# Almost everything you need to know about spark plugs!

By John Butler, HMCCQ

## 1. Introduction

A spark plug is an electrical device used in an internal combustion engine to produce a spark which ignites the air-fuel mixture in the combustion chamber. As part of the engine's ignition system, the spark plug receives high-voltage electricity (generated by an ignition coil in modern engines and transmitted via a spark plug wire) which it uses to generate a spark in the small gap between the positive and negative electrodes. The timing of the spark is a key factor in the engine's performance, and the spark plug usually fires shortly before the combustion stroke commences.

The spark plug was invented in 1860, however its use only became widespread after the invention of the ignition magneto in 1902.

*Source: Wikipedia, Oct 2023.*

## 2. Purpose

The purpose of this paper is to help interested members further develop their knowledge and understanding of spark plugs including components, performance and plug reading.

## 3. Structure and content of this paper

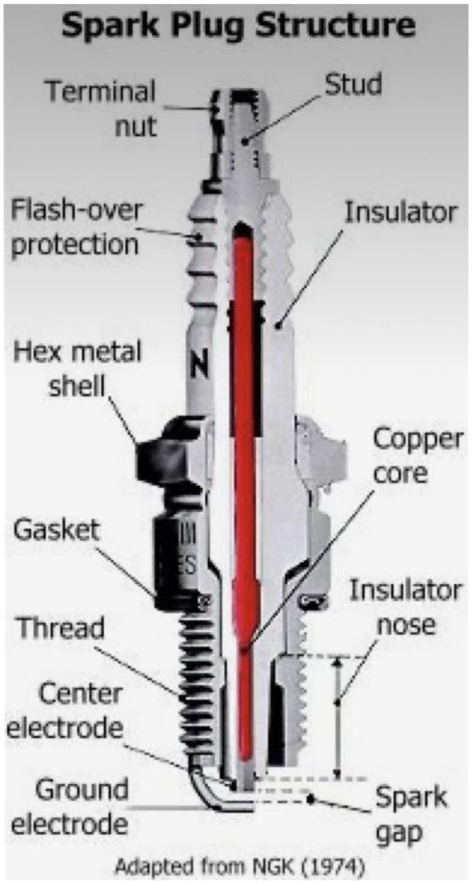
There are several main sections with information logically grouped in each. Page numbers for each section are provided below so you can skip directly to a section of particular interest. The different sections are:

**4. Spark plug componentry**

This section provides a diagram, list and description of the primary components of a spark plug. Relevant industry terminology is used here and throughout the paper.

4.1 Terminal Nut:

The shiny round thing that screws onto the terminal post. Sometimes not required depending on the high tension lead (coil lead) spark plug cap fitment.




4.2 Terminal stud or post:

The threaded bit that the above nut screws onto. The post screws into the Insulator and is fixed in place with a high temperature cement/glue. In some types this post is made as the top half of the centre electrode.

4.3 Centre electrode:

In a standard type of spark plug the centre electrode is made in two halves, the top piece being mild steel. This is welded to the lower half which is a nickel alloy mix. Nickel can withstand very high combustion temperatures. Through some very clever engineering, a piece of copper is moulded into the centre of this nickel wire. All copper cored plugs are made in this way, the copper helps transfer the heat away from the electrode tip at a more progressive rate.

Resistor designs vary by manufacturer, some opting to place a resistor and spring between the terminal post and the top of the centre electrode, while others place a glass seal (sand) type resistor between the two ends of the centre electrode in the centre of the Insulator.

Small air gaps may occur between the terminal post and resistor, or, between the glass seal and centre electrode, which does not hamper the spark, but means trying to check the resistance or continuity with an OHM meter is useless.

There have been many special types of precious metal centre electrodes manufactured over time with each one claiming some benefit, be it improved fuel economy, better spark, improved acceleration, longer life, etc. Usually, each improved type comes with an increase in price, so the benefits always need to be weighed up against price. Most of these design types are beneficial in certain engines but not across all engine types or vehicles.

As an overview, your ‘standard’ type design is very good in a broad range of applications. They are especially good when restoring an old engine and tuning it to your requirements as they are affordable enough that if they become fouled you can throw them away.

Platinum tipped electrodes have been used for ‘long life’ situations. Workshops found high resistances on some platinum tips which is due to certain chemicals that are in some fuels.

NGK “V Groove” types give the centre electrode two extra sharp edges for the spark to jump from and operate very well. Spark voltage will ‘leave’ from a sharp edge rather than a flat surface. Champion’s ‘double copper’ designs require less firing voltage due to having copper within the trapezoidal shaped ground electrode. This odd shaped electrode improves Ionisation, resulting in improved fuel economy.

Currently, iridium centre electrodes are excellent as they operate very well on all types of fuels, low through to high octane fuels, including ethanol fuel mixes, and can resist contaminants caused by the combustion process.

One point to note is that due to the high cost of the precious metals used, they are actually blended with other metals such as yttrium, rhodium or platinum.

4.4 Insulator:

The insulator is made from at least 90% alumina oxide powder, similar to talcum powder, the actual final chemical mix being a very well-kept industry secret. It is moulded into shape, then heated in a very high temperature (1600 Degrees C) kiln, where it shrinks to about one third of its original size. The end result is a very hard ceramic which is the correct size and shape, both internally and externally.

The quality of the ceramic is critical for good spark plug performance and service life.

The ‘ribs’ around the top of the insulator provide flashover protection and reduce the chance of any spark voltage tracking down the side of the insulator.

4.5 Steel shell:

This is the steel bit that is threaded so it can be screwed into the cylinder head. Years ago they were machined from hexagonal bright (silver) steel and machined internally and externally which was very time consuming and expensive. They are now made from softer steel bar which is put through an extruding machine which forms the shell both inside and out. The extrusion process hardens the steel with each shell being threaded then zinc or nickel plated.

The steel shell is not only a means of securing the spark plug into the cylinder head, but it assists in transferring the combustion heat that both it, and the ceramic, are subjected to. It also has to withstand the varying combustion pressures within the combustion chamber.

4.6 Earth electrode:

Sometimes referred to as the ground electrode, the earth electrode is usually made from a high temperature nickel alloy and is welded to the steel shell. This welding process may occur before or after the assembly process. The electrode is bent over, and the spark gap is set depending on the application. Some earth electrodes are copper cored, similar to the centre electrode or may be a mix of other precious metals, or be platinum tipped.

