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(54) Title: WEAR PROTECTION FEATURE FOR CORONA IGNITER

(57) Abstract: A corona igniter (20) comprises an electrode with a central extended member (22) extending along a cen-
tral axis (A) and a crown (34) extending radially outwardly from the central extended member. The central extended
member has an extended length (le) and the crown has a crown length (lc). The extended length is greater than the
crown length such that the extended member approaches a piston more closely than the crown. In addition, the firing
tips of the crown each present a first spherical radius which is less than a second spherical radius of the central extended
member. Thus, if arcing occurs, it forms from the central ex-
tended member, rather than from the crown. Accordingly, the firing tips of the crown experience less wear and remain
sharp. In addition, due to the sizes of the spherical radii, corona discharge is more likely to form from the firing tips
than from the central extended member.

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WEAR PROTECTION FEATURE FOR CORONA IGNITER

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Patent Application number 61/799,117, filed March 15, 2013, the entire contents of which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0002] This invention relates generally to a corona igniter for emitting a radio frequency electric field to ionize a fuel-air mixture and provide a corona discharge, a corona discharge ignition system, and methods of manufacturing the same.

2. Related Art

[0003] A corona igniter of a corona discharge ignition system receives a voltage from a power source and emits an electrical field that forms a corona to ionize a mixture of fuel and air of an internal combustion engine. The igniter includes an electrode extending longitudinally form an electrode terminal end to an electrode firing end. An insulator is disposed along the center electrode, and a shell is disposed along the insulator.

[0004] The electrode terminal end receives the voltage from the power source and the electrode firing end emits the electrical field that forms the corona. The electrode of the corona igniter may also include a crown at the firing end for emitting the electrical field. The electrical field includes at least one streamer, and typically a plurality of streamers forming the corona. The mixture of air and fuel is ignited along the entire length of the high electrical field generated from the electrode firing end. An example of a corona igniter is disclosed in U.S. Patent Application Publication No. US 2010/0083942 to Lykowski et al.

[0005] In an ideal corona ignition system, the corrosion and/or erosion of the metallic parts of the corona igniter in the combustion chamber is low since a corona
discharge does not have the high current and high temperatures associated with the discharge of a conventional spark. Although the corona igniter does not include any grounded electrode element in close proximity to the firing tips of the crown, in some applications, there are grounded engine components that come close to the firing tips. Accordingly, it is not always possible to avoid an arc formation, also referred to as arcing, between the corona igniter and grounded component. If an arc forms, the high current and temperatures associated with the arc formation could cause some erosion and/or corrosion damage to the firing tips of the crown. Overtime, the erosion and/or corrosion damage could decrease the quality of corona formation and combustion.

SUMMARY OF THE INVENTION

[0001] One aspect of the invention provides a corona igniter comprising an electrode extending along a central axis for emitting an electrical field that forms a corona, an insulator formed of an electrically insulating material disposed around the electrode and extending along the central axis to an insulator firing end, and a shell formed of a metal material disposed around the insulator. The electrode includes a central extended member extending longitudinally along the central axis to a central firing end. The electrode also includes a crown disposed outwardly of the insulator firing end. The crown includes at least one branch extending radially outwardly of the central extended member. The crown also extends along the central axis from a top surface to at least one firing tip. The crown presents a crown length between the top surface and the at least one firing tip, and the central extended member presents an extended length extending from the top surface of the crown to the central firing end. The crown length and the extended length are parallel to the central axis. The extended length presented by the central extended member is greater than the crown length presented by the crown.
Another aspect of the invention provides a corona discharge ignition system including the corona igniter with the extended length greater than the crown length. The system includes a cylinder head presenting an opening for receiving the corona igniter, a piston disposed opposite the cylinder head and presenting a space therebetween, and a cylinder block connected to the cylinder head and surrounding the piston. The cylinder head, cylinder block, and piston present a combustion chamber therebetween. The corona igniter is position in the opening of the cylinder head such that the central firing end of the central extended member and the crown are disposed in the combustion chamber.

Yet another aspect of the invention provides a method of manufacturing the corona igniter for use in the corona discharge system including the step of providing the central extended member so that extended length is greater than the crown length.

