Why Outboard Motors Use Special Spark Plugs

Back when Ole Evinrude was just beginning production of the very first successful outboard motors in 1909, selecting which spark plug to use was not too difficult. There wasn't much of a range available to choose from. Things have become a little more complicated since then, but surprisingly many of the basics are still the same. The criteria required to select the correct spark plug for any particular engine or application are now well established and an review of just what's required will help to explain all those unusual outboard motor spark plugs types, and some of the problems you might see associated with spark plugs.

Fouling

Very early in the development of spark ignition internal combustion engines it was discovered that used plugs gave problems which new ones did not. And it only took a few minutes of use in some cases before the engine would start to misfire, or even stop. The cause was a layer of conductive carbon deposits on the insulator nose during combustion. This is what's known as fouling.

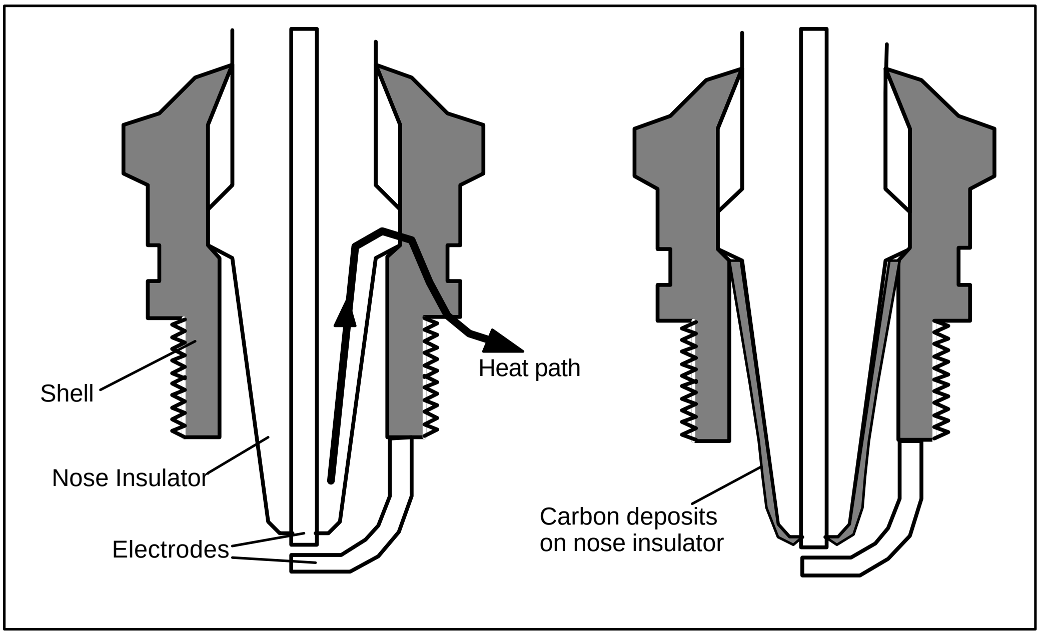

Figure 1 - Firing end of a typical spark plug.

Figure 1 shows a typical spark plug nose insulator shape. Once a thin layer of soft, wet carbon as formed on the nose insulator (as shown on the right) it provides a partial short circuit that bleeds off electrical energy nearly as fast as it is being generated. If enough energy is bled off, there will not be sufficient left to jump the gap and a misfire occurs.

The traditional cure for fouling was to construct the spark plug so that the nose insulator stayed quite hot, hot enough to burn off the carbon deposits as they formed, but not so hot that it caused ignition of the of fuel before the spark. Different engines required different shape nose insulators to get the temperature just right, and this became known as the "heat range" of the spark plug. The arrow shown on the left side of Figure 1 shows the path heat must travel to get from the nose insulator to the cooling system. The longer the path, the hotter the nose insulator would run.

Heat Range

In the early days spark plug heat range was established by trial and error, today it's done by using special thermocouple spark plugs that measure combustion temperature and computers are used to record these temperatures across the speed range so the correct plug heat range can be selected. Figure 2 shows the results of just such a test in a large modern outboard motor.