4.7 Assembly process:

This varies depending on manufacturer, with some (Bosch, Nippon Denso) using the ‘hot lock’ design where the ceramic is fitted into the shell, with the top of the shell being rolled over to hold it in place and then heating the shell to shrink it around the ceramic. The swaged option (Champion, NGK, others) is where the ceramic is placed into the shell with the top portion being filled with alumina oxide powder and a sealing gasket before having the top of the shell rolled over, but also compressing the shell enough to form a swage around the shell at the same time. This design provides a cushioning effect on the ceramic which is an advantage in engines that may develop high frequency combustion chamber vibrations during operation.

The centre electrode is usually fitted to the ceramic insulator prior to the above process.

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## 5. Spark plug operation

This section uses a Q&A format to explain how spark plugs work and other factors that influence their operation.

5.1 What do spark plugs need to work?

Good compression, correct air / fuel mixture (or enough fuel and air to "light the fire") and enough electrical voltage for a spark to be created and jump from the centre electrode to the earth electrode.

5.2 Why are there so many types of plugs?

Vehicle manufacturers usually prescribe the type (design) of the plug that they want. This is usually done in consultation with spark plug company engineers with the final design providing optimum power, fuel economy, service life and lowest possible emissions.

As emission laws have become stricter over the past decades, firing tip design, positioning of the firing tip inside the combustion chamber and the materials used has become paramount to accomplish the desired emission result.

The last 40 years has seen countless engine variations and, variations in spark plug firing tip design, that you must consult the vehicle manufacturers recommendations. Some spark plugs are only available through the vehicle's dealer network due to the engine manufacturer owning the intellectual property of both the engine and components.

The following is a description of popular firing tip designs used:

- *Regular gap or standard type:* This is where the firing tip is almost level with the end of the steel shell. This has been the traditional design for many decades and, is the 'go to' design to use when modifying an engine.
- *Projected nose or projected tip:* This is an extension of the above**.** The firing tip extends past the end of the shell by about 2 to 3mm.
- *Extra-long projected:* As the term suggests, the firing tip can extend up to 12mm past the end of the shell. These types are usually found in what is termed 'lean burn' engines.

***Note:*** The actual insulator nose measurements are taken from up inside the shell where the insulator seats against it, to the end of the insulator at the firing tip. This is referred to as Insulator nose length.

5.3 How much voltage does a spark plug require?

Provided good combustion criteria are present, i.e., good fuel / air mix and compression, a spark plug will only require enough coil voltage for a spark to jump between the electrodes.

However, a phenomenon known as *Ionisation* occurs at the tip of the centre electrode as the voltage arrives. Ionisation is a magnetic field that attracts fuel molecules towards the firing tip. As the spark starts to move across the gap, it takes electrons from the centre electrode (electrode wear) and with Ionisation, the gap becomes more conductive.

Electrode gap, electrode temperatures, mixture strength, compression pressure and combustion chamber temperature all have a bearing on Ionisation.

This is why so many differing firing tip designs and materials have been developed over the years. Changing the firing tip design and placement, may assist in extracting more power, or fewer emissions from an engine.

5.4 What is coil reserve?

Coil reserve is the difference between the coil's total voltage output compared to what is required at the plug's firing tip. In most battery / coil ignition systems the coil can produce 30,000 to 35,000 volts when the plug should only require 6,000 to 16,000 volts leaving you plenty in reserve.

High energy ignition (HEI.) systems and some early capacitor discharge ignitions (CDI) can produce more than 50,000 Volts.

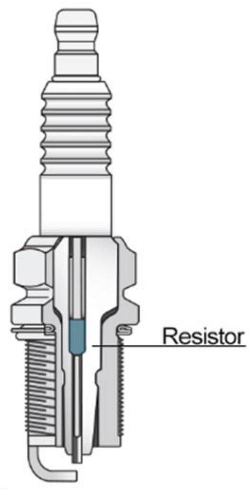
In the 1970's, CDIs were developed for 2-stroke marine and motorcycle engines to enable the spark plug to fire through the heavy fuel and oil mixtures present and the resulting deposits in these engines.

As fuel injection became computerised in the 1980's, engine manufacturers found that they could run engines on very little fuel. However, problems arose with both hard starting and lean burn misfire. This was due to insufficient fuel molecules near the firing tip of the spark plug.

High energy ignitions were developed along with extra-long projected nose plugs with wide firing tip gaps to ensure the spark could reach all the fuel particles that were around.

5.5 What are resistor plugs?

Resistor plugs are designed to reduce radio frequency interference (RFI). When high voltage passes through a spark plug at high frequency it can create its own magnetic field. Once the spark has jumped the gap, the magnetic field collapses, and this reverse spike in voltage causes the RFI, often heard as a crackling noise in older car radios.




As a spark jumps off the centre electrode, some electrons move with it resulting in electrode wear which is normal. While high voltage is good, high amperage is not, more amperage results in more wear. Resistors reduce some of the current flow (amps) as the voltage moves through the plug. This has the benefit of increasing electrode life especially in HEI and CDI systems.

Bosch, Denso, and NGK use the glass seal type resistor, (melted glass fragments mixed with carbon) whereas Champion uses a wire wound inductive coil type which absorbs nearly all of the magnetic field as it breaks down.

However, it appears that older motorcycle magneto ignitions produce an even higher current flow, and this can be detrimental to the glass seal type resistors fitted to some brands. While a resistor type will work, its life may be shorter than a non-resistor type. Resistors in plugs do not reduce the spark.

Even though the current flow is minimal, it appears that the varying frequency of engine RPM and Loads, (i.e. varying voltages from the coil) reduces the life of these resistor plug types in older magneto ignitions.

***Note:*** The use of non-resistor spark plugs may cause RFI interference with vehicle components such as ABS, GPS, mobile phones, traction control, ECU's, digital fuel injection and ignition systems, helmet intercoms, electronic instrumentation, etc.

5.6 What is 'heat range'?

When the fuel and air inside an engine is compressed by the upward stroke of the piston (compression pressure) and its ignited by the spark plug at the right time (ignition timing) the result is extreme pressure and heat forcing the piston to commence its downward travel. Combustion heat can be anywhere between 120 degrees C at idle, to 850 degrees C under extreme load. The spark plug is subjected to all these temperatures!

The *ideal* operating temperature for a spark plug is between 350 degrees C and 850 degrees C. This is achieved once the engine is at operating temperature and under normal operating conditions.

