



SPARK PLUG TECHNICAL INFORMATION (WHITEPAPER)

SPARK CENTER ELECTRODE and TIP DESIGN

The performance tuning industry is brimming with misinformation regarding spark plug center electrode design, with perhaps the largest misconception of all being that because copper is a better conductor than iridium the so-called “copper” spark plugs offered by many manufacturers are also somehow superior. It is true that copper is superior to iridium in its heat and electrical conduction capabilities, however it is also a completely unsuitable material to be used as a high voltage electrode, and it not used as electrode material on any spark plug. The so-called “copper” plugs often spoken about use copper “plugged” nickel/chrome alloy for the center electrode.

Perhaps contrary to intuitive thinking, in spark plug design the conduction of electricity is of secondary concern to minimizing the power needed to ionize the spark gap. This is because ionization of the gap requires the largest amount of the total electrical energy supplied to the plug—this is known as the gap *breakdown* voltage. Also, from the perspective of lighting an engine fuel charge, this is wasted energy, which if reduced could instead be used to sustain the spark for a longer period, improving ignition and combustion.

In the quest to minimize breakdown voltage, a smaller center electrode generally makes a better performing spark plug as it requires less voltage to fire than a larger electrode. However there are many other considerations in the development of tip size. Finding a well balanced tip design is fundamental for creating a spark plug that has a long, high performance service life.

For example, an iridium center electrode with a very small diameter 0.1mm will prove to deteriorate very rapidly. Testing has also shown that as tip diameter reaches 0.4mm acceptable, yet not optimal tip life can be achieved. Iridium tips of 0.5mm to 0.6mm diameter have been shown to provide the best long term operation.

In this documentation WeaponX has recorded how they determined the optimal tip size for their 360° laser welded iridium spark plug.

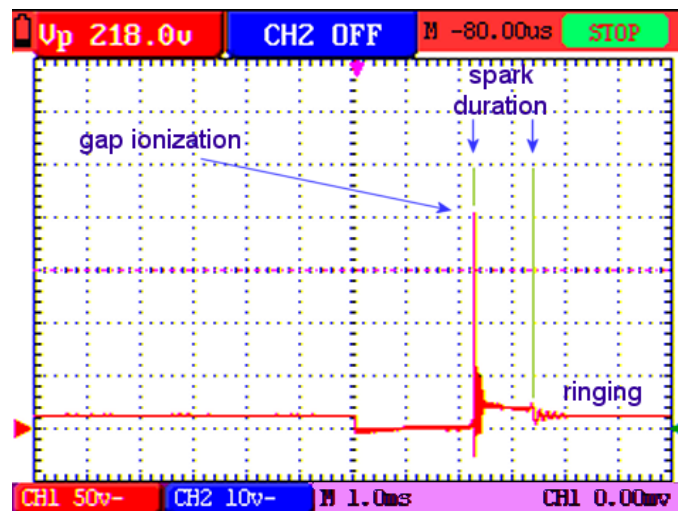
THE EVENTS*Figure 1*

Figure 1 displays an oscilloscope trace of a typical spark plug firing event; from ionization of the gap (the large voltage spike on the left), to the actual spark duration (the horizontal plateau between the green markers), to the end of the spark and the dissipation of any power remaining in the coil (the “ringing” at the right end of the trace).

Note that it is the ionization event that requires the most voltage, 7 to 10 times or more than the actual spark.

