June 29, 1943. M. F. PETERS 2,322,773

ELECTRICAL CONDUCTORS

Filed July 28, 1941

Fig. 1.

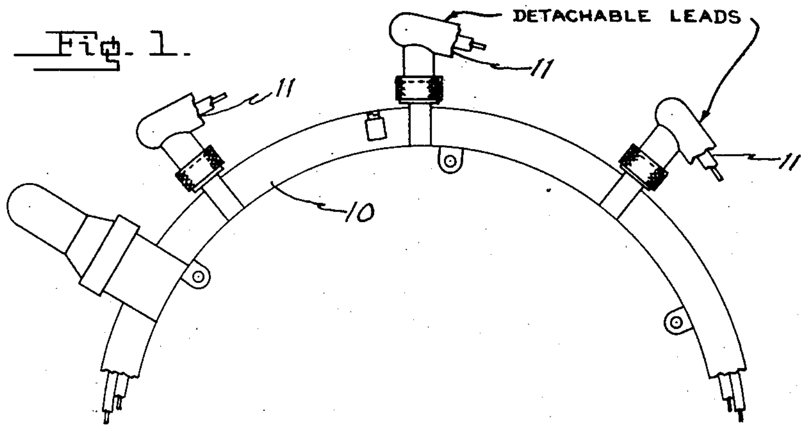


Fig. 2.

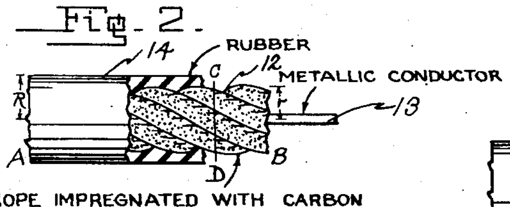


Fig. 5.

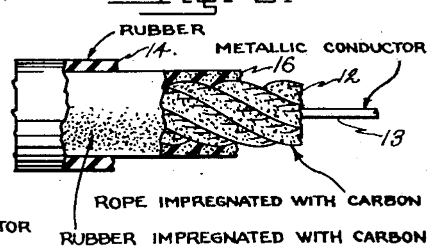


Fig. 3.

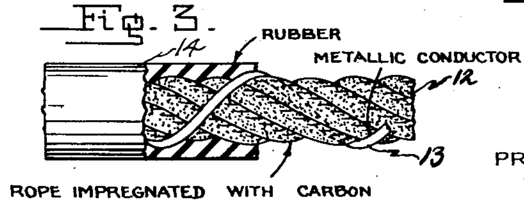


Fig. 6.

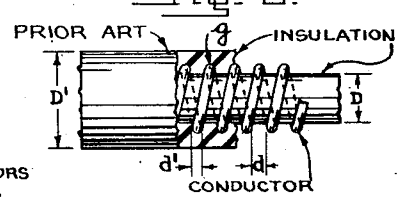
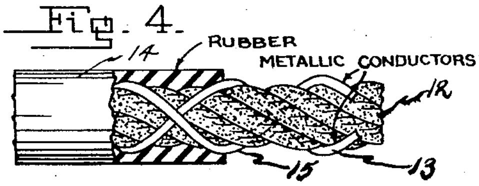


Fig. 4.



INVENTOR
Melville F. Peters
BY
K. C. Caldwell
ATTORNEY

Patented June 29, 1943

2,322,773

UNITED STATES PATENT OFFICE

2,322,773

ELECTRICAL CONDUCTOR

Melville F. Peters, Beltsville, Md.

Application July 28, 1941, Serial No. 404,281

11 Claims. (Cl. 174—119)

(Granted under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)

This invention relates to improvements in electrical conducting cables, particularly high tension cables adapted to conduct currents of relatively large magnitudes for a very short period, or to conduct relatively small magnitude currents for an appreciable period. In other words the coulomb capacity of the type of cable to which this invention relates is relatively small. The high tension cables constructed in accordance with this invention may be useful generally in the art but are particularly adapted for use in an ignition circuit of an internal combustion engine.