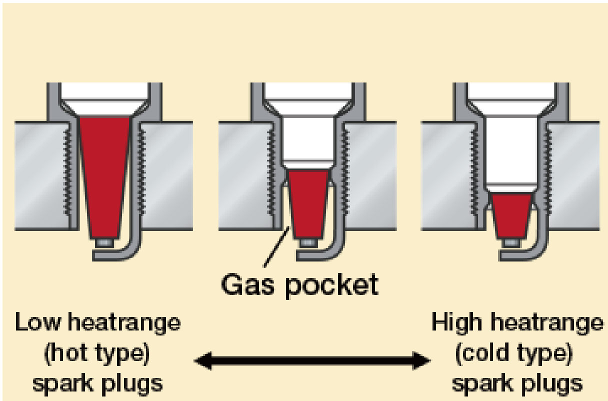
During highway cruising on light throttle, the tip temperature will settle around 350 to 450 degrees C. Hard acceleration and full throttle will see this temperature rise to between 650 and 800 degrees C.

Hard acceleration, even if it's just from traffic light to traffic light, will see temperatures move from 200 degrees C at idle, to around 850 Degrees C, just before reaching peak RPM. This means the firing tip temperature of your spark plug(s) rises as quickly as your tacho!

The Insulator, as well as wearing all that heat, also wears combustion deposits. In the days of leaded fuels and carburettors, fuel and carbon fouling on the insulator were a big problem. At certain combustion temperatures, this fouling may become conductive allowing the spark voltage to track up the side of the insulator nose and short out to the shell instead of jumping the gap. This is called *misfire.* Ethanol fuel mixes of more than 10% can also carbon foul plugs as described above.

The *heat range* of a spark plug is its ability to transfer the combustion heat out of the insulator nose at a controlled rate to burn off any carbon deposits at low speed, but not to become overheated at high speeds or loads. This is done by lengthening or shortening the insulator nose length to dissipate the heat at the correct rate.

A *hot plug* is one with a long insulator nose, a *cold plug* has a short insulator nose.




Spark plug manufacturers have refined this so well that regular gap, projected nose, and extra-long projected nose designs can all have the same heat range.

All spark plug manufacturers use this manufacturing method to establish their own heat ranges. However, manufacturers don't just take a guess. When designing a spark plug for an engine all aspects of engine design, components, power characteristics, emissions and type of use, are considered.

All spark plug heat ranges have an IMEP ( Indicated mean effective pressure) rating. The higher this rating is, the colder the plug. It's effectively the highest combustion pressure the spark plug firing tip can stand before it incites pre-ignition.

The ratings can be calculated mathematically or by mechanical means. These ratings are a secret between manufacturers. This means that even though different brands of spark plugs all have these ratings, the actual heat ranges are rarely identical between brands.

***Note:*** Be cautious when cross referencing, there is usually an overlap towards either hot or cold between different brands

Spark plug heat ranges are designated with a number, with each manufacturer using their own numbering system.

Most manufacturers use thermo-couple plugs which have temperature sensors embedded into the ceramic insulator nose to accurately determine the combustion temperatures the plug will be subjected to.

On-road thermo-couple testing is also used to confirm the spark plug manufacturers' recommendations as listed in their catalogue, as well as clarifying heat ranges in areas where low quality fuel may be used around the world.

The ideal fuel / air mixture is 14 parts of air to 1 part of fuel. This results in *complete burning* during combustion, resulting in very low emissions, improved power, greater fuel economy and longer life of all engine components including spark plugs. This has become possible with the development of digital fuel injection and computer-controlled engine management systems.

This almost perfect combustion effectively broadens the heat range of any given plug resulting in spark plugs lasting longer.

*5.7 Fuels*

When unleaded fuel was first introduced it wasn't without its problems. Engine manufacturers found it was not as 'forgiving' as the old leaded fuel.

Unleaded fuel caused engines to run hotter, many lacked power and it was difficult to find the 'sweet spot' when it came to tuning and meeting emission targets.

Since its introduction, engine design has changed dramatically, bigger, taller cylinder heads, larger water jackets and cooling systems and much more refinement of fuel injection and engine management systems.

Spark plugs changed as well, longer physically to fit the higher cylinder heads, many differing firing tip designs and materials, and some having both taper and gaskets seats on the one plug.

Champion informed us at the time, and confirmed by an NGK engineer 25 years later, that:

- 91 octane … explodes!
- 91 octane with ethanol added … explodes! But does have a benefit of being cooler.
- 95 octane … burns.
- 98 octane … burns more slowly and more evenly … Ah good.
- Safety Data Sheets from Shell suggest that Shell 98 and 95 octanes are very similar in design but indicate they are both high detergent types 'which will clean out the residue in the combustion chamber through the use of 91'!
- Shell suggest using a valve seat additive for every 3 hours of continuous hard use.
- BP have used the same chemical make up on all 3 types ,except 91 with 10% ethanol suggests it is water soluble! It's also less dense so will sit slightly higher in your carburettor.

## 6. Spark plug reading - background

Spark plug reading means ascertaining the condition, set up and performance of an engine by assessing a range of spark plug data.  An understanding of the following will help with spark plug reading.

### *6.1 Plug chops.*

Whether the engine that you are tuning is old or new, 4-stroke or 2-stroke, occasionally you should carry out a 'plug chop'.  This is simply putting the engine under some load at wide open throttle (WOT) preferably in top gear, but a lower gear will also give you a good reading. Any long uphill load is also good.

### *6.2 Inspection.*

It is important that after any adjustment has been made to the tuning of an engine, you should look at the plugs and make a note of any changes that you see.

### *6.3 Fuels.*

To obtain a clear reading on a plug you need to use a high octane fuel.  The use of 98 octane fuel is recommended in every engine until you see good clean readings. Avoid any fuel that has ethanol in it.  **(**Ethanol is largely made up of hydrocarbons and as such it makes plug reading almost impossible due to the high carbon deposits that remain on the plug).

### *6.4 Combustion chamber.*

The combustion chamber is the area above the piston when it's at top dead centre (TDC).  Combustion chambers can vary in shape in both 2 & 4-stroke and rotary engines. Some designs cause turbulence to assist in better mixing of the fuel and air, but most are designed to get the biggest volume of fuel and air into and out of the chamber as quickly as possible. This is referred to as 'volumetric efficiency'.

Cast Iron cylinder heads attract fuel particles to the surface of the combustion chamber and, for best burning and power output, it's advised to use regular gap type plugs to keep the spark firing tip as close to that surface as possible.