VOLTAGE REQUIREMENTS

Figure 2

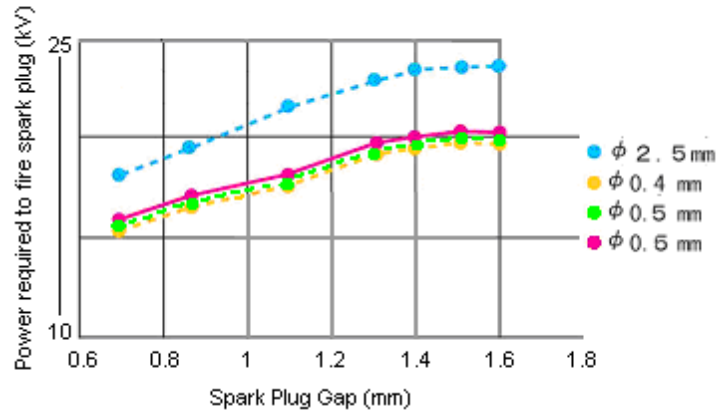


Figure 2 shows that in back to back comparisons of 0.4mm, 0.5mm, and 0.6mm center electrode tips the voltage required to ionize the gaps are nearly identical. Also shown is that when the electrode diameter is increased to 2.5mm, a size typical of a conventional nickel/chrome alloy center electrode plug—the ionization voltage requirement increases significantly, even at gaps as small as 0.7mm (0.028”).

Electrons prefer to jump from a smaller and/or pointed electrode, and while it would be easiest to pull electrons from a sharp pointed electrode, a sharp pointed electrode of any material used in an internal combustion engine ignition system would erode after only a few seconds, and therefore be quite impractical.

Instead spark plugs use square ended electrodes, and the electrons that initialize ionization of the gap are emitted from the sharp edges at the circumference of the electrode's end. These edges erode as would a sharp point, just more slowly, with precious metal electrodes eroding much more slowly than conventional nickel/chrome designs. As the edges wear the spark becomes weaker and less reliable.

We have seen the desirability of a smaller center electrode however conventional nickel/chrome electrodes simply cannot be made smaller because of their poor resistance to erosion.

So which spark plug design, small or large diameter center electrode, would be considered superior?

The iridium design wins in 2 areas:

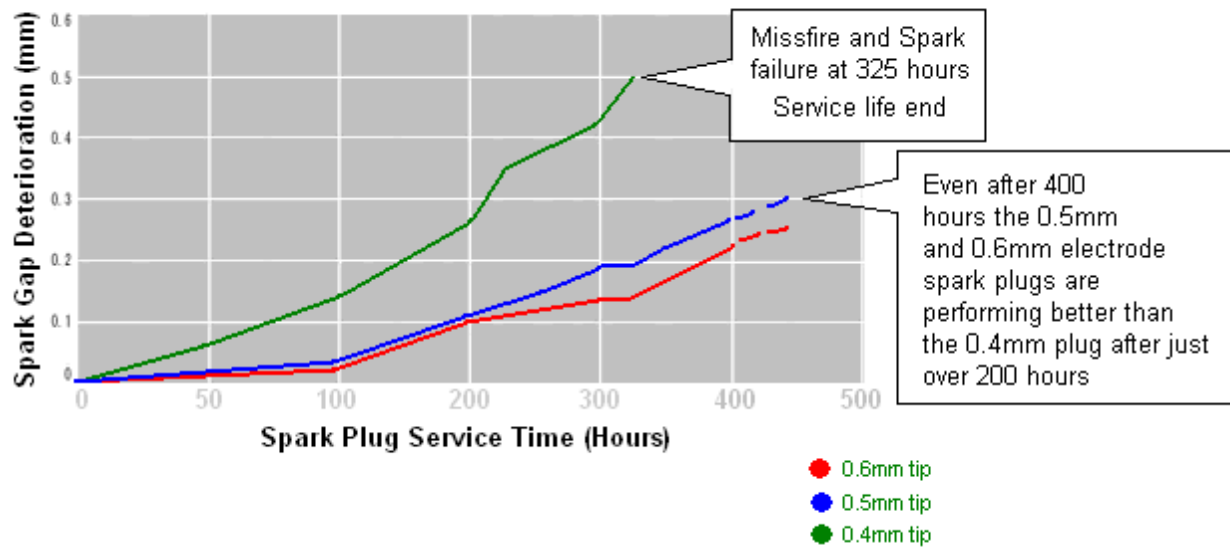
1. the electrode can be made smaller because of its superior erosion resistance;
2. because of this the gap ionization voltage requirement for iridium is much less;

