Spark Plugs Technical Paper

A spark plug by definition is a device that carries (or leads) a high voltage into a combustion chamber and converts it into a spark (by jumping a gap) to ignite any available air-fuel mixture. The ideal air-fuel mixture for an internal combustion engine is considered to be 14.7:1. The reason that 14.7:1 is considered the ideal air-fuel mixture is that tests have proven that at this ratio CO's, HC's and NOx are at their lowest levels. At the point of explosion, under average operating conditions, the maximum combustion chamber of the internal combustion engine reaches 3,800 to 4,500 degrees Fahrenheit and pressures of 700 pounds per square inch. Conditions which create the variables include (but are not limited to) sudden temperature changes or by sudden pressure changes that are brought to bear by high temperature of burned gases or low temperature of the incoming air-fuel mixture. The spark plugs are subjected to typical firing conditions that heat the 'nose' of the spark plug in the firing chamber to between 1,600 and 1,700 degrees Fahrenheit and suddenly cooled by intake air-fuel mixture. Industry standards require testing of a spark plug to 140 pounds per square inch, whereas NGK Spark Plugs pass tests to 210 pounds per square inch in internal combustion engines. In higher compression engines the spark gap traditionally is lowered as the compression ratio increases. The secondary requirement (grossly overlooked) is that the spark plug is the major path by which heat being generated by the ignition of air-fuel leaves the firing chamber.

The center electrode is commonly made up of a nickel alloy with chrome, manganese and silicone added. It is press formed with a nickel tip welded onto a pure copper core for thermal conductivity. More recent NGK Spark Plugs center electrodes have platinum laser-welded onto a nickel alloy center electrode. NGK's newest exotic center electrode has iridium laser-welded onto a nickel alloy center electrode to offer longevity and lowered resistance to carrying the voltage necessary to jump the gap between the center electrode and some form of ground (whether it be the shell itself (for surface-gapped plugs) or standard ground straps welded onto the shell). For endurance, NGK offers racing spark plugs that have iridium-tipped center electrodes with platinum alloy or iridium alloy ground electrodes.**

The insulator is made of high purity alumina (Al2O3) that is fired at approximately 2,900 degrees Fahrenheit. This is necessary to withstand the extreme conditions the 'nose' of the insulator is exposed within the firing chamber plus contain the high secondary voltages necessary to jump the gap thereby firing the plug under high cylinder pressures.

The metal shell can be formed by either cold forming (rolling) and machined or by cutting and machining from a solid hexagon bar. The

ground electrode is welded in position and the entire finished product is surface plated.

Some spark plugs may be designed to have two, three or four ground electrodes. It must be emphasized as this point that according to the law of physics, the spark occurs at the point of least resistance. Multiple ground electrodes do NOT indicate that there is more than one spark at a time to ignite the air-fuel mixture. Multiple ground electrodes are designed to reduce the possibility of the ground electrode heating to the point of potential pre-ignition. Multiple ground electrode designs also have a tendency of eroding (opening the preset gap) at a higher rate than normal (due to the firing taking place from the very tip of the ground to the center electrode). Therefore, in a standard ignition system, multiple ground electrode designs are created to allow the spark to occur unobstructed directly in the air-fuel mixture, but in no way should be construed as allowing multiple sparks to occur.

Heat range by definition is the range in which the spark plug works well thermally. If the firing end temperature of a spark plug drops below its 'self-cleaning temperature', carbon will accumulate on the firing end, causing the voltage supplied by the ignition system to 'leak away' and NO spark will occur at the gap. NGK Spark Plugs offers a heat range "2" for the hottest heat range up to a "12" for the coldest heat range. That is, the lower the number, the hotter the NGK plug. The higher the number, the colder the plug is considered in overall heat range.

In a simple demonstration, the distance the heat must travel from the 'firing end' to the shell (for heat dissipation through the engine head and air or water jacket) is shorter in a 'colder' plug thereby allowing the tip to cool at a faster rate. This design consequently is considered a "cold plug". The other side of the spectrum, the heat travels a longer distance, forcing the 'firing end' to retain the temperature for a longer period of time thereby making it a 'hotter' plug. Projected-tip ceramic plugs (those that have the ceramic extending beyond the limits of the metal shell) perform a similar alternate function of becoming a 'hotter' heat range.