The corona igniter including the central extended member with the extended length greater than the crown length provides several advantages over comparative corona igniters without the central extended member. When a grounded component, such as the piston, comes close to the central firing end of the central extended member and the firing tips of the crown, if any arc forms, it will preferentially form between the piston and central firing end of the central extended member due to the extended length of the central extended member, its proximity to the grounded component, and hence its higher field strength, compared to the firing tips of the crown. Therefore, if arcing does occur, corrosion and erosion damage to the firing tips of the crown is reduced.

Furthermore, in situations where the grounded components are far from the corona igniter, the central extended member tends to repel the corona streamers as they form, thereby providing a wider volume of corona discharge and reducing the tendency of the corona discharge to approach the piston and form an arc.
BRIEF DESCRIPTION OF THE DRAWINGS

[0006] Other advantages of the present invention will be readily appreciated, as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

[0007] Figure 1 is a cross-sectional view of a portion of a corona igniter according to one exemplary embodiment of the invention;

[0008] Figure 1A is a bottom view of a crown of the corona igniter of Figure 1;

[0009] Figure 1B is an enlarged view of a central extended member and the crown of the corona igniter of Figure 1;

[0010] Figure 1C is an enlarged view of a firing tip of the crown of the corona igniter of Figure 1 showing a first spherical radius;

[0011] Figure 1D is an enlarged view of a central firing end of the central extended member of the corona igniter of Figure 1 showing a second spherical radius;

[0012] Figures 2-11 are cross-sectional views of portions of corona igniters according to other exemplary embodiments of the invention;

[0013] Figure 12A is a cross-sectional view of a corona discharge ignition system including the corona igniter of Figure 1 when the corona igniter is spaced from a piston;

[0014] Figure 12B is a cross-sectional view of the corona ignition system including a comparative corona igniter, without the central extended member of the present invention, when the comparative corona igniter is spaced from the piston by the same distance as the corona igniter of Figure 12A;

[0015] Figure 13A is a cross-sectional view of the corona ignition system including the corona igniter of Figure 1 when the corona igniter is close to the piston;
[0016] Figure 13B is a cross-sectional view of the corona ignition system including the comparative corona igniter of Figure 12B when the comparative corona igniter is in the same position as the corona igniter of Figure 13A;

[0017] Figure 14A is a Finite Element Analysis (FEA) of a corona igniter according to another exemplary embodiment of the invention providing a corona discharge when the corona igniter is disposed a distance from a piston;

[0018] Figure 14B is FEA of a comparative corona igniter providing a corona discharge when the comparative corona igniter is disposed the same distance from the piston as the corona igniter of Figure 14A;

[0019] Figure 15A is a FEA of the corona igniter of Figure 14A providing a corona discharge when the corona igniter is disposed at a typical location of ignition;

[0020] Figure 15B is a FEA of the comparative corona igniter of Figure 14B providing a corona discharge when the comparative corona igniter is disposed at the typical location of ignition;

[0021] Figure 16A is a FEA of the corona igniter of Figure 14A when the corona igniter is disposed closest to the piston, and wherein arcing occurs from the central extended member of the corona igniter;

[0022] Figure 16B is a FEA of the comparative corona igniter of Figure 14B when the comparative corona igniter is disposed at the same distance from the piston as the corona igniter of Figure 16A, and wherein arcing occurs from the crown of the comparative corona igniter;

[0023] Figure 17 is a FEA of the corona igniter of Figure 14A when an insulating coating is applied to the central extended member;
Figure 18 is a chart including exemplary data which can be used to obtain the peak electric field for a range of spherical radii at various distances from the piston and cylinder block; and

Figure 19 is a graph providing the peak electric field for a range of spherical radii at various distances from the piston and cylinder block.

DESCRIPTION OF THE ENABLING EMBODIMENT

Referring to the Figures, wherein like numerals indicate corresponding parts throughout the several views, a corona igniter 20 including a central extended member 22 which is capable of providing improved corona discharge 24 and improved combustion performance is generally shown.

As shown in Figure 1, the corona igniter 20 includes an electrode extending along a central axis A for emitting an electrical field that forms the corona discharge 24. As in conventional corona igniters, an insulator 28 formed of an electrically insulating material, such as alumina, is disposed around the central extended member 22 and extends along the central axis A to an insulator firing end 30. A shell 32 formed of a metal material is disposed around the insulator 28. The electrode includes the central extended member 22 and a crown 34.