If an 18mm to 14mm adaptor is used, it's a good idea to check exactly where the firing tip of the plug is. In most cases the use of a projected nose design in an adaptor brings the firing tip into the best position. You may have to take the head off to ascertain exactly where the firing tip is.

Conversely, alloy heads are almost the opposite in that fuel particles will stay suspended within the incoming mixture.

Avoid using projected nose designs in two strokes unless recommended by the engine manufacturer. When you bring the spark plug firing tip closer to the top of the piston, you bring the flame closer, causing excessive heat into the piston crown.

Any machining of the combustion chamber will directly affect the compression ratio in all types of engines.

*6.5 Ignition Timing.*

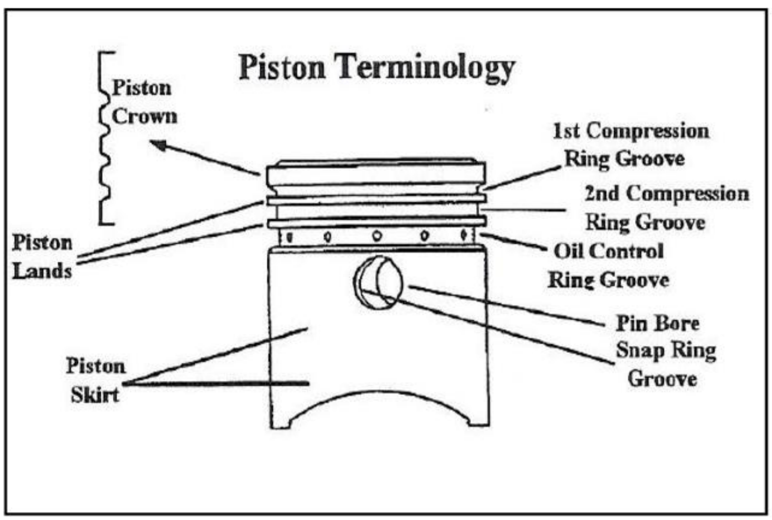
All types of fuels take time to ignite, therefore the spark at the firing tip has to occur slightly before the piston arrives at TDC. Getting the timing of that burn right results in maximum downward pressure on the piston as it starts its downward stroke. This is where and how maximum power is obtained.

Simply put, if the spark occurs too early as the piston is rising, flame propagation will begin resulting in total burning before the piston reaches TDC. This is *advanced timing* and results in huge pressure being applied to the top of the piston while trying to move to TDC, usually causing a knocking or pinging sound.

Even though some modern computer-controlled ignition systems automatically adjust the timing to meet varying engine loads, there will always be an initial setting for it to work from. The same applies to CDI and transistor ignitions designs.

*6.6 Detonation.*

As described above, over advanced timing ignites the mixture as the piston is heading toward TDC. Should sufficient burning occur before TDC the result is a huge increase in pressure as the piston is trying to compress the expanding flame. Increasing pressure results in increasing heat, which ignites any remaining fuel in the combustion chamber. The collision of two or more flame fronts is detonation.




The pressure waves from sustained detonation removes pieces of carbon and alloy from the piston crown giving the appearance of it being sandblasted.

Sustained detonation will hammer a hole through the piston. The hole is usually sharp edged. Radial cracks and a depressed area may be found adjacent to the actual break and crushed or broken ring lands (see diagram) may also be evident.

The increase in combustion temperatures may cause something within the combustion chamber to become incandescent and possibly overheat the spark plug firing tip, igniting the mixture well before any spark arrives at the firing tip. This simply compounds all that is happening.

With the aid of a slow-motion camera viewing a combustion chamber, Champion found it took as little as nine power strokes of a piston to destruct due to detonation. *Abnormal combustion* is the term used for this.

Factors that contribute to detonation include:

- Ignition timing too far advanced.
- Poor quality or old fuel.
- Fuel octane rating too low.
- Incorrect carburetion or air leaks in the intake manifold.
- Excessive intake manifold temperatures.

- Machining of the cylinder head or an increase in the compression ratio, modified cams and porting can instigate detonation.
- Spark plug heat range too hot.
- Poor cylinder head cooling

*6.7 Compression ratio.*

This is often overlooked when examining spark plugs as it does not leave a mark on a plug, it is literally invisible.

Compression ratio is a mathematical calculation of the cylinder volume with the piston at BDC, combined with the volume of the combustion chamber. This total is divided by the combustion chamber quantity. For example: Cylinder volume 350cc, combustion chamber volume 36cc, total 386cc divided by 36cc equals 10.7, so the compression ratio is 10.7 : 1.

Any increase in the compression ratio of an engine also results in increases in combustion pressure, power and heat. It is suggested to use a spark plug one or two heat ranges colder until some plug readings can be taken.

*6.8 Pre-Ignition.*

As the term implies, pre-ignition is ignition of the fuel /air charge prior to the timed spark. Factors that may instigate pre-ignition include:

- Any *hot spots* within the combustion chamber such as glowing carbon deposits, metallic edges such as the edge of a valve, part of the head gasket protruding into the chamber.
- Spark plug heat range too hot.
- Very lean mixture on that cylinder.
- Poor cylinder head or engine cooling.
- In 2-strokes, it is often a lack of lubrication causing *piston scuffing* resulting in over heated spark plugs.
- Spark plug not tightened securely.

Whatever the reason, the extreme heat caused by pre-ignition results in melted piston crowns and severely deformed pistons.

**7. Spark plug reading - what can they tell you?**

Because the spark plug 'lives' in the combustion environment, it 'sees' and 'records' all that occurs, no matter what the conditions!

Champion were the first spark plug company to offer 'plug reading' to all competitors in F1, Indy Car, NASCAR, Speedway, Drag Racing and all car and motorcycle GPs around the world and even at club level events when and where they could.

The reading of spark plugs is the same for all designs of internal combustion engines whether it's a lawn mower, or a Top Alcohol drag car.

The following steps are in the order in which I was taught many years ago when I worked for the Champion spark plug company, follow and repeat these steps every time you want to analyse a spark plug.