PERFORMANCE THROUGHOUT THE SERVICE LIFE

Service life is also affected by erosion of the ground strap (side electrode), Figure 3 below shows the results of tests performed using a high power ignition system. Note that with the 0.4mm center electrode, used by many manufacturers of iridium spark plugs, ground strap degradation rapidly increases as there is not enough surface area on the tip to equally distribute the spark along the ground strap. This causes rapid deterioration of a small area closest to the spark center electrode. In turn this causes accelerated degradation of spark output and soon misfire events, engine horsepower loss and compromised gas mileage follow.

PERFORMANCE VS. SERVICE LIFE

Figure 3



Using a 0.5mm or 0.6mm center electrode such rapid deterioration is not as much an issue, because the spark plug center electrode has sufficient outer diameter for a long life span with a high quality spark output.

Even after 400 hours of use both the 0.5mm and 0.6mm tips are providing a more accurate and intense spark than the 0.4mm after only 200 hours. Shown at the right is a comparison of side electrode erosion caused by 0.4mm and 0.5mm electrode diameters.

The advantage is obvious; the 0.5mm tip offers the best of both worlds.

Iridium electrodes are over 2000 times harder than conventional electrodes, permitting production of high temperature electrodes using smaller center wire, and having sharper edges that will not melt or erode. The smaller electrode also absorbs less heat from the spark and initial flame energy, allowing further enhanced output.

Iridium design plugs outperform conventional copper-core plug designs and provide over 60,000 miles of use.

IGNITABILITY POTENTIAL

Ignitability is a measure of how effectively and efficiently a spark plug can ignite a compressed air/fuel mixture, in the combustion chamber. It is best measured by leaning out the air/fuel mixture until misfire occurs, this because lean mixtures are more difficult to ignite. This test provides engineers an indication of which spark tip styles will produce better overall ignition characteristics, and design spark plugs that perform better in normal operation, with the end result being more power, lower emissions, and higher overall efficiency of the ignition system.

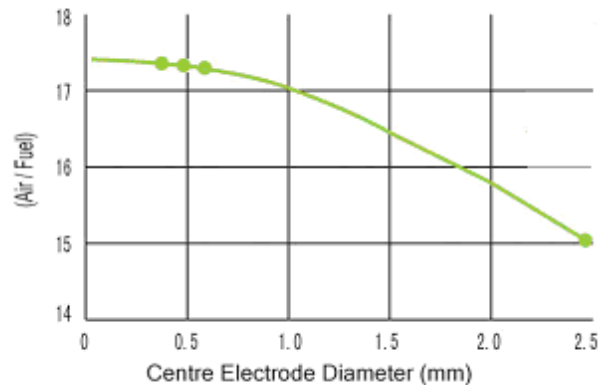
Spark plugs with a smaller center electrode diameters offer better ignitability results.

The standard spark plug center electrode of 2.5mm diameter, needed with nickel/chrome designs, has 25 times the area at its tip than that of a 0.5mm fine wire electrode. You can see in the chart below that a conventional 2.5mm electrode starts to have ignitability problems at air/fuel ratios of 15:1, whereas the fine wire plug can light off mixtures at 17:1 and leaner (Figure 3)



IGNITABILITY

Figure 4



During testing, the limits to improving ignitability using a reduction in center electrode diameter were found to be finite, you can see in *Figure 4* that the ignitability curve flattens as the tip diameters falls below 0.5mm. This means that using a 0.4 or finer electrode would yield little additional performance, *and be less resistant to the tip and side electrode deterioration, and erosion, issues previously presented.*

It was at this point WeaponX engineers determined this negligible improvement in ignitability did not compensate for the loss of performance throughout a spark plug's service life—making the 0.5mm fine wire electrode unquestionably superior to all others.