The crown 34 of the electrode is disposed outwardly of the insulator firing end 30. The crown 34 surrounds the central axis A and the central extended member 22. The crown 34 of the electrode also includes at least one branch 36 extending radially outwardly of the central extended member 22, but typically includes a plurality of branches 36 each extending radially outwardly from the central axis A and radially outwardly of the central extended member 22. In an exemplary embodiment, the crown 34 includes four branches 36 spaced an equal distance from one another around the central axis A, as shown in Figure 1A. Each of the branches 36 presents a firing tip 38 for emitting the electrical field.
that forms the corona discharge 24. As best shown in Figure IB, the crown 34 presents a
crown diameter $D_c$ disposed perpendicular to the central axis A. The crown diameter $D_c$ is
the distance between two points of the crown 34 disposed directly opposite one another, such
as the radially outermost points of two opposing firing tips 38.

[0029] Also shown in Figure IB, the crown 34 extends along the central axis
A from a top surface 40 to the at least one firing tip 38. A crown length $l_c$ is thus presented
between the top surface 40 and the at least one firing tip 38. As shown in Figure IB, the
crown length $l_c$ is parallel to the central axis A and it is equal to the distance between a first
plane 42 and a second plane 44 each extending perpendicular to the central axis A. The first
plane 42 is disposed at the uppermost point of the top surface 40 of the crown 34 and the
second plane 44 is disposed at the lowermost point of the lowermost firing tip 38.

[0030] Each branch 36 of the crown 34 also presents at least one first
spherical radius $r_1$ located at or adjacent to the associated firing tip 38. Figure 1C shows a
portion of the crown 34 of Figure IB including two of the first spherical radii $r_j$ at the firing
tip 38 of the crown 34. A spherical radius at a particular point along a surface is obtained
from a sphere having a radius at that particular point. The spherical radius is the radius of the
sphere in three-dimensions, specifically along an x-axis, a y-axis, and a z-axis.

[0031] The crown 34 can be formed of various different metal materials. In
one exemplary embodiment, the crown 34 is formed of nickel, nickel alloy, or a precious
metal, such as platinum or iridium. Due to the central extended member 22 of the electrode,
the material of the crown 34 can be formed of a less wear resistant material and experiences
less corrosion and erosion if arcing occurs during operation of the corona igniter 20.

[0032] The central extended member 22 of the electrode extends
longitudinally along the central axis A to a central firing end 46. The central extended
member 22 presents an extended length $l_e$ extending from the top surface 40 of the crown 34
to the central firing end 46, as best shown in Figure IB. The extended length $l_e$ is parallel to
the central axis $A$ and it is equal to the distance between the first plane $42$ and a third plane
48 extending perpendicular to the central axis $A$. The first plane $42$ is disposed at the
uppermost point of the top surface $40$ of the crown $34$, and the third plane $48$ is disposed at
the lowermost point of the central firing end $46$. The extended length $l_e$ provided by the
central extended member 22 is greater than the crown length $l_c$. Due to the extended length
$l_e$, during operation, the central extended member 22 approaches a grounded component, such
as the piston, more closely than the firing tips $38$ of the crown $34$. Thus, if any arcing occurs
during operation of the corona igniter 20, the arcing will preferentially form from the central
firing end 46 of the central extended member 22, rather than from the firing tips $38$ of the
crown $34$. The extended length $l_e$ of the central extended member 22 can also increase the
size of the corona discharge 24 formed by the electrode.

[0033] The central extended member 22 presents at least one second spherical
radius $r_2$ located at or adjacent to the central firing end 46. Figure 1D shows a second
spherical radius $r_2$ at the central firing end 46. Each of the second spherical radii $r_2$ at or
adjacent to the central firing end 46 of the central extended member 22 are less than each of
the first spherical radii $r_1$ along the firing tips $38$ of the crown $34$. In other words, the firing
tips $38$ of the crown $34$ are sharper than the central firing end 46. Therefore, during
operation, the electric field is higher at the firing tips $38$ of the crown $34$, and corona
discharge 24 is more likely to form from the firing tips $38$ than from the central extended
member 22, which is preferred for best combustion performance.

[0034] Also shown in Figure IB, the central extended member 22 presents an
extended diameter $D_e$ disposed perpendicular to the central axis $A$. The extended diameter $D_e$
may vary along the central axis $A$, but in the area located between the crown $34$ and the
central firing end 46, the extended diameter $D_e$ is less than the crown diameter $D_e$.  