***Note:*** *More guidance on plug reading is provided in the diagrams in Appendix 1.*

| Reading step | What reading tells you |
|---|---|
| **1.** Remove all spark plugs and look at the threads. | • 3 to 3 ½ threads should be discoloured by heat, no more. This is a very good sign. This indicates that this cylinder has at some time been working hard, developing power and the plug has been dissipating the correct amount of combustion heat. It also indicates the plug's heat range is pretty close but do not rely on this alone.<br>• Turbocharged, supercharged and rotary engines may discolour 4 to 4 ½ threads. Discolouration of more than 4 threads on a naturally aspirated 4-stroke usually indicates retarded exhaust valve timing or blocked exhaust, muffler or catalytic converter.<br>• On multi-cylinder engines it pays to number all of the plugs. Check that they appear the same. If one plug has 4 or 5 threads discoloured, then there is a problem with that cylinder. If two corresponding plugs from a liquid cooled multi-cylinder engine show extra heat, this may indicate the head gasket between these two cylinders is leaking.<br>• 2-stroke engines rarely discolour more than 3 ½ threads. |
| **2.** Check the gasket and tapered seat areas. | • A Plug will simply overheat because it was not tightened sufficiently and any readings on it will be false.<br>• Check the gasket, it should be compressed evenly, if it's squashed very flat it has been overtightened.<br>• Do not use the plug again.<br>• If it's a tapered seat design, check the threaded portion of the Steel shell for signs of stretch or cracking indicating that it's been over-tightened. If it looks suspicious do not re-use it. |

| Reading step | What the reading tells you |
|---|---|
| **3.** Check both the centre and ground electrodes. | You are looking for the following:<br>• 'Blueing' or 'graining' around the tips of the electrodes indicates overheating. A small amount of blueing is OK. None is better!<br>• A deep blue colour or cracking on the tip of the ground electrode, closest to the piston, means the plug is 'seeing' too much heat. Check that the plug is the correct heat range for this engine type. If it's a projected nose design then revert to a regular gap type until the true cause is found.<br>• Either all the ground electrode or just one side will be coloured by the combustion heat, possibly a yellow or tan colour. This colour may cover part of the electrode or all the electrode right back to where it's welded to the shell.<br>• It shows two things, 1) the electrode is dissipating the heat that it is seeing, and 2) this is your ignition timing mark. This 'heat mark' should change to a darker colour at half the length of the electrode or halfway around the bend.<br>• On modern computer-controlled engines this heat discolouration may go all the way to the steel shell but don't be concerned as the computers are continually altering the Ignition timing and most have knock sensors to detect detonation so they don't stay over advanced for very long.<br>• On other than computer-controlled engines, the ignition timing is correct if the colour change is halfway around the bend.<br>• If there is no mark or just the tip is discoloured, it means the timing is retarded. The same colour all the way to the shell is slightly over advanced. We are only talking a few degrees either way.<br>• Electronic / computerised Ignition systems may go all the way to the steel shell.<br>• CDI, battery coil, and magneto ignition systems should not go past halfway around the bend.<br>• Check the firing tip of the centre electrode for a burnished half-moon mark, usually on the side of the electrode most likely out of the path of the incoming gas flow. This mark indicates that the whole ignition system is very performing very well!<br>• If no burnished mark is visible but the end face of the C/E has a light grey colour across it, this can indicate reasonable voltage but usually indicates a weakness of voltage in the primary side of the ignition system. |

| Reading step | What the reading tells you |
|---|---|
| **3.** Check both the centre and ground electrodes (continued) | • Poor connections in the ignition wiring or plug leads and caps not fitting securely can also contribute to this.<br>• A dry matt carbon coating without any visible voltage marks indicates weak voltage, which is usually coil related.<br>• Shiny black wet looking carbon over the nose of the plug is 'fuel fouling' which may be excessive fuel allowing the spark voltage to 'track' to the shell or a combination of both, too much fuel and weak ignition. |
| **4.** Check the terminal nut or post. | • Any black marks on the sides or top of the nut or stud indicates voltage has been jumping from the spark plug lead terminal to the post or nut if used.<br>• Poor fitting leads or severe engine vibration can cause this. |
| **5.** Check the end of the shell face. | • The shell face should have a smooth flat coating of carbon on it (it may take a few kilometres to 'colour up'). Smooth is good!<br>• If the end of the shell face is rough like the top of a pizza, the shell face is seeing detonation. The first things to check are ignition timing and fuel quality.<br>• Modern day unleaded fuel goes 'stale' very quickly. Sometimes fresh fuel will remedy this.<br>• If you see tiny shiny white specks, then the plug is being subjected to some serious detonation and the shiny specks are pieces of the piston.<br>• Cracks or chips in the ceramic insulator nose also suggest detonation has occurred or is occurring.<br>• Remember, detonation is not always audible!<br>• A few small 'pock' marks in the carbon on the shell face is acceptable and usually indicates a very small amount of detonation at some point through the power range. |
| **6.** Check the ceramic insulator. | • This step is the most important. Look up inside the steel shell to where the insulator touches the shell. Just before that point, check for a black carbon ring around the ceramic. This is the 'heat range ring'.<br>• This indicates that the insulator is cooling at the correct rate and that this spark plug's heat range is correct for this engine. The 'width' of this ring will vary with application, (type of engine, power output, type of use, etc.) but you should see one on every spark plug from every cylinder.<br>• As a guide, on carburetted 4-stroke engines, this ring may be as wide as one quarter of the length of the insulator nose. |

| Reading step | What the reading tells you |
|---|---|
| **6.** Check the ceramic insulator (continued) | • On electronically controlled fuel injected engines, the heat range ring may be as thin as a pencil line. The same applies for race engines.<br>• 2-stroke engines require a broader ring as there is no cooling intake charge sweeping across the plug as there is in a 4-stroke.<br>• Heat range marks are difficult to see however a magnifying torch makes it easier. To obtain the best view simply cut the thread off the plug to verify what you see (this is cheaper than melting a piston!).<br>• Check the firing end of the insulator for sugar like crystallising of the ceramic which indicates the firing tip is too hot even though you may have a safe looking heat range ring. Revert to a regular gap design or remove the steel gasket and replace it with a slightly thicker copper gasket. This will pull the nose back a bit and as copper transfers heat more quickly, it makes the plug half a heat range colder.<br>• Pepper like spots on the ceramic nose indicate the fuel / air mixture is too lean at some point through the power range. Go slightly richer in mixture or, do the above.<br>• With changes to fuels and oils you can no longer read the insulator for mixtures. You may see an oil or fuel stain on one side of the insulator nose. This is due to some oil or fuel sweeping across the nose with the incoming mixture. The oil will be from leaking valve guides and / or seals. Any other stain is from additives in the fuel melting onto the hot ceramic - nothing to worry about unless the deposits become excessive.<br>• Each time you alter a mixture setting you should also check the insulator for changes.<br>• Each time you go leaner at wide open throttle (WOT) the heat range ring will diminish. Each time you go richer the ring will get slightly broader. |
| **7.** Check the internal surface of the steel shell. | • This is where the plug records mixture strengths. Unleaded fuel has high hydrocarbon content and its residue is usually black in colour. The mixture strengths in an efficient 4-stroke unleaded engine will be recorded on the shell wall. It is extremely hard to see.<br>• The firing tip end of the inner shell wall has the darkest colour as this is the low speed and idle mixture reading.<br>• Halfway up the shell is the mid-range and this should be lighter in colour than the low speed colour.<br>• The top of the shell is the top-end or WOT position and again you should see a lighter shade. |

