the manifold ring clamps,

Fig. 6 is a diagrammatic illustration of the ferrous shield on a portion of ignition cable, the shield being in the form of a helix,

Fig. 7 is a similar view with the ferrous shield braided over the insulation of the electric cable,

Fig. 8 is a similar view with the ferrous shield shown as a thin ribbon or tape wound in a helix about the insulated cable, and

Fig. 9 shows the ferrous shield in the form of a tube through which the cable is run.

But these illustrations and the corresponding description are for the purpose of disclosure only and are not intended to put unnecessary limitations on the claims.

In Figure 1 engine cylinders 10 are indicated about a crank case 11 on the front of which is a Breeze ring 12 shown as a circular piece of tubing within which a portion of the ignition cables 13 is enclosed. In the ordinary construction the manifold ring is electrically and magnetically open at the lower side by a considerable gap, which, in the case of this invention, is closed by a sleeve 14 (Fig. 2), or a braided or other flexible conductor 15 (Fig. 3). In the illustration shown in Figure 2, the closure for the manifold ring is a piece of tubing telescoped over its adjacent ends 16 and 17 which may be made fast in any approved mechanical manner.

In Fig. 3 the connector is made of a length of braided cable secured to the adjacent ends 16 and 17 of the manifold ring by clamps 18. But again any appropriate mechanical means will serve instead of the clamps.

As shown in Figures 4 and 5, the manifold ring is made fast to and supported upon the crank case by clamps 19 which should be of goodly number in order to provide ample electrical and magnetic connection between the manifold ring and the crank case.

Ordinarily insulating material is inserted between the clamp and the manifold ring with the result that the latter is insulated from rather than connected with the crank case. According to this invention, the cushioning material is bridged by sufficient metal to provide actual and sufficient electrical connection between the manifold ring and crank case. As shown, the clamp 19 surrounds a sleeve of cushioning material 20 made of some composition of rubber or the like and this sleeve is spanned by a hairpin shaped strip of metal 21, one arm 22 of which is clamped against the manifold ring and the other arm 23 of which is gripped by the clamp which in turn is made fast to the crank case by the studs 24. Thus it will be seen that good electrical connection is established between the hairpin shaped strip of metal and the manifold ring on one side and the clamp on the other so that there is low resistance, etc., between the manifold ring and the crank case. This, of course, is only an illustrative construction and engineers will readily design other devices for making the manifold ring fast and securing the proper electrical connection.

In Fig. 6, the ignition wire 25 is shown enclosed within insulation 26, and, that in turn is enclosed within a helix 27 of ferrous wire. That wire may be of any appropriate magnetic alloy, enameled, plated or bare. The effectiveness of the helix 27 will be increased by having the adjacent convolutions in substantial contact for that serves the main purpose of providing impedance to the induction caused by high frequency electrical disturbances.

In Figure 7, the helix 27 is replaced by the braided ferrous wire 28. In Figure 8, the helix is formed by tape or ribbon 29, and, in Figure 9, the ferrous shielding takes the form of a tube 30.

From mechanical considerations the magnetic material should have reasonable resistance to abrasion and vibration without being so hard as to adversely affect its magnetic properties. For convenience in application in the form of wire either wrapped on or braided, the wire size chosen would be relatively small in diameter; say 5 to 10 mills in diameter and applied to a total effective thickness of approximately 10 mils which is adequate to provide sufficient damping impedance to the high frequency induction. However, the effective thickness of magnetic coating can exceed this thickness without adversely affecting its normal functions to ignition impulses, and, if in the form of a tube or magnetic manifold ring, may have a thickness not exceeding ⅛". If magnetic material selected on the basis of magnetic properties is not sufficiently resistant to corrosion, corrosion resistance may be attained by plating or other coating on the wire or tubing.

Since, in addition to the materials mentioned, nickel, cobalt, carbon steels, many "alloy" steels, alloys of manganese with aluminum and copper and alloys of manganese with bismuth are magnetic, the terms used herein for material should be interpreted broadly.

As the form of the shielding will depend somewhat on choice and somewhat on fitness to the chosen material, the terms should be construed broadly as to the form in which the shield is embodied.

We claim:

1. Means for protecting insulated ignition wires of airplane engines from high frequency induction, including a continuous ring-shaped metal manifold enclosing the wires and forming a closed circuit.

2. Means for protecting insulated ignition wires of airplane engines from high frequency induction, including ferrous shields of magnetic material enclosing each of the insulated wires separately.

3. Means for protecting insulated ignition wires of airplane engines from high frequency induction, including inductive ferrous wire shields and a continuous ring-shaped metal manifold enclosing the insulated wires, and means for forming an electrical connection between said manifold and engine.

4. Means for protecting insulated ignition wires of airplane engines from high frequency induction, including ferrous wire shields enclosing the insulated wires.

5. Means for protecting insulated ignition wires of airplane engines from high frequency induction, including ferrous shields enclosing the insulated wires, and a continuous ring shaped ferrous manifold enclosing portions of the insulated wires.

6. Means for protecting insulated ignition wires of airplane engines from high frequency induction, including separate magnetic and electrostatic shielding about each of the insulated wires.

7. In an airplane engine having cylinders and insulated ignition wires, means for protecting those wires, including a continuous ring-shaped metal manifold enclosing portions of them, and numerous low resistance electrical connections from the manifold to the engine.

8. In an airplane engine having cylinders and insulated ignition wires, means for protecting the wires, including a continuous ring-shaped metal manifold for enclosing portions of them, and means to mount the manifold on the engine, including electrically conducting pads.

9. In an airplane engine having a cylinder and an insulated ignition wire, a distributed choke coil on the ignition wire consisting of a continuous housing of magnetic material.

10. In a radial airplane engine having a metal manifold extending around the axis of the engine and containing high tension ignition wires, said manifold having its ends close together, the improvement which consists of a direct electrical connection between the adjacent ends of the manifold.

11. In a radial airplane engine having a metal crankcase, a metal manifold extending around the axis of said crankcase and having its ends close together, resilient means for supporting said manifold on said crankcase, and high tension ignition wires in said manifold, the improvement which consists of a direct electrical connection between the adjacent ends of the manifold and independent of said crankcase and said supporting means.

12. In an airplane engine having a high tension ignition wire, the improvement which consists of magnetic material enclosing said high tension ignition wire over its entire length and increasing its distributed inductance.

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