Figures 2-11 illustrate other exemplary designs of the corona igniter 20 including the central extended member 22. The designs may be selected to meet the requirements of the particular engine application and to provide the best possible thermal performance. In each case, the extended length $l_e$ of the central extended member 22 is greater than the crown length $l_c$. Also in each embodiment, each of the second spherical radii $r_2$ at or adjacent to the central firing end 46 of the central extended member 22 are greater than each of the first spherical radii $r_1$ at the firing tips 38 of the crown 34. Figure 3A is an enlarged view of a portion of the design of Figure 3, wherein the central extended member 322 includes a relatively small second spherical radius $r_2$, but this second spherical radius $r_2$ is still greater than the first spherical radii $r_1$ of the crown 334. In each design, the extended diameter $D_e$ of the central extended member 22 can decrease in a direction moving from the crown 34 toward the central firing end 46, or increase in a direction moving from the crown 34 toward the central firing end 46. In addition, the central extended member 22 does not need to be symmetrical.

Various different materials can be used to form the central extended member 22, such as nickel, copper, precious metals, or alloys thereof. Portions of the central extended member 22 can also be formed of an insulating material. The central extended member 22 is typically formed of a first material and the crown 34 is typically formed of a second material different from the first material. The first material used to form the central extended member 22 is typically more resistant to erosion and corrosion than the second material used to form the crown 34, since the central extended member 22 is more likely to be in contact with high current and temperature of the arc, if arcing does occur.

The central extended member 22 is oftentimes formed of a plurality of separate pieces joined together, such as a body portion 52 and a wear element 54, as shown in Figures 5, 9, 10, and 11. However, any of the shapes shown in Figures 2-11 could comprise a
single piece, or a plurality of pieces joined together. For example, in Figure 5 the central extended member 522 includes a body portion 552 and a wear element 554 connected to one another. In this embodiment, the wear element 554 is coaxial with the body portion 552, but it does not need to be.

[0038] In each embodiment, the wear element 54 presents the central firing end 46. Thus, the wear element 54 is typically formed of a material having good thermal characteristics and being more resistant to wear than the material of the body portion 52. In one embodiment, the wear element 54 is formed of a nickel-based alloy, a noble metal, or a precious metal, such as platinum, tungsten, or iridium. In another embodiment, the wear element 54 is formed of an electrically insulating material preferably having a relative permittivity of greater than 2, and more preferably greater than 8, for example an alumina-based material. The wear element 54 can also comprise a coating of metal material or a coating of electrically insulating material.

[0039] The wear element 54 may be applied to the body portion 52 of the central extended member 22 by any suitable means, for example PVD, co-extrusion, or co-sintering. Alternatively, the wear element 54 may be attached by brazing or a similar process. When the wear element 54 is a coating, the coating can be applied by plating, spraying, sintering, or another suitable method. The material of the body portion 52 and the material of the wear element 54 should be selected and joined to provide good bonding, no small gaps, good thermal contact, and to avoid problems with differential thermal expansion, for example.

[0040] In the embodiment of Figure 10, in order to better withstand the effects of arc discharge, the central extended member 1022 includes a core 56 formed of copper or a copper alloy, and the core 56 is surrounded by a cladding 58 formed of a nickel alloy. In the embodiment of Figure 10, the wear element 1054 is attached to the cladding 58 and forms the
central firing end 1046. Alternatively, the cladding 58 of the nickel alloy could form the central firing end 1046. As shown in Figure 10, the core 56 preferably has a core length \( l_{\text{core}} \) extending from the top surface 1040 of the crown 1034 to a core firing end 80. The core length \( l_{\text{core}} \) is parallel to the central axis A and it is equal to the distance between the first plane 42 and a fourth plane 82 each extending perpendicular to the central axis A. The fourth plane 82 is disposed at the lowermost point of the core 56. Preferably, the core length \( l_{\text{core}} \) is greater than the crown length \( l_c \). In this case, the cladding 58 of the central extended member 1022 still protects the copper core 56. This design can significantly reduce the maximum temperature of the firing tips 1038 and can prolong the life of the firing tips 1038 and the central firing end 1046.