WEAPONX – IMPROVING IGNITABILITY BEYOND 0.4MM ELECTRODE DESIGNS

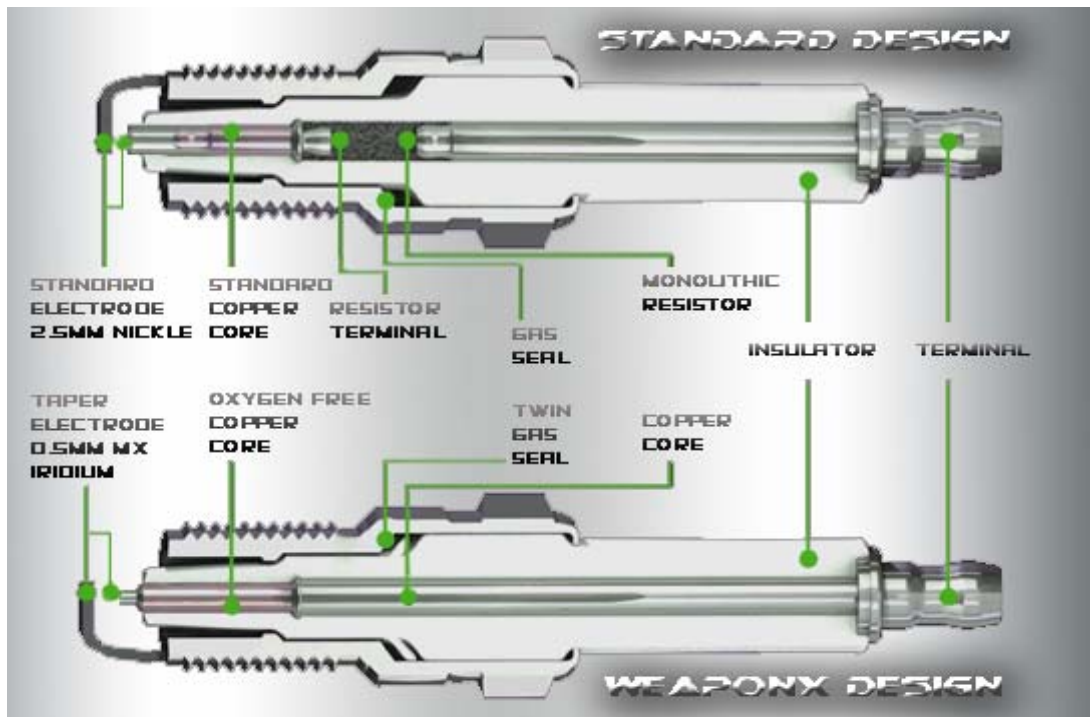
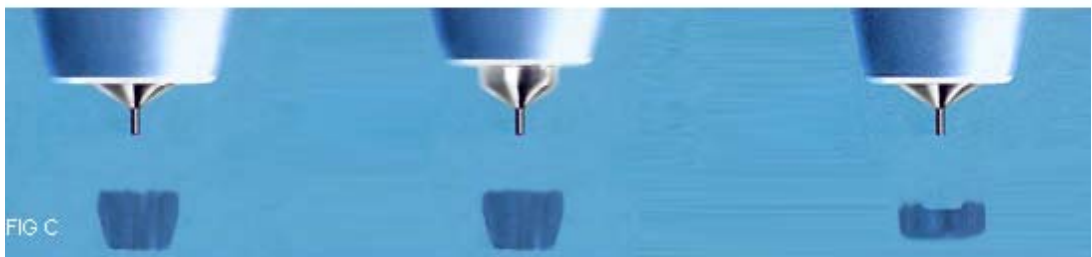
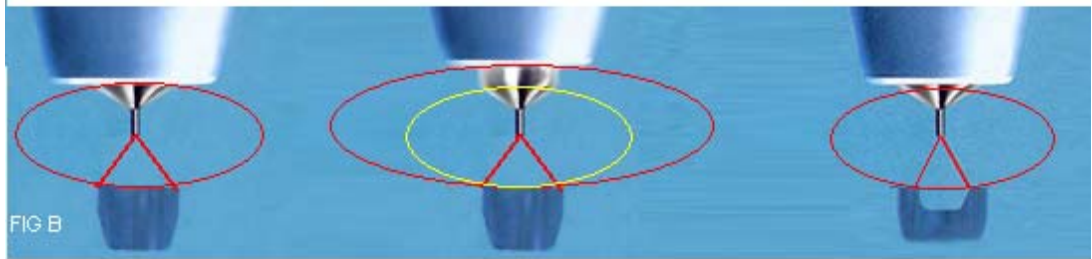
The easier it is for fuel and air to make it to the spark kernel the better the combustion event, however the more the center electrode tip is shrouded, the more difficult it is for the spark to light off the fuel air mixture. Also, a more open the area around the spark kernel offers greater ability for the flame front to propagate. The faster the flame front propagates, the more complete the combustion and the more engine power generated.