When a radio receiving apparatus is carried by a vehicle driven by an internal combustion engine, the ignition system of the engine sets up certain electrical oscillations which interfere considerably with the reception of the radio signal in the receiving apparatus. In the prior art, in order to prevent or at least decrease the interference caused by the ignition system, it has been the practice to shield the entire ignition system. This is usually accomplished by surrounding the ignition system with a metallic shielding harness. The use of such a shielding harness has been effective in eliminating the interference caused by the lower frequency oscillations, but it has not proven to be a very successful means for preventing interference from the oscillations having an ultra short wave length.

In order to prevent these ultra short wave length oscillations from interfering with the radio reception I propose to use a high resistance cable in that portion of the ignition circuit where these oscillations occur, the value of cable resistance being properly selected so that these oscillations will be damped out.

It should be understood that the cable of my invention is not limited for use only in combination with a shielding harness, because the total resistance of a cable designed in accordance with my invention may be selected so that the prior art high resistance elements commonly termed "suppressors" which are frequently used to damp out interfering oscillation set up in non-shielded ignition system would no longer be required. No one in the prior art has to my knowledge disclosed a practical ignition cable construction which could be designed to have a resistance equivalent to the resistance of these "suppressor elements," except perhaps for the prior art construction illustrated in the drawing accompanying the specification.

In this prior art construction the fine metallic conductor is wound about some insulating core so that the windings are close enough together to prevent the electrical gradient in the insulation which is in contact with the conductor, from becoming excessive. For example in Fig. 6 in the drawing accompanying this specification which has a legend "Prior art," if the distance *d* is zero and adjacent turns are in contact, the electrical gradient at *g* will not be excessive if the gradient for a solid conductor of a diameter D is not excessive. As the distance *d* is increased, however, the gradient at *g* is also increased and approaches the value which a single insulated conductor of the diameter *d'* would have.

This prior art construction can be used as a conductor for high tension ignition cables only by making the distance *d* small enough to prevent an excessive gradient in the insulation. The capacitance would, however, be too large for an efficient design, if the diameter *d* of the conductor were made large enough to prevent the resistance from becoming excessive. The conductors must be wound very close together in order to keep the gradients small, consequently a large number of turns is required and the resistance per unit length must be large. The diameter of the conductor and the capacitance of the cable would then be larger than desired in the preferred design.

It is thus apparent that I have devised a new cable construction the use of which eliminates the necessity of the prior art "suppressor elements" in either shielded or unshielded ignition systems. In all of the prior art ignition cables of which I have knowledge except that referred to above, the metallic conductor must be strong enough to give the cable sufficient mechanical strength so that it may be drawn into a conduit and support itself in service. Therefore, the resistance of the cable cannot be increased without decreasing the cross-sectional area of this metallic conductor and consequently the mechanical strength of the cable.

I have found and previously disclosed in my prior patent, No. 2,058,619, that a high resistance cable is not only desirable as a radio interference prevention means, but is also desirable from the standpoint of efficient spark plug operation, since the high resistance of the ignition cable reduces the intensity of the current in the spark, causing less wear on the spark plug electrodes.

The present invention aims, therefore, to provide a practical conductor which will have a sufficient resistance in the relative short length of cable that is usually required in an ignition circuit to damp out the interfering waves, and at the same time retain sufficient mechanical strength in the cable to withstand the mechanical and electrical stresses to which these cables are subjected.

It is therefore a specific object of this invention to provide a cable with a composite conductor, the resistance of which is greater than that of any known metallic conductor having an equivalent cross-sectional area, the composite conductor being made up of a conductive reinforcing member and a metallic member. The conductivity of the metallic member is greater than the conductivity of the reinforcing member, but the reinforcing member has the greater mechanical strength.

It is also an object of this invention to provide an insulated high tension cable in which the cross-sectional area of the metallic conductor is limited solely by its current carrying capacity and may be reduced to a minimum without increasing the electrical stresses in the insulation above certain allowable limits, and without decreasing the mechanical strength of the entire cable or increasing its over-all diameter.

It is well known that if the electromotive intensity at any point in a dielectric is increased a limit is reached at which there is a sudden electrical discharge through the dielectric. The electromotive intensity at which this rupture takes place is a measure of the electric strength of the dielectric. The electric strength of the various materials used as insulators for cables is known, but nevertheless, the electromotive intensity in the dielectric must be taken into consideration in the design of a high tension, high resistance cable since it has been shown that the voltage which is required to break down a given insulation depends upon two factors, (1) the electrical strength of the dielectric and (2) the distribution of the electrical stress in the dielectric.