[0041] Another aspect of the invention provides a corona discharge ignition system 60 including the corona igniter 20 with the central extended member 22 to reduce corrosion and erosion at the firing tips 38, as shown in Figures 12A and 13A. For comparison, Figures 12B and 13B show s system with another type of corona igniter 20', which does not include the extended length of the present invention. The system 60 includes components found in a conventional internal combustion engine, such as a cylinder head 62, a cylinder block 64, and a piston 50. The piston 50 is disposed opposite the cylinder head 62 and presents a space therebetween, and the cylinder block 64 is connected to the cylinder head 62 and surrounds the piston 50. Thus, the cylinder head 62, cylinder block 64, and piston 50 present a combustion chamber 66 therebetween.

[0042] The cylinder head 62 presents an opening 68 for receiving the corona igniter 20. The shell 32 of the corona igniter 20 is typically coupled to the cylinder head 62, for example threaded into the opening 68 of the cylinder head 62, as shown in Figures 12 and 13. A gasket 70 is typically disposed between the shell 32 and the cylinder head 62. The corona igniter 20 can include a terminal 72 for receiving the power from a power supply
(now shown), and an insulation material 74 can be disposed between the terminal 72 and the electrode. A portion of the insulator 28, as well as the central firing end 46 and the firing tips 38, are disposed in the combustion chamber 66. A fuel injector 76 is also received in the cylinder head 62 for delivering fuel in the form of finely atomized spray 78 into the combustion chamber 66.

[0043] During operation, power is supplied to the corona igniter 20, the fuel is sprayed toward the corona igniter 20, and the piston 50 reciprocates with the cylinder block 64, moving towards and away from the cylinder head 62 and the corona igniter 20, as in a conventional corona ignition system. In Figure 12A, the piston 50 is spaced from the corona igniter 20 by a significant distance. Corona discharge 24 forms from the firing tips 38 of the crown 34, and no arc formation occurs between the corona igniter 20 and the piston 50 or any other grounded component. In the system 60 of Figure 12B with the comparative corona igniter 20', the corona discharge 24 is also formed without arc formation.

[0044] In Figures 13A and 13B, however, the piston 50 approaches the corona igniter 20, 20' and arcing 25 does occur. When the system 60 includes the inventive corona igniter 20, such as in Figure 13A, the arcing 25 does not occur from the firing tips 38 of the crown 34, as it does when the comparative corona igniter 20' of Figure 13B is used. Rather, the arcing 25 occurs from the central firing end 46 of the central extension member 22. The extended length le of the central extended member 22 restricts the arcing 25 to only the central extended member 22. Since the firing tips 38 of the crown 34 are less exposed to the high temperatures caused by the arcing 25, they experience less corrosion and erosion. Thus, the firing tips 38 stay sharp and continue to provide a strong corona discharge 24 during future ignition cycles.

[0045] As mentioned above, the electrode of the corona igniter 20 of the present invention can also increase the size of the corona discharge 24 during operation.
Figures 14-16 each include a Finite Element Analysis (FEA) of an inventive corona igniter 20 or a comparative corona igniter 20' when power is supplied to the corona igniter 20, 20'. The lines of the FEA images show the most likely direction and length of the corona discharge 24. Figure 14A shows the inventive corona igniter 20 and associated corona discharge 24 when the piston 50 is spaced a significant distance from the central firing end 46 and firing tips 38; Figure 15A shows the inventive corona igniter 20 and the associated corona discharge 24 when the piston 50 is at the location of typical ignition; and Figure 16A shows arcing 25 which occurs from the central firing end 46 of the inventive corona igniter 20 when the piston 50 comes very close to the corona igniter 20. For comparison, Figures 14B-16B each include a FEA of the corona discharge 24 provided by the comparative corona igniter 20' when the piston 50 is in the same positions as Figures 14A-16A.

[0046] Figures 14A and 15A show that the corona igniter 20 of the present invention provides a stronger corona discharge 24 when the piston 50 is spaced from the corona igniter 20, relative to the comparative corona igniter 20' of Figures 14B and 15B. The extended length lₚ of the central extended member 22 tends to repel the corona streamers as they form, thus providing a more open shape, giving a larger volume, and being less likely to encounter the piston 50. In addition, Figure 16A shows that if arcing 25 occurs, the arcing will form from the central firing end 46 of the central extended member 22, rather than from the firing tips 38 of the crown 34. This is an advantage over the comparative corona igniter 20' of Figure 16B, wherein the arcing 25 forms from the firing tips 38' of the crown 34'.

