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## Spark Plug Attributes and Their Effect on Spark Ignition vs. Plasma Ignition

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In this technical paper I will discuss the differences between spark ignition and plasma ignition relative to these spark plug attributes: electrode size, electrode shape and configuration, electrode material, combustion chamber swirl and spark plug heat range.

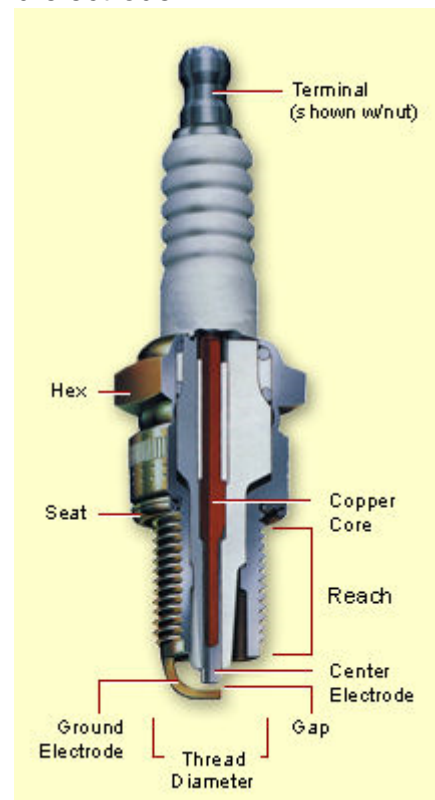
For many years, the most popular spark plug configuration for automobile engines has been the J configuration, so named for the shape of the ground electrode. In conventional spark ignition, the center electrode size and shape are as important as the material of which it is constructed. At right is a cut away view of a conventional J type spark plug with a copper core center conductor. In the past ten years or so there have been many improvements in spark plug technology with the Bosch Company emerging as one of the leading companies in spark plug manufacturing. Bosch led the way with the introduction of platinum center electrodes, shown below. The Bosch conventional J spark plug, pictured below, has a very small electrode that is embedded in the porcelain. In other brands of spark plugs, the center electrode protrudes from the porcelain, but is machined down to a small tip at the end.



Platinum center electrode.



Machined center electrode.



“J” configuration

This small center electrode configuration is advantageous for spark ignition because it forces the spark to jump from the tip of the center electrode to the end of the ground electrode in order to reduce the shadow from the ground electrode. The ground electrode shadow is the area inside the combustion chamber behind the ground electrode that is prevented from being directly exposed to the spark. This shadow, especially the shadow created directly above the center electrode, reduces the combustion efficiency of the engine and therefore its performance and fuel efficiency. On conventional, large center electrode J-configuration spark plugs, the spark can jump between the side of the center electrode and the inside curve of the ground electrode; this creates a larger ground electrode shadow. Spark



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plugs that force the spark to be concentrated at the tip of the electrodes prevent the spark from jumping to the inside of the electrodes so that the ground electrode shadow is minimized. This is why the platinum plugs and other small center electrode plugs are an improvement over the older style, large center electrode plugs.

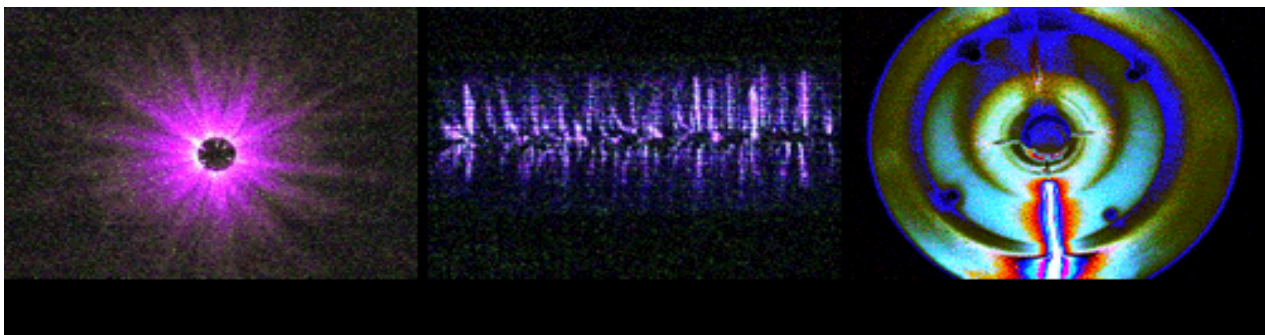
The reason platinum is used for the center electrode is that, unlike steel, it will not burn away due to the high current flow of direct spark ignition systems. This is especially true of small center electrode spark plugs due to the concentration of electron flow at the small surface area of the tip of such an electrode.

One of the best new advances in spark plug technology is the X configuration, pictured at right, so named for the placement of four ground electrodes. The difference between the X configuration and the conventional J configuration is the comparative reduction of the ground



electrode shadow resulting from the ground electrode not covering the end of the center electrode. In addition, the X configuration provides multiple spark paths so as to reduce the chance of the spark being blown out by combustion chamber swirl. This is why years ago, racers used crush gaskets of varying thickness under the seat of the spark plug to index the J plug so that the open part of the J faced in a certain direction. With four ground electrodes, there is no need to index the plug because at least one of the ground electrodes will be positioned in the right orientation. This is what Bosch means in their advertisements when they say, "the spark can seek its most efficient path".