When a conductor is insulated by surrounding it with a homogeneous dielectric the stress is the greatest at the surface of the conductor and less on the outer layers of insulation. The electric stress at any point in the dielectric may be computed by means of the formula

$$F=\frac{E}{r_x \log_e \frac{R}{r}}$$

where R is the outer radius of the insulation, r the radius of the conductor, and r_x the distance from the center of the conductor to the point where the dielectric stress is F when the electromotive force between the conductor and the outer sheath of the cable is equal to E.

The maximum value of F is given when r_x is equal to r, or in other words, the dielectric stress and the flux density is greatest at the surface of the conductor. If the applied voltage remains constant and the outside diameter of the insulation also remains constant, the inner radius of the conductor may be varied to a point wherein the flux density and the dielectric stress is a minimum. This is shown to occur when r is equal to

$$R\times\frac{1}{e}$$

where e is the natural logarithmic base equal to 2.718+. Therefore, in order to secure the most favorable (maximum) stress conditions, the ratio of outer to inner radii of the insulation should not exceed 2.718+.

I do not necessarily propose in my cable design to maintain this exact ratio of R to r because it may also be desirable to provide a cable which will have a low capacitance, high resistance and safe electrical gradient in the insulation. I have found, and previously disclosed in my prior Patent No. 2,151,715, that the ignition cable of minimum capacitance is the cable with a conductor of the smallest possible diameter consistent with safe potential gradients in the dielectric and required mechanical strength. I have also found that the optimum ratio of the radius of conductor to the radius of the cable is equal to $1/e^2$, in which e is the Napierian or natural logarithmic base.

Since it is an object of this invention to obtain a high resistance cable by reducing the cross-sectional area of the metallic conductor, the dielectric stress at the surface of the metallic conductor would obviously be increased, and the diameter of insulating material would also be increased if it were to withstand the increase in stress.

It is, however, also an object of this invention to keep the overall diameter of the cable as small as possible or within certain allowable limits. Therefore, in order to obtain the objects of the invention a new conductor capable of meeting the requirements as to resistance and mechanical strength is required.

It has been the practice in the prior art, from the standpoint of economy and cable flexibility, to keep the diameter of the conductor and the diameter of the cable at a minimum, the diameter of the conductor being limited primarily by mechanical strength and electrical gradient requirements of the cable.

There are two general methods employed in the prior art whereby the cable diameter may be maintained at a minimum without increasing the diameter of the expensive, inflexible metallic conductor. First, the cable may be graded either by grading the capacity of the inner layers of insulation or by inserting metallic layers between the layers of insulation. Such cables have been designed giving a reduction in cable volume of more than one quarter that which would normally be required to withstand the dielectric stresses for the particular size conductor if a non-graded cable had been used. The patent to Silberman, 1,701,278 may be cited as illustrating this type of cable. A second method proposed by the prior art is illustrated by the patent to Sievert et al., 1,656,329, wherein it is proposed to make the layers of insulation adjacent the metallic conductor slightly conductive by impregnating said layers with graphite, carbon black or other such conductive material.

All of these prior art teachings are lacking in one particular feature which is of the utmost importance in the design of ignition cables for aircraft engines. In each of these cables the metallic conductor is the member which gives the cable its mechanical strength, and the cable resistance cannot be increased without decreasing the mechanical strength of the cable. Furthermore, since it is the primary object of this invention to reduce the size of the metallic conductor to an absolute minimum, some additional strength giving means must be provided in the cable. Accordingly, therefore, the significant feature of this invention is in the provision of a composite conductor which is made up of a strength giving member and a metallic conductive member. The strength giving member is also made conductive by being impregnated with a conducting material so that there will be substantially no voltage gradient across its cross-sectional area, but its lineal resistance will be higher than the resistance of any known metallic conductor having an equivalent cross-section or of equivalent mechanical strength. Since the entire cable core is conductive the radius of the composite conductor is the radius r in the formula set forth above. This radius can be maintained large enough to maintain the optimum ratio of radii for the condition of minimum electric stress in the dielectric and at the same time secure the required resistance and mechanical strength.