[0047] Figure 17 is a FEA analysis of the inventive corona igniter 20 when the wear element 54 in the form of an insulating coating is applied over the central firing end 46 of the central extended member 22. This analysis shows that the insulating coating does not detrimentally effect the operation of the corona igniter 20 or the benefits provided by the central extended member 22.
Another aspect of the invention provides a method of manufacturing the corona igniter 20 for use in the corona discharge ignition system 60, which includes providing the central extended member 22 so that extended length $l_e$ of the central extended member 22 is greater than the crown length $l_c$.

Various techniques can be used to determine the appropriate extended length $l_e$ of the central extended member 22 in order to provide the preferred performance. In one embodiment, the method first includes (a) identifying the firing tip 38 of the crown 34 which will be closest to the cylinder block 64 when the corona igniter 20 is received in the cylinder head 62. Next, then method includes (b) determining a point during movement of the piston 50 where a distance from the firing tip 38 identified in step (a) to the cylinder block 64 is equal to a distance from the firing tip 38 identified in step (a) to the piston 50. When the piston 50 is located at this point, or closer to the firing tips 38, there is a possibility of arcing between the firing tips 38 and piston 50, but this possibility is mitigated by the central extended member 22.

The method next includes (c) selecting the extended length $l_e$ of the central extended member 22 such that when power is provided to the electrode and when the firing tip 38 identified in step (a) is at the point identified in step (b), the peak electric field at the central firing end 46 of the central extended member 22 is equal to or greater than the peak electric field at the firing tip 38 identified in step (a). The peak electric field at the central firing end 46 of the central extended member 22 depends on the distance between the central firing end 46 and the piston 50, and the distance between the central firing end 46 and the cylinder block 64. The method can also include adjusting the extended length $l_e$ of the central extended member 22 to space the central firing end 46 of the central extended member 22 farther from the cylinder block 64 and/or the piston 50 during operation.
The method also typically includes step (d): selecting the first spherical radii $r_1$ of the firing tips 38 and the second spherical radii $r_2$ of the central firing end 46 such that during operation, corona discharge will preferentially form from the firing tips 38, and arcing, if any occurs, will preferentially form between the piston 50 and the central firing end 46 of the central extended member 22. The step of selecting the spherical radii $r_1$, $r_2$ can be conducted before or after selecting the extended length $l_e$. The step of selecting the spherical radii $r_i$, $r_2$ includes selecting the first spherical radii $r_1$ for each of the firing tips 38 of the crown 34 and selecting the second spherical radii $r_2$ for the central firing end 46 of the central extended member 22 such that each of the first spherical radii $r_i$ at the firing tips 38 of the crown 34 are smaller than the second spherical radii $r_2$ of the central extended member 22.

The spherical radii $r_i$, $r_2$ are preferably selected so that when power is provided to the electrode, and the at least one firing tip 38 of the crown 34 and the central firing end 46 of the central extended member 22 are spaced from the cylinder block 64 and the piston 50, and a corona discharge 24 is provided from the firing tips 38, the peak electric field at the firing tip 38 closest to ground is at least 25% higher than the peak electric field at the central firing end 46 of the central extended member 22. This may be achieved, for example, by using data of the form shown in Figure 18. The first column of Figure 18 is the distance, in millimeters, from the central firing end 46 or the firing tip 38 to ground, also referred to as the gap to ground. The second column is the spherical radius, in millimeters, and it could be the spherical radius of either the central firing end 46 or the firing tip 38. The third column is the peak electric field, in volts per meter, when 1 volt is applied. The values in Figure 18 are only examples. A dimensionless relationship between the spherical radii $r_2$ of the central firing end 46 of the central extended member 22, the spherical radii $r_1$ of the firing tips 38, and the extended length $l_e$ of the central extended member 22 could be obtained based on the data in Figure 18.
Figure 1 is a graph providing the peak electric field for spherical radii ranging from about 0.05 mm to about 1.15 mm at various distances from the piston 50 and cylinder block 64. Figure 19 specifically provides the peak electric field when the distance from the firing tip 38 to the piston 50 and to the cylinder block 64 is 0.254 mm, 0.508 mm, 1.27 mm, 2.54 mm, 5.08 mm, 12.7 mm, 24.5 mm, and 50.8 mm. The peak electric field at the firing tip 38 should be 25% higher than the peak electric field at the central firing end 46 of the central extended member 22 only at the larger distances, but this is not required at the shorter distances, for example only at 50.8 mm, but not at 0.254 mm.