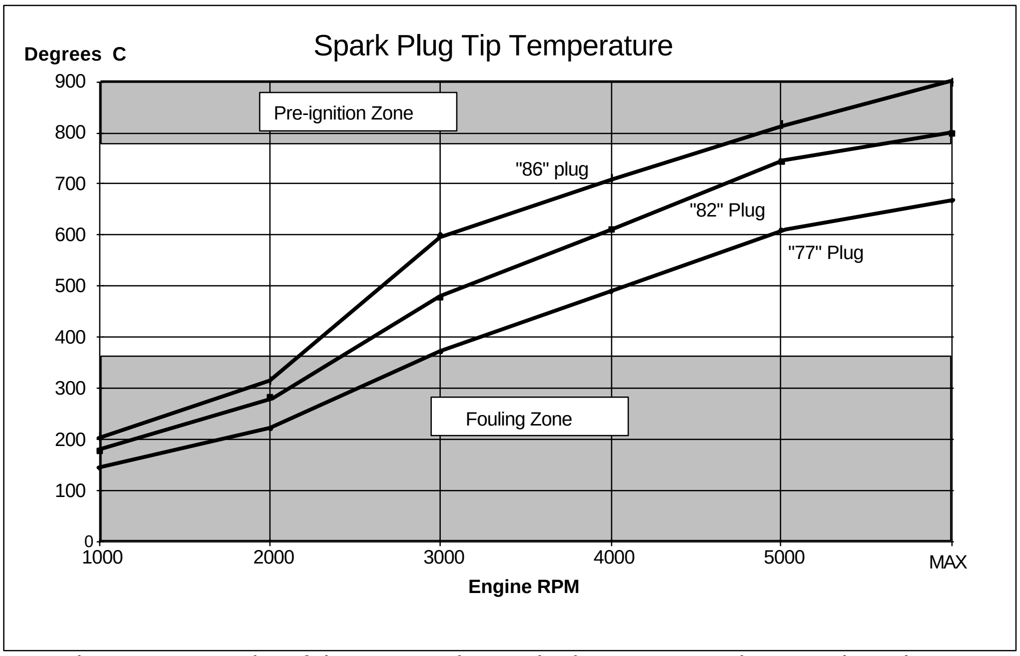

Figure 2 - Results of thermocouple spark plug tests on a large outboard.

Testing has shown that fouling occurs if the end of the nose insulator, or tip, goes below 350 to 400 degrees C. This is the fouling zone. At the opposite end of the scale, if the tip temperature gets above 750 to 800 degrees C combustion can occur without a spark. This is the pre-ignition zone.

Figure 2 shows three different heat range spark plugs tested in the same engine, fitted to a large offshore fishing rig and tested on the water. All three plugs start out quite cold at low speed and get progressively hotter as the speed, and power output, rises. All three plugs tested are cold enough at low speed to experience fouling problems. The "86" and "82" test plugs also get hot enough to cause pre-ignition a high speed.

On this modern high output engine a spark plug that stays warm enough to prevent low speed fouling would then easily cause pre-ignition at high speed. Or alternatively, a plug which stays below the pre-ignition temperature zone at high speed is then far too cold at low speed. This is common on high output engines and really started to cause headaches for engine designers in the 1950's and 1960's. Up until then power output per litre was lower and heat range alone was usually sufficient to prevent either fouling or pre-ignition.

Once designers realised that selecting heat range was no longer sufficient, they started looking in other directions. Spark plug developments gave some assistance, for example, extending the nose insulator out into the combustion chamber (as shown in Figure 1) caused it to stay warmer at low speed (because it was longer), but cooler at high speed (because it was cooled by the fresh charge flowing past). This type of design provided a wider heat range, but for larger outboard motors it was not enough.

Low speed fouling is inconvenient, but pre-ignition is life threatening to the engine, so the decision on which plug to use came down to using a relatively cold heat range plug, then employing a variety of strategies for avoiding low speeds, and therefore fouling. Strange as it may seem today, there were engines around up into the 1950's that basically did not idle nor did they have any neutral gear. You just pointed the boat away from the shore, and any other obstacles, then hit the starter and off you went at relatively high speed. OK for some race boats maybe, but not really acceptable for family boating.

Rise Time

Another