The invention will be more clearly understood from the following description with reference to the accompanying drawing in which:

Fig. 1 is an elevational view of a portion of shielded ignition circuit showing the detachable secondary leads;

Fig. 2 is a cross-sectional elevational view of the composite conductor of this invention;

Fig. 3 is a cross-sectional elevational view of a modification showing a metallic conductor of greater length than the metallic conductor of Fig. 1;

Fig. 4 is a cross-sectional view of a further modification showing a plurality of conductors wrapped about the reinforcing member;

Fig. 5 is a cross-sectional elevational view of a further modification showing impregnated insulating material surrounding the composite conductor; and

Fig. 6 is a cross-sectional view of a prior art construction.

Referring now to the drawing, there is illustrated in Fig. 1 a form of shielded ignition circuit showing an ignition manifold, indicated generally at 10 with shielded leads 11 detachable therefrom. In this circuit the detachable leads are constructed in accordance with the features hereinafter described and forming the essence of this invention.

The preferred form of my invention is illustrated in Fig. 2. The strands of the fibrous rope or cord 12 are wound about a fine metallic conductor which is indicated at 13 on the drawing. The fibrous rope or cord 12 has been made conductive by being impregnated with carbon or other poor conductive material. As an alternative structure, the rope or cord may be constructed of fibrous glass and made conductive by applying a coating of conductive enamel over its surface. The resistance of the carbon, impregnated cord, rope, or the enameled fiber glass is high enough so that little or no current will be conducted from A to B but is also low enough so that there is substantially no voltage gradient across any section C—D. The radius of the conductor r in the equation

$$F_{max.} = \frac{E}{r \log_e \frac{R}{r}}$$

is the radius of the carbon soaked cord or enameled fiber glass, instead of the radius of the very fine resistance wire 10 which may have a diameter of about one one-thousandth of an inch (.001''). A suitable insulating material 14 having a radius R is formed about the composite conductor.

It should be borne in mind that the size of the wire 13 is determined by the particular coulomb capacity desired, no other restrictions in design need be imposed upon the selection of the size of this wire.

For example, when the cable is used to form a portion of the secondary circuit of an ignition system, such as a detachable lead, as illustrated in Fig. 1, the peak currents conducted by this cable may be of the order of 80 amperes or more. The duration of this peak current is, however, only about one millionth of a second. This current alternates at a frequency of about 7×10^6 cycles per second and has an amplitude which decreases exponentially with time. In other words the oscillations are damped. The factor

$$e^{\frac{-Rt}{2L}}$$

wherein e is natural logarithm base, R the resistance, t the time, and L the inductance, accounts for the decrease in amplitude and R/2L is known as the damping factor. Since R is large when compared to L the amplitude is rapidly damped and the average current for the entire ignition period may be only a few amperes (from 3 to 5 for example). Furthermore, since the circuit is nearly aperiodic, as will be evidenced later, the coulomb capacity of the cable need not be large.

Where a high resistance is desirable as a radio interference prevention means to damp out the wave lengths which are short compared to the length of the harness, the resistance of the cable may be as great or greater than

$$R=2\sqrt{\frac{L}{C}}$$

If the value of resistance is greater than or equal to

$$2\sqrt{\frac{L}{C}}$$

the oscillations in the transient state are rapidly damped out. The lower limit of resistance for a cable which is to be used in combination with radio interference prevention means should be set at this value although reduction in spark plug wear is obtained with a higher resistance.

One of the important features of this invention resides in the fact that each increment of length of cable is made aperiodic, i. e. for increment of length Δl; ΔR the resistance of the increment length of cable Δl is equal to or greater than

$$2\sqrt{\frac{\Delta L}{\Delta C}}$$

wherein ΔL is the inductance and ΔC the capacitance of the same increment length of cable. The upper limit of resistance occurs only when the time constant becomes an appreciable factor in considering the total energy transferred. The time constant of a circuit containing resistance and capacitance is equal to the product of the resistance and the capacitance or $R\times C$. Therefore, if the capacitance can be reduced by reducing the size of the conductor, the resistance may be accordingly increased without having the time constant so large that the cable would be inefficient as an energy transmitting means.