Once the distance is identified in step (b), and the spherical radii $r_1, r_2$ are selected in step (d), the method typically includes (e) determining the peak electric field of the firing tip 38 identified in step (a) at the distance identified in step (b). As an example again, the data of Figure 18 can be used to determine this peak electric field. In one preferred embodiment, the firing tips 38 each have a spherical radius $r_1$ of 2.54 mm and a peak electric field of 330 V/m at a distance of 25.4 mm from the piston 50. The method can further include adjusting the spherical radii $r_1, r_2$ to meet all safety and operating conditions.

Obviously, many modifications and variations of the present invention are possible in light of the above teachings and may be practiced otherwise than as specifically described while within the scope of the appended claims.
CLAIMS

What is claimed is:

1. A corona igniter, comprising:
   an electrode extending along a central axis for emitting an electrical field that forms a corona discharge;
   said electrode including a central extended member extending longitudinally along said central axis to a central firing end;
   an insulator formed of an electrically insulating material disposed around said electrode and extending along said central axis to an insulator firing end;
   a shell formed of a metal material disposed around said insulator;
   said electrode including a crown disposed outwardly of said insulator firing end;
   said crown including at least one branch extending radially outwardly of said central extended member;
   said crown extending along said central axis from a top surface to at least one firing tip;
   said crown presenting a crown length between said top surface and said at least one firing tip, said crown length being parallel to said central axis;
   said central extended member presenting an extended length extending from said top surface of said crown to said central firing end, said extended length being parallel to said central axis; and
   said extended length being greater than said crown length.

2. The corona igniter of claim 1 wherein said crown presents at least one first spherical radius at each of said firing tips, said central extended member presents at least one
second spherical radius at said central firing end, and each of said first spherical radii are smaller than each of said second spherical radii.

3. The corona igniter of claim 2 wherein said crown includes a plurality of branches each extending to one of said firing tips, each of said firing tips having at least one of said first spherical radii each being smaller than each of said second spherical radii.

4. The corona igniter of claim 1 wherein said central extended member is formed of a first material and said crown is formed of a second material different from said first material, and said first material is more resistant to erosion and/or corrosion than said second material.

5. The corona igniter of claim 1 wherein said central extended member includes a core formed of copper or a copper alloy and a cladding formed of a nickel alloy surrounding said core, and said cladding of said central extended member presents said central firing end.

6. The corona igniter of claim 5 wherein said core has a core length extending from said top surface of said crown to a core firing end, and said core length is greater than said crown length.

7. The corona igniter of claim 1 wherein said central extended member includes a plurality of separate pieces joined together.

8. The corona igniter of claim 1 wherein said central extended member includes a body portion and a wear element connected to one another, and said wear element presents said central firing end.
9. The corona igniter of claim 8 wherein said wear element is formed of a nickel-based alloy, a noble metal, or a precious metal.

10. The corona igniter of claim 8 wherein said wear element is a coating.

11. The corona igniter of claim 8 wherein said wear element is formed of an electrically insulating material having a relative permittivity of greater than 2.

12. The corona igniter of claim 1 wherein said crown presents a crown diameter disposed perpendicular to said central axis, said central extended member presents an extended diameter disposed perpendicular to said central axis, and said extended diameter is less than said crown diameter.

13. The corona igniter of claim 1 wherein said central extended member presents an extended diameter disposed perpendicular to said central axis, and said extended diameter decreases in a direction moving from said crown toward said central firing end.

14. The corona igniter of claim 1 wherein said central extended member presents an extended diameter disposed perpendicular to said central axis, and said extended diameter increases in a direction moving from said crown toward said central firing end.