| Reading step | What the reading tells you |
|---|---|
| **7.** Check the internal surface of the steel shell (continued) | • You may see three distinct bands or the colour may change progressively as you look up the shell.<br>• It appears that in 4-strokes, the lighter you can get the top-end colour the better the power but this is only trial and error.<br>• Top quality methanol will have a mauve-brownish colour when the mixtures are correct. You will know when you have got the mixtures correct as the plugs will be clean and the colouration is distinct.<br>• Poor quality methanol shows up as a blackish-brown colour whether the mixtures are correct or not.<br>• 100 to 130 Octane racing fuel reveals colours slightly lighter to those of unleaded.<br>• 2-stroke Plugs are now read the same way but again, it's very difficult. What I have found is that the best reading inside the shell is on the opposite side from where the intake charge is sweeping in.<br>• Recent on-road-testing that I have done indicates that it's taking a long time for the plugs to see any colour, and the modern synthetic 2-stroke oil that I am using is leaving very few deposits.<br>• The 98 Octane fuel also runs very clean. |

***Footnote:*** I have read hundreds of spark plugs and have followed the above steps every time. Initially it seems slow but over time your eye will notice things before you realise it.

The trick is to keep doing it, keep looking at those plugs!

**8. Myths and truths!**

These are some of the things I have heard about spark plugs, and my response!

*'Wide gaps make you go faster'.*

**Myth!**

- The gap is set at the factory and is designed to cover the widest range of applications for that plug's design type.
- Drag racing teams increased plug gaps from 0.6mm to 1.00mm and more which improved initial acceleration but the elapsed time remained the same.
- Having different gaps on different cylinders does not mean the ignition timing is wrong on each cylinder unless there is a huge difference in gap sizes e.g., 0.6mm to 2.4mm.

*'The plug is leaking compression'.*

**Myth!**

- A purplish / brownish mark may appear around the ceramic insulator just above the shell roll over. This is known as corona discharge. As voltage travels through the Insulator the magnetic field that it creates attracts metallic dust and oil particles to stick to the ceramic. This was common many years ago when there was fuel and oil vapour and dust around engines. Atmospheric conditions also play a part in this occurring.

*'You get more power by putting the spark closer to the piston'.*

**Myth!**

- As discussed above, the position of the firing tip is confirmed by several factors including the desired emissions, power, torque, economy, fuel type etc. No matter what the combustion chamber design is, there is a point that if the firing tip is too close to the piston all you will succeed in doing is burning holes in pistons (pre-ignition).
- I found when dyno testing a 383c.i. sprint car engine, when we took the regular gap plugs out and put in some projected nose types of the same heat range, we got 10% improvement in torque with little drop off in horsepower. They didn't last very long (2 dyno runs) as the high compression, high horsepower and, high RPM resulted in the earth electrodes showing signs of melting. In this situation a colder plug would not have helped as the failure was the earth electrode alone. An earth electrode with copper inside it (double copper) may have survived.

*'Shortening the earth electrode will make it go faster'.*

***Truth!***

- In some combustion chambers filing back the earth electrode so that it covers half of the centre electrode results in improved 'flame propagation'. That is, the ionisation effect is improved, and the initial flame front is not hampered by the earth electrode. The industry term is 'J gap'. Champion produce them, (DJ8J) and NGK have a similar design, (B8HCS and B8ECS). I don't suggest it for all applications, but it does appear to work well in 2-strokes.

*Plug indexing, good or bad?*

***Don't Know!***

- Plug indexing is where the spark plugs earth electrodes are all pointing in the same direction. The question is which direction?
- The go-kart fraternity try to have the 'open face' of the earth electrode facing the incoming charge. some tuners swear by it, others don't agree.
- It's time consuming as each plug must be shimmed out a little to get them all facing which ever direction is desired.

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## 9. Do's and don'ts

**Do…** make sure you tighten all the spark plugs that you fit. Otherwise, the plug will overheat if it can't transfer the heat into the cylinder head.

With new gasket seat types, I suggest tightening the plug firmly then, loosen it off and re-tighten. You will find you will get an extra 1/8 $^{th}$ of a turn.

Tapered seat types are a bit tricky. Manufactures recommend tightening them 'finger tight' first, then 1/16 $^{th}$ of a turn. Make sure the area around the plugs is clean before removing them.