If a higher resistance is desirable in a comparatively short length of cable, the fine wire 13 may be woven within or wrapped about the fibrous cord 12 as indicated in Fig. 3. This particular modification has a further advantage over the construction illustrated by Fig. 2, in that the metallic wire is less likely to be stretched beyond the breaking point. The longitudinal deformation or elongation of the fibrous material for a given applied tensile stress (lbs./in.^{2}) is greater than the elongation of the metallic conductor under an equivalent tensile stress. Therefore, under excessive stresses the metallic conductor may be stretched beyond the rupture point if the longitudinal deformation of the metallic conductor is to remain equal to the longitudinal deformation of the fibrous cord. In the modification illustrated in Fig. 3, however, the conductor may be woven in the fibrous cord so that it will have a slight movement relative thereto, and will be merely straightened out without being excessively stretched as the fibrous cord is elongated by excessive stresses, irrespective of any relative movement between conductors since the metallic wire is of a length greater than that of the fibrous cord and the deformation (per unit length) if uniform may not be excessive even though the elongation in the cord would subject a metallic wire of equivalent length to excessive stresses, provided it were elongated an amount equivalent thereto.

The disadvantage in the use of this particular modification is that the wrapped or woven conductor produces what may be considered as an undesirable magnetic field. To eliminate this magnetic field a second conductor 15, as shown in Fig. 4, is wrapped about or woven within the fibrous cord in the reverse direction. This additional conductor will, however, decrease the resistance of the cable.

If present known alloys were to be used in place of the composite conductor, the maximum resistance desired in this type of cable for use in radio interference prevention could not be attained, since the limit to which the conductor diameter could be reduced without decreasing the mechanical strength below a certain limiting value would be reached before the conductor resistance per unit length would be sufficiently high. Furthermore the potential gradient would be increased beyond the permissible values. This is, however, of secondary importance since other methods in the art to which reference has been made in this specification may be used to prevent these excessive dielectric stresses. Under this invention, however, by suitable design the strength of the cord can be made great enough to supply the needed mechanical strength and no limit need be placed upon its size and resistance except as otherwise stated herein.

Fig. 5 illustrates a further modification wherein a portion 16 of the insulating material 14 may be made conductive by being impregnated with carbon or the like. The conductor is made up of carbon impregnated rope or cord 12 and the fine metallic wire 13. The rope or fibrous material gives the cable sufficient mechanical strength, whereas the impregnated insulating material 15 prevents excessive gradients in the insulation 14 surrounding the cable.

Other modifications and changes in the number and arrangement of the parts may be made by those skilled in the art without departing from the nature of the invention, within the scope of what is hereinafter claimed.

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

I claim:

1. A high tension electrical conducting cable for use in a shielded ignition circuit for damping out electric oscillations having ultra short wave lengths, the combination including a composite conductor comprising a reinforcing member and a fine metallic wire, the reinforcing member having a greater mechanical strength than said metallic wire, said reinforcing member comprising a twisted fibrous cord member impregnated with a conducting material so as to have substantially no voltage gradient throughout its cross-sectional area but at the same time having a resistance greater than the resistance of any metallic member of equivalent cross-section, or equivalent mechanical strength, the diameter of the metallic wire being selected so that the total resistance of the composite conductor may be sufficient to damp out the high frequency oscillations, and an insulating covering for said cable, the ratio of the outer diameter of said conductor to the outer diameter of said insulating covering being equal to $1/e^2$ wherein e is the natural logarithmic base.

2. A high tension electrical conducting cable having a composite conductor comprising a reinforcing member, and a metallic conductive member, said reinforcing member comprising a twisted fibrous cord member of high mechanical strength, said cord member being impregnated with a conductive material, the diameter of the conductor being selected so that the cable will have sufficient resistance to damp the electric oscillation in the conductor, and an insulating covering for said composite conductor, the ratio of the outer diameter of said composite conductor to the outer diameter of said insulation being equal to $1/e^2$ wherein e is the natural logarithmic base.