Through the use of our exclusive CB insulator we have been able to surpass the ignitability potential of a 0.4mm electrode design, even though WeaponX uses a 0.5mm fine wire iridium electrode—bringing ignitability potential to the next level.

WeaponX's advanced design provides a 0.5mm iridium fine wire electrode that actually surpasses the ignitability of a 0.2mm electrode; while still offering a long, high performance service life. (*see FIGs A and B below*)

In FIG A you can see the tip design of leading competitor's spark plugs vs the WeaponX spark plug. The WeaponX is designed with a drawn back porcelain insulator which opens a larger area to the air/fuel charge that greatly increases ignitability and also allows for faster flame front propagation.

In FIG B you can see that the initial flame front on the WeaponX spark plug grows faster and more intensely than the competitor spark plugs (yellow indicates competitor flame front size vs the WeaponX flame front).



GROUND ELECTRODE DESIGN – FURTHER INCREASING IGNITABILITY

The ground electrode strap is an additional key area of spark plug development. Some manufacturers offer a U-groove side electrode design, and while an interesting concept, the actual increase in area for flame front propagation achieved by slotting the ground strap does not justify the U-groove vs. WeaponX's exclusive porcelain cutback design.

In fact, the U-groove reduces service life of the spark plug dramatically (see *FIG C*). There is more rapid deterioration of the U-grooved electrode since the removal of material from machining the groove weakens the electrode's resistance to erosion. Over time the U-groove design electrode deteriorates, and so does the overall performance of the spark plug.

Tapered style ground electrodes erode less and over time offer longer service life and performance. Additionally, note that the spark prefers to jump to the outer edges of the ground strap (*FIG B*). With the-U grooved plug the spark prefers to jump to the inner edges of the groove, further shrouding the spark kernel and flame front.

WeaponX's narrow tapered side electrode increases flame front propagation and ignitability, while still allowing a long and high performance service life.

OTHER PERFORMANCE ENHANCEMENTS AND IGNITABILITY

Lowered Internal Resistance

WeaponX has designed the *ExtremeX* and *SuperX* spark plugs with high output in mind and as *WeaponX* spark plugs are classified differently from our competitor's we are freed from Federal Communication Commission (FCC) requirements for electrical and radio frequency noise emissions. These requirements mandate the use of *resistor* style spark plugs. However *WeaponX* spark plugs are classified as non-resistor and offer lower internal resistance than the competition's iridium plugs.

The FCC noise suppression regulations mandate that all street driven vehicle spark plugs must adhere to published standards that effectively reduce the power output of the spark plugs. Typical street oriented spark plugs reduce electrical and radio frequency noise by using internal resistances ranging from 5,000Ω to 10,000Ω thus compromising spark energy.

Figure 5 below demonstrates the increased power required to maintain a spark in the electrode gap as internal resistance levels rise.