At the opposing end of the spectrum, when the 'firing end' temperature exceeds the pre-ignition temperature, the air-fuel mixture (typically 14.7:1) in the combustion chamber will be pre-ignited, resulting in loss of power, overheating, or piston damage from what is commonly known as 'pinging'. The ideal firing heat range at the 'firing end' of the center electrode is a well-maintained 1,325 degrees Fahrenheit (or self-cleaning temperature). Should the 'firing end' go above the 1,800 degrees Fahrenheit temperature, pre-ignition occurs. Should the 'firing end' drop below 850 degrees Fahrenheit, this is considered the fouling region and carbon can be built up with unburned fuel. Therefore, the spark plug being selected for a particular application should be in the 850 degree Fahrenheit to 1,800 degree Fahrenheit operating range with the goal to maintain the self-cleaning range of 1,350 degrees Fahrenheit.

Where extreme conditions exist (upwards to 14,000+ RPM for some two-cycle ATV's, motorcycles or water craft and racing engines that generate in excess of 500 to 1,000 HP) heat range issues are particularly important to prevent permanent damage to the engine. Of course, the average engine of today can sustain a certain amount of abuse, but over time may result in permanent damage as well.

The spark plug structural factors that determine heat range are:

- Gas volume being determined by space formed 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 more importantly the overall design.
- The total structure of the center electrode.
- The relative position of the insulator tip to the shell end.
- Number of ground electrodes present.

The spark plug operational factors affecting temperature are:

- The internal combustion engine's air-fuel ratio.
- The overall compression ratio of the engine.
- The internal combustion engine ignition timing.
- The octane of the fuel.
- The engine RPM and overall load.

The spark plug operational factors affecting the required voltage of the internal combustion engine are:

- The required voltage (to jump the gap thereby firing the plug) *decreases* with the *increase* in richness of the air/fuel ratio.
- The required voltage (to jump the gap thereby firing the plug) *increases* proportionally to the increase of (cylinder) pressure.
- Ignition timing definitely affects the required voltage (whether the timing is advanced or retarded). As the compression pressure at top dead center (T.D.C.) reaches the maximum, the required voltage reaches the maximum as well. The required voltage lowers in relationship to the advance of the ignition timing since the compression pressure lowers and the spark plug temperature rises.
- Fuel types and mixtures will affect required voltage.

- **The spark plug gap (and resulting temperature) affects the required voltage.**
- **The polarity of the available secondary voltage will affect the required voltage. The required voltage is lower with minus polarity than with positive polarity.**

When making a visual analysis of the spark plug the following may be considered in the cause and effect issue:

Causes of overheating:

- **Over advanced ignition timing.**
- **Insufficient cooling and lubricating within the engine.**
- **Too lean air-fuel mixture.**
- **Too hot of a spark plug heat range.**
- **Insufficient torque of the spark plug gasket.**
- **Excessive deposits of unburned fuel in combustion chamber.**
- **Too low octane fuel.**
- **Continuous driving under too heavy load for engine application.**

Causes of oil and carbon fouling: ***

- **Improper use or abuse of choke.**
- **Continuous low-speed driving. ******
- **Too rich air-fuel mixture.**
- **Too cold spark plug heat range.**
- **Lowered compression pressure and engine oil entering combustion chamber.**
- **Over retarded ignition timing.**
- **Overall deterioration of system.**
- **Pre-delivery fouling (consistent with continuous low-speed driving.**

Footnotes:

**** Nickel alloy has a melting point of 2,200 to 2,400 degrees Fahrenheit continuous.**

***** Common deposits include carbon, lead, bromine, calcium, sulfur, barium, zinc, iron, silicon or aluminum.**

****** If engine is operated at constant low speeds, a larger surface area at the ceramic tip improves the self-cleaning characteristics of the spark plug.**