3. A high tension electrical conducting cable adapted for use in an ignition circuit to prevent radio interference, having a composite conductor comprising a twisted fibrous cord member impregnated with conductive material and a metallic member, the conductivity of the metallic member being greater than the conductivity of the cord member, but of a lesser mechanical strength, and an insulated covering for said composite conductor.

4. In a composite electric cable, the combination comprising a metallic conductor member and a flexible non-metallic member, said flexible member being impregnated with conductive material, and being disposed in electrical contact with said metallic member but having an electrical resistance per unit length substantially higher than said metallic member, said flexible member constituting the principal element opposing elongation of said cable when subjected to longitudinal stresses to prevent rupture of said metallic conductor.

5. In a cable having an insulated composite conductor, the combination comprising a central metallic conductor, a twisted cord member overlying said central member and in contact therewith, said cord member being impregnated with conductive material but having an electrical resistance per unit length substantially higher than said metallic conductor, and an insulating sheath overlying said cord member, said cord member constituting the principal element opposing elongation of said cable when subjected to longitudinal stresses to thereby prevent rupture of said metallic conductor.

6. In a cable having an insulated composite conductor, the combination comprising a central metallic conductor, a twisted cord member overlying said central member and in contact therewith, said cord being impregnated with conductive material but having an electrical resistance

per unit length substantially higher than said metallic conductor, said cord member constituting the principal cable element opposing elongation of said cable when subjected to longitudinal stresses to thereby prevent rupture of said metallic conductor, and an insulating sheath overlying said cord member, the ratio of the diameter of the cord member to the outer diameter of the insulating sheath being equal to $1/e^2$ wherein e is the natural logarithmic base.

7. In the secondary circuit of an ignition system having a shielding harness, a cable therefor comprising a metallic conductor, a twisted cord member overlying said metallic conductor, said cord member being impregnated with conductive material but having an electrical resistance per unit length substantially higher than said metallic conductor, said cord member constituting the principal element of said cable resisting longitudinal stresses applied thereto to prevent rupture of said metallic conductor and an insulating sheath overlying said cord member, the ratio of the diameter of said cord member to the outer diameter of the insulating sheath being equal to $1/e^2$ wherein e is the natural logarithmic base, and the resistance of each unit length of cable Δl being equal to or greater than

$$2\sqrt{\frac{\Delta L}{\Delta C}}$$

wherein ΔL is the inductance and ΔC is the capacitance respectively for each unit cable length Δl.

8. A high tension electrical conducting cable adapted to be used as a detachable lead in a portion of a shielded ignition circuit comprising a composite conductor including a reinforcing conductive twisted fibrous cord member and a metallic conductive member, the resistance of each increment length of cable Δl being equal to or greater than

$$2\sqrt{\frac{\Delta L}{\Delta C}}$$

wherein ΔL is the inductance and ΔC the capacitance for each increment of length Δl whereby each increment of cable length is made aperiodic.

9. In a composite electric cable, a central twisted cord member impregnated with conductive material, a metallic conductor disposed in a helix and in electrical contact with said cord member, the electrical resistance per unit length of said cord member being substantially higher than said metallic conductor, said cord member constituting the principal element opposing elongation of said cable when subjected to longitudinal stresses, and an insulating sheath overlying said metallic conductor.

10. In a cable, a central twisted cord member impregnated with conductive material, a metallic conductor disposed in a clockwise progressive helix about said cord member and in contact therewith, a second metallic conductor disposed in a counter-clockwise helix about said cord member, the electrical resistance of said cord member per unit length being substantially higher than the electrical resistance of said metallic conductors connected in parallel, said cord member constituting the principal element opposing elongation of said cable when subjected to longitudinal stresses, and an outer insulating sheath surrounding said metallic conductors.

11. In a cable, the combination comprising a central metallic conductor, a twisted cord member overlying said central member and in contact therewith, said cord member being impregnated with conductive material but having an electrical resistance per unit length substantially higher than said metallic conductor, said cord member constituting the principal element opposing elongation of said cable when subjected to longitudinal stresses to thereby prevent rupture of said metallic conductor, a rubber sheath overlying said cord member, said sheath being impregnated with conductive material but also having an electrical resistance per unit length substantially higher than said metallic conductor, and an insulating sheath overlying said impregnated rubber sheath.

MELVILLE F. PETERS.