RESISTANCE VS. POWER REQUIREMENTS

Figure 5

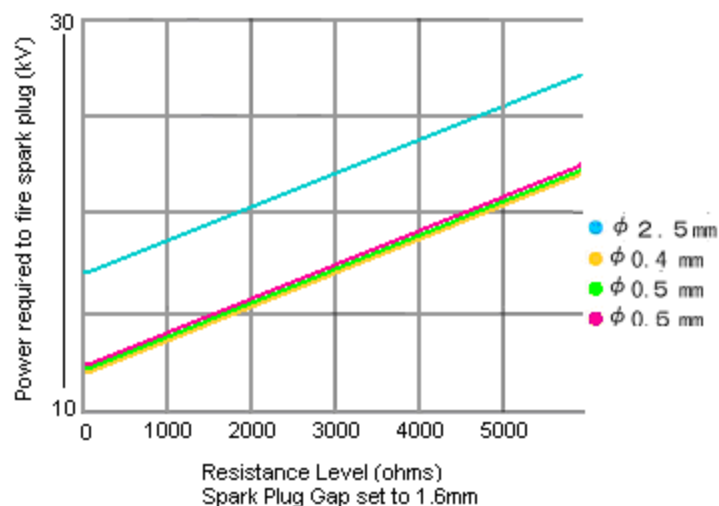
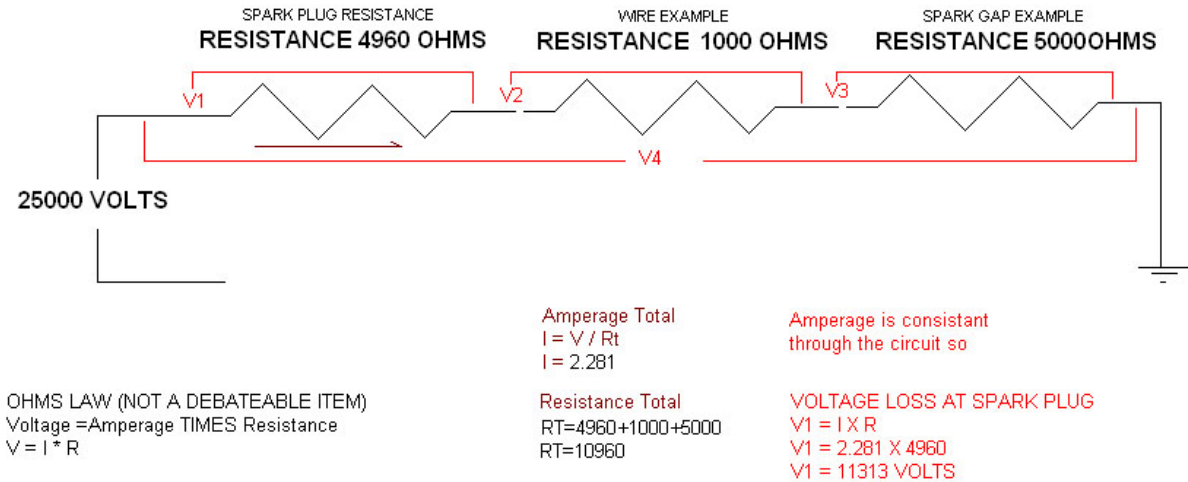
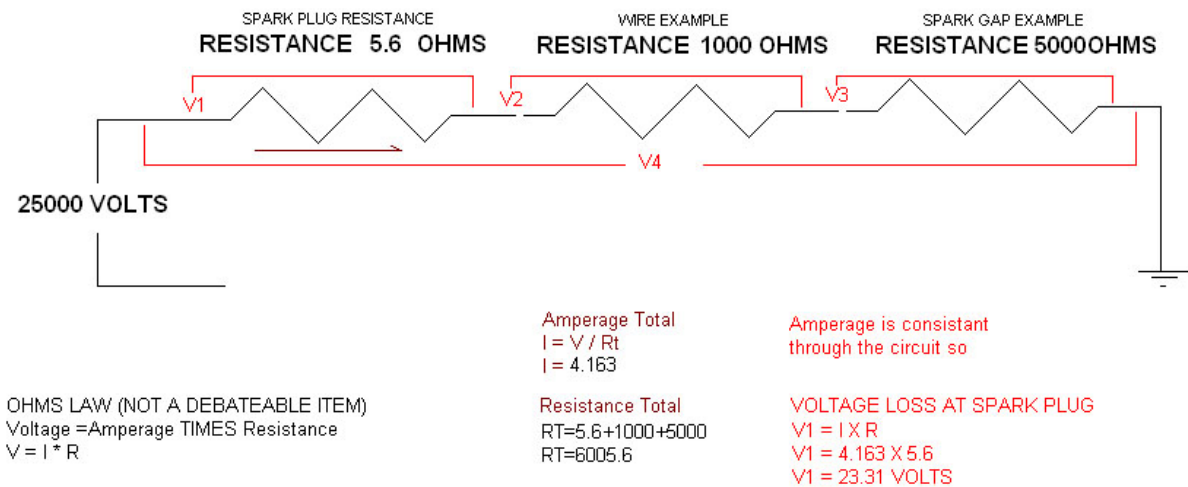