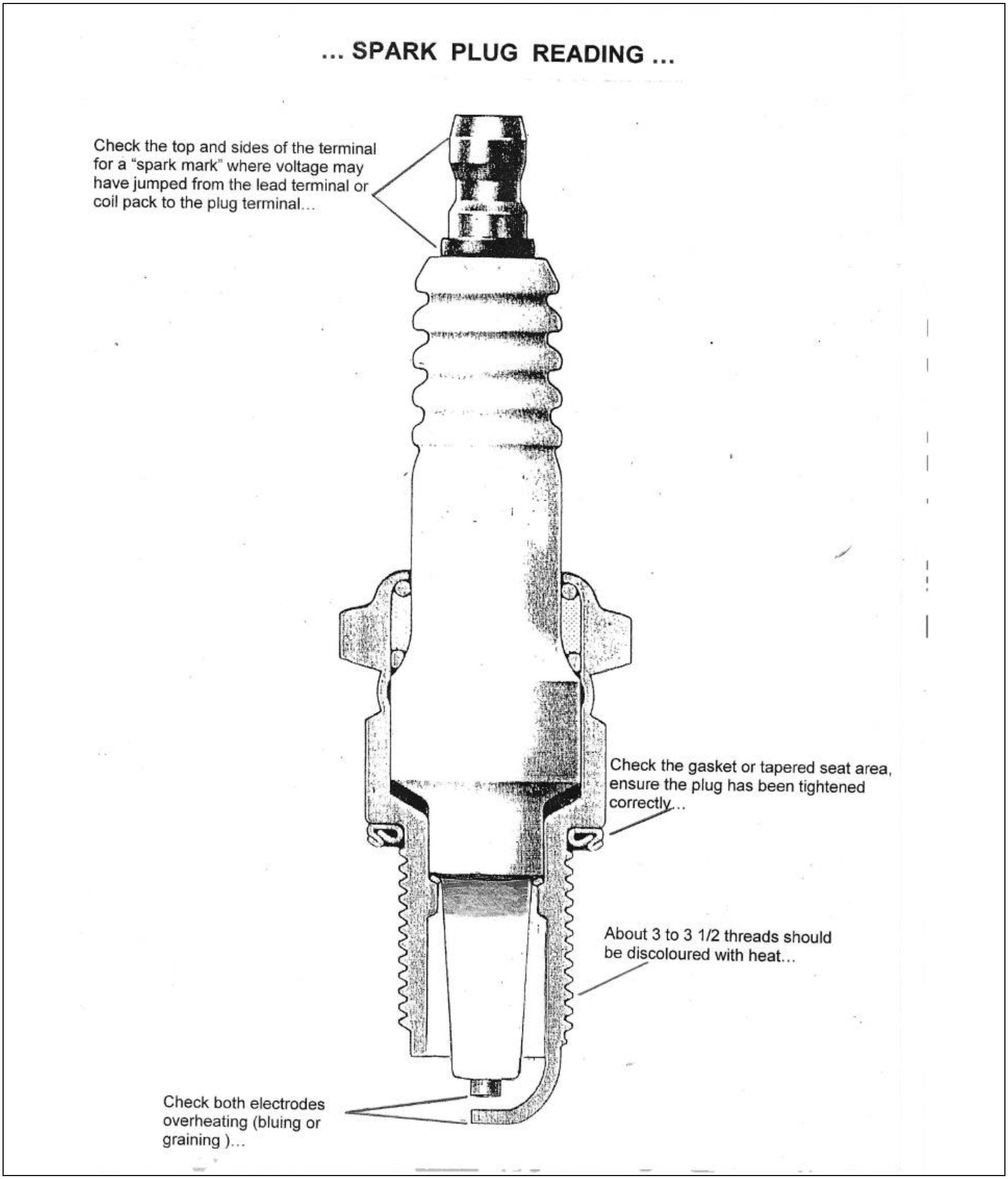
**Do** … use a drop of light oil on the thread, or a 'never seize' type lubricant, but only a tiny amount and make sure it is *non-conductive* as some brands are.

**Don't…** use grease.

**Don't …** wire brush the firing tip or insulator nose. Particles from the wires will remain embedded in the ceramic.

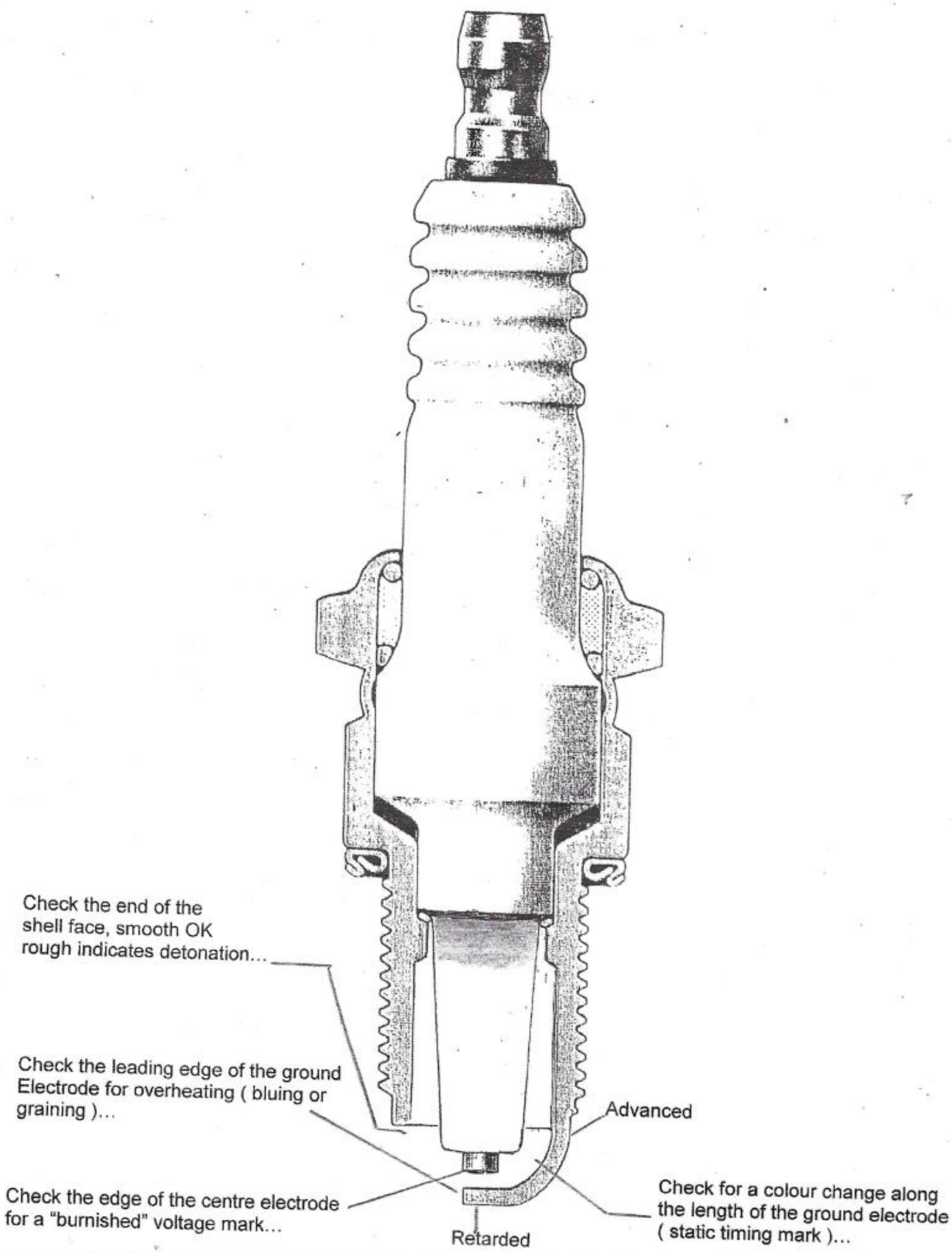
**Don't …** spray de-watering fluid or any chemicals around the top of a plug. Fluids such as these can ingress into the gas tight sillment powder under the roll over and dissolve it allowing the ceramic to move away from the shell and no longer transfer heat.