Now let's talk about plasma ignition, which works on completely different principles than spark ignition. While the X configuration plugs still reduce ground electrode shadow caused by the J configuration, the similarities end there.



The pictures above were taken by the University of Southern California to illustrate plasma ignition taking place. The photo on the left shows an end view of an established



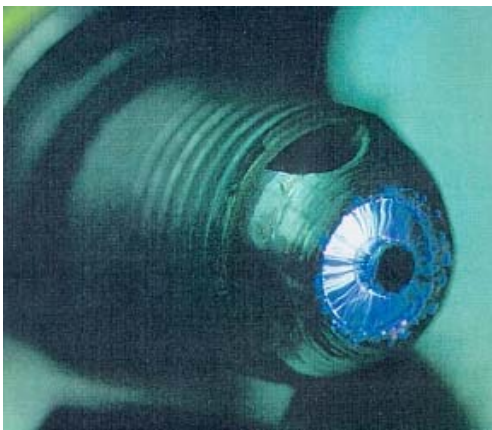
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plasma field, the center photo is a side view of the plasma field and the right picture shows the electron stream entering the plasma field.

Plasma theory holds that the plasma field exists BETWEEN the two electrodes and so the field can only be as large as the surface area of the electrodes. If one electrode is smaller than the other electrode, then the field is only as big as the surface area of the smaller electrode. With a very small center electrode of the Bosch platinum plug, the plasma field will be correspondingly smaller. A smaller plasma field means that there will be fewer electron and fuel/air molecule interactions to ignite a flame front, resulting in an inefficient burn.

The reason that four ground electrodes work better with plasma ignition than one ground electrode is simply because there is more electrode surface area and therefore more fuel/air molecules can be converted into their plasma state between those electrodes. This in turn increases the number of electron and fuel/air molecule interactions to carry on the flame front.

The Beru Company manufactures an X configuration spark plug called the Ultra-X that has a large center electrode. The Ultra X has a great deal more surface area than almost any other plug and therefore will afford the largest plasma field when used with plasma ignition. There are other spark plugs that have more electrode surface area than Beru's, like the Torque Master ring configuration spark plug pictured below. However, unlike Beru plugs, these plugs have not been proven reliable and are not available for as many engines as the Beru.



Torque Master ring configuration



End view of X configuration



Plasma ignition is measured in nanoseconds. To put this into perspective, light moves at 186,000 miles per second; in one nanosecond light moves a little over one foot. Since



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the entire ignition process of plasma ignition takes only about 6 nanoseconds, (as opposed to about 100 times longer for conventional spark ignition and in the case of multiple spark and long duration spark ignition, much longer) the issue of swirl does not come into play for two reasons.

First, fuel/air molecules passing between the electrodes reach the plasma state in less than one nanosecond and so the molecules move very little in that time, additionally, the molecules exiting the space between the electrodes that revert to their stable state are replaced by ones moving into the area between the electrodes and thereby become part of the field.

The second reason is that the speed of the swirl of the combustion charge is much slower than the time it takes the electrons to permeate the plasma field (about 5 nanoseconds) and the electrons are electro-magnetically driven to the fuel/air molecules that are in their plasma state. The swirl therefore cannot "blow out" plasma ignition.

Spark plug heat range is another thing that changes with plasma ignition. The heat range value of a spark plug is determined by how fast heat generated at the center electrode is dissipated. The temperature of the electrode is affected by many factors, including combustion chamber pressure, ignition spark current, ignition spark duration, multiple ignition sparks among other factors.

This heat range value is very important with spark ignition. A spark plug electrode that is hot aids spark ignition. If the spark plug is too hot, the electrodes will be damaged and the spark plug will create a hot spot in the combustion chamber that can damage the piston and or valves. With spark ignition the best results are found when the spark plug gets as hot as possible without getting hot enough to cause damage to the engine. Choosing the correct heat range for a particular engine is a delicate balance between performance and longevity and is why spark plugs need to be so rugged.

Since the temperature of plasma is about 5,000 degrees Kelvin, plasma ignition does not need the assistance that a hot spark plug electrode can render. In fact, a cold electrode is preferred so as to eliminate any possibility of damaging the engine or spark plug electrodes. Although plasma is extremely hot, the duration of time that it exists in the combustion chamber is so short that it does not pose a thermal threat to engine components or spark plug electrodes. This is why spark plugs last so much longer with plasma ignition and why there is no advantage to using expensive platinum materials in the construction of the spark plug electrodes.

In this technical paper I have covered the effects on spark ignition and plasma ignition of these spark plug attributes: electrode size, electrode shape and configuration, electrode material, combustion chamber swirl and spark plug heat range.



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The table below is a reference guide for comparing spark plug attributes in spark ignition and plasma ignition environments.

<b><i>Spark Plug Attribute</i></b>	<b><i>Spark Ignition</i></b>	<b><i>Plasma Ignition</i></b>
Large Center Electrode	Not Good	Good
Small Center Electrode	Good	Not Good
J Ground Electrode	Not Good	Not Good
X Ground Electrode	Good	Good
Platinum Electrode	Good	Doesn't Matter
Chamber Swirl	Sensitive	Not Sensitive
Spark Plug Heat Range	Hot	Cool