Figure 6



Voltage loss at the spark plug with this example using a standard spark plug is 11,313 volts.

Figure 7



Voltage loss at the spark plug with this example using a WeaponX spark plug is 23.31 volts.

Figures 6 and 7 above compare the overall circuit resistance of a typical resistor type spark plug, versus that of a WeaponX plug. **The WeaponX spark plug's voltage loss to internal resistance is only 23.3V, as compared to over 11,000V for the resistor plug!**

IMPROVED ENGINE POWER THROUGH REDUCED RESISTANCE

Lowered resistance has been proven to increase available voltage at the spark gap. At the moment of gap ionization 2,000 or more volts are typically available, with over 11,000 volts more available during the spark event. This allows the air/fuel in the combustion chamber to be ignited reliably and consistently when the PCM commands the spark—increasing the accuracy, spark kernel size, and overall power of the spark.

A SPARK IS NOT JUST A SPARK

A small spark can only release an equivalent amount of energy in another process, such as starting a large flame kernel in the combustion chamber; and the fact is that engines *need* a hotter spark for a more complete, higher horsepower combustion event. While many theoretical elements of science are not relevant to real world applications, this is not one of them.

It is, to put it plainly, an undisputable fundamental of making power.

This is why it is critical to increase available spark output, so that more energy per combustion event can then be released by the spark creating a more energetic kernel and flame front.

WeaponX spark plugs excel in increasing spark energy, as compared to other designs, and contribute to realizing the full potential of your engine.

HIGHER POWER OUTPUT FOR GREATER ELECTRODE GAP

All these improvements mean one thing, increased available performance. Our design provides more available voltage at the spark gap and therefore allows the gap size to be increased providing strong ignition and improved combustion, even in high compression and forced induction applications. In all applications the stronger spark and improved efficiency result in higher engine performance and fuel economy.

The lower internal resistance and ionization and spark event voltage requirements also allow the ignition system to perform optimally with less overall stress to ignition coils and other ignition system components, creating better performance and longer service life.

DUAL 360° BLOW BY SEALS AND DETONATION PREVENTION

The 360° upper and lower steel seals help make blow by through the center of the spark plug non-existent by reliably tapering and sealing the inner section of the spark plug. This extra seal helps eliminate blowby at the base of the spark plug in extreme operating environments.

WeaponX has also balanced the attributes of a ribbed anti flashover tower section with a higher than average cross section of material to provide exceptional power transfer and energy retention characteristics.

PLATED BODY

WeaponX spark plugs have nickel/cadmium or zinc plated bodies which resist corrosion, improve the spark plug body's electrical properties, and improve service life. This also increases electrical potential at the ground electrode helping to maintain reliability.

HIGH GRADE UPPER TERMINAL

WeaponX upper terminals are manufactured of aluminum which is a superior conductor than our competitor's steel or other metal upper terminals.

Our terminals are spun on and stamped in place for exacting tolerances. This allows for exceptional drop in fit, especially when used with our line of high end ignition coils. Our competitor's upper terminals often do not conform to high tolerance specifications or friction fit applications.