15. A corona discharge ignition system, comprising:
a cylinder head presenting an opening for receiving a corona igniter;
a piston disposed opposite said cylinder head and presenting a space therebetween;
a cylinder block connected to said cylinder head and surrounding said piston;
said cylinder head and said cylinder block and said piston presenting a combustion
chamber therebetween;

a corona igniter received in said opening of said cylinder head;

said corona igniter including a shell coupled to said cylinder head;

said corona igniter including an insulator formed of an electrically insulating material
surrounded by said shell and extending along a central axis to an insulator firing end;

said corona igniter including an electrode surrounded by said insulator and extending
along said central axis into said combustion chamber for emitting an electrical field that
forms a corona discharge;

said electrode including a central extended member extending longitudinally along
said central axis to a central firing end;

said electrode including a crown disposed outwardly of said insulator firing end;

said central firing end of said central extended member and said crown being disposed
in said combustion chamber;

said crown including at least one branch extending radially outwardly of said central
extended member;

said crown extending from a top surface to at least one firing tip;

said crown presenting a crown length between said top surface and said at least one
firing tip, said crown length being parallel to said central axis;

said central extended member presenting an extended length extending from said top
surface of said crown to said central firing end, said extended length being parallel to said
central axis; and

said extended length being greater than said crown length.
16. A method of manufacturing a corona igniter for use in a corona discharge system comprising:

   a cylinder head for receiving the corona igniter, a piston disposed opposite the cylinder head for moving toward and away from the cylinder head, a cylinder block connected to the cylinder head and surrounding the piston such that the cylinder head and the cylinder block and the piston present a combustion chamber therebetween;

   the corona igniter including a shell received in the cylinder head, an insulator formed of an electrically insulating material surrounded by the shell and extending along a central axis to an insulator firing end, an electrode surrounded by the insulator and extending along the central axis, the electrode including a central extended member extending longitudinally along the central axis to a central firing end, the electrode including a crown disposed outwardly of the insulator firing end, the crown including at least one branch extending radially outwardly of the central extended member, the crown extending from a top surface to at least one firing tip, the crown presenting a crown length between the top surface and the at least one firing tip, the crown length being parallel to the central axis, the central extended member presenting an extended length extending from the top surface of the crown to the central firing end, and the extended length being parallel to the central axis; and

   the method comprising the step of:

   providing the central extended member so that extended length of the central extended member is greater than the crown length.

17. The method of claim 16 wherein the step of providing the central extended member so that the extended length is greater than the crown length includes:

   (a) identifying the firing tip of the crown which is closest to the cylinder block when the corona igniter is received in the cylinder head during operation;
(b) determining a point during movement of the piston where a distance from the firing tip identified in step (a) to the cylinder block is equal to a distance from the firing tip identified in step (a) to the piston;

(c) selecting the extended length of the central extended member such that when power is provided to the electrode and when the firing tip identified in step (a) is at the point identified in step (b), the peak electric field at the central firing end of the central extended member is equal to or greater than the peak electric field at the firing tip identified in step (a).

18. The method of claim 17 including adjusting the extended length of the central extended member to space the central firing end of the central extended member farther from the cylinder block and/or the piston.

19. The method of claim 17 wherein the each of the firing tips of the crown present at least one first spherical radius, the central firing end of the central extended member presents at least one second spherical radius, and the method further comprises:

(d) selecting the at least one first spherical radius for each of the firing tips of the crown and selecting the at least one second spherical radius for the central firing end of the central extended member such that the at least one first spherical radius of each of the firing tips is smaller than each of the at least one second spherical radius of the central extended member.

20. The method of claim 19 wherein the peak electric field at the firing tip identified in step (a) at the point identified in step (b) is at least 25% higher than the peak electrode field at the central firing end of the central extended member when power is provided to the electrode and when the firing tip identified in step (a) and the central firing
end of the central extended member are spaced from the cylinder block and the piston and when a corona discharge is provided from the crown.
FIG. 1C

FIG. 1D
* Add some as FIG. 12A except 25 stead of 24

* Add some #s as FIG. 12A except 25 stead of 24 and 20'
Corona formation with piston at a distant location
Corona formation with piston at location of typical ignition
Corona formation with piston at closest approach
Effect of an insulating layer to protect the electrode
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A. CLASSIFICATION OF SUBJECT MATTER

INV. H01T13/50 H01T13/46
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H01T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Further documents are listed in the continuation of Box C.

X See patent family annex.

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Date of the actual completion of the international search

12 June 2014

Date of mailing of the international search report

24/06/2014

Authorized officer

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Form PCT/ISA/210 (second sheet) (April 2006)
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