**Appendix 1**

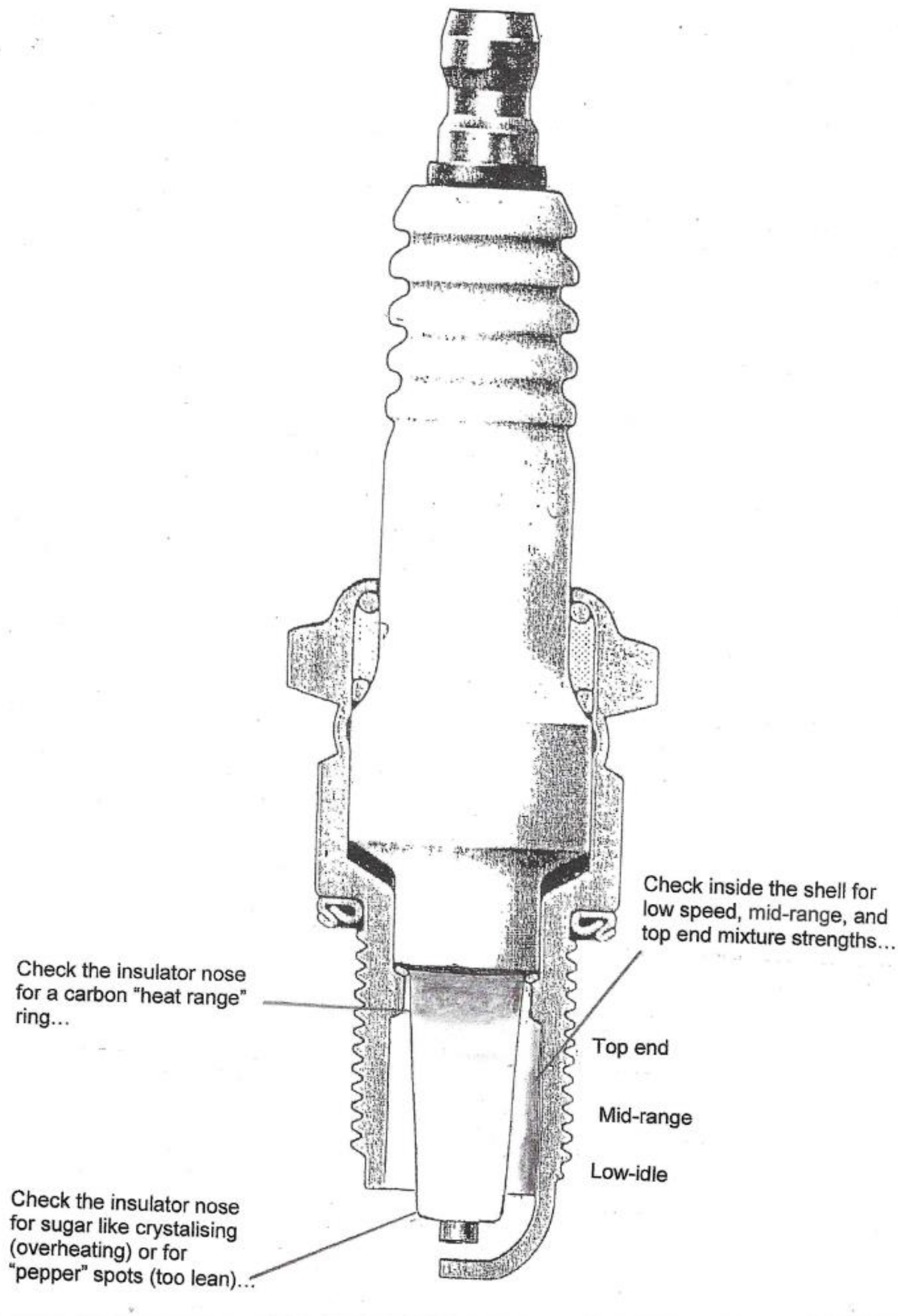


... SPARK PLUG READING ...
Check the top and sides of the terminal for a "spark mark" where voltage may have jumped from the lead terminal or coil pack to the plug terminal...
Check the gasket or tapered seat area, ensure the plug has been tightened correctly...
About 3 to 3 1/2 threads should be discoloured with heat...
Check both electrodes overheating (bluing or graining )...

# ... SPARK PLUG READING ...



# ... SPARK PLUG READING ...



**Appendix 2:**

**About the Author:**

I realised as I was doing this that I probably saw my first spark plug when I was about 6 years old. By the time I was 10 while we were playing with go-karts, I realised that it was the only thing in an engine that 'knew what was going on'. At 16, I started my mechanics apprenticeship at the Victorian Police Force Garage in Melbourne. Here I learnt a lot about plugs and it was normal to look at every plug and to know which cylinders each plug came from.

I was racing 2-stroke motorcycles at the time so I was always checking mixtures. I really didn't know what else to look for!

I moved to New Zealand and worked in motorcycle workshops, eventually working at Kawasaki N.Z. where I became involved in the race team preparing production bikes which scored many NZ titles. At the time I studied for and obtained my A-Grade in motorcycle engineering.

Due to health reasons, I was told to change my occupation and was then fortunate to gain employment at Champion Spark Plug N.Z.

I thought I could read plugs! I knew nothing but I soon learned.

Part of the job was conducting technical presentations to mechanics all around the country. New Zealand had the highest lead content of any fuel in the world which caused multiple problems with vehicles and Champion were changing some designs to combat the problems. We also attended as many race meetings as we could to reinforce the Champion brand and it was through this that I learnt a whole lot more about plug reading.

Champion transferred our family to Queensland in 1990 and I was involved in the first three Indy car race meetings on the Gold Coast. I was offered a position within Champion International to assist Simon Arkless and John Glover reading plugs and PR work in F1 and Indy car. Sadly, it never eventuated as Champion had begun to shrink its worldwide operations.

I was seconded by NGK Australia and was lucky enough to spend time in Japan on a 'technical trip'. I stayed with NGK for several years where I continued to do technical presentations and read plugs when I could.

I continue to read plugs and please feel free to contact me on johnfbutler52@outlook.com if you have any questions that are not answered above!

Thank You.

John Butler

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**Credits:**

Champion Spark Plug Company, USA, New Zealand & Australia.

NGK Australia, Japan.

To the many Race Teams and Engineers who waved spark plugs at me asking if I could see anything. They learnt something, and I learnt a lot.