COPPER CORE

The copper core spark plug with a 2.5mm nickel/chrome alloy center electrode has been standard issue from many manufacturers for many years, and our iridium spark plugs also utilize a copper core to maximise energy and heat transfer. The WeaponX IridiumMX electrode out-conducts a typical copper core spark plug with a nickel/chrome alloy electrode by 35% or more to further maximize the electrical conductivity of the spark plug.

IRIDIUMMX CENTER ELECTRODE MATERIAL

WeaponX developed an iridium/rhodium alloy that is superior to all conventional spark plugs based on hardness, strength, electrical properties, and melting point. The new alloy is composed primarily of iridium, with rhodium added to prevent oxidation and erosion. This alloy is extremely hard and has the greatest potential for wear resistance in today's demanding environments of any material, meaning that the life of the spark plug can be extended beyond that of typical designs, while delivering superior performance.

WeaponX spark plugs will, at over half their life expectancy, still outperform a typical brand new copper cored nickel alloy center electrode spark plug.

360° LASER WELDED IRIDIUMMX ELECTRODE

WeaponX produces all of our products in state of the art manufacturing facilities utilizing high technology processes, such as our 360° laser welded tip which holds up to harsh combustion chamber environments, and delivers the best possible mechanical mounting and electrical contact.

HEAT INDEX PROPERTIES

As power levels increase so do the incoming air/fuel charge temperatures, Because of this spark plug heat index must be correctly chosen for the vehicle in question.

Spark plug structural factors that determine heat range are:

- Gas volume as determined by the space between the metal shell and the insulator nose at the firing end;
- Surface area and/or length of insulator nose at the firing end;
- Thermal conductivity of the materials for the insulator, center electrode, and of the overall design;
- The total structure/mass of the center electrode;
- The relative position of the insulator tip to the shell end;

Spark plug operational factors affecting temperature are:

- Air/fuel ratio;
- Compression ratio;
- Ignition timing;
- Octane of the fuel;
- Engine RPM and load;

TIP PROJECTION

As the volume and velocity of air/fuel rushing into the cylinder increases, greater spark plug tip projection increases the probability of spark blow out. Because of this, WeaponX has designed our spark plugs rated for higher output engines to have less projection into the cylinder. This minimizes the spark kernel's being exposed to the incoming fuel charge, and helps to eliminate spark blowout while increasing performance and reliability of the ignition system.

The reverse holds true for lower power engines. As power levels decrease so does the volume and velocity of the fuel charge. In order to reliability ignite these lower volumes of air and fuel it is best to project the spark kernel as deeply as possible into the combustion chamber, moving the kernel directly into the air/fuel path.

WeaponX Spark Plug Specifications

<i>characteristic</i>	<i>K5RF-ipt</i>	<i>K6CF-ipt</i>	<i>K7CF-ipt</i>	<i>K8CF-int</i>
Resistance	~3.2Ω-6.5Ω	~0.8Ω -1.8Ω	~0.8Ω -1.8Ω	~0.8Ω -1.8Ω
Thread Reach	17.55mm	17.55mm	17.55mm	17.55mm
Thread Type	M14x1.25	M14x1.25	M14x1.25	M14x1.25
Hex Size	5/8"	5/8"	5/8"	5/8"
Seat Type	tapered	tapered	tapered	tapered
Tip Type	0.5mm iridium	0.5mm iridium	0.5mm iridium	0.5mm iridium
Ground Electrode	fine taper	fine taper	fine taper	fine taper
Center Electrode	IridumMX	IridumMX	IridumMX	IridumMX
In-Cylinder Projection	projected	projected	semi-projected	non-projected
Projection Reach	3.7mm	3.1mm	2.6mm	1.2mm
Heat Index (NGK)	5	6	7	8
Cutback Technique	full	partial	n/a	n/a
Body Plating	nickel	zinc	zinc	zinc
Typical MAX HP	450	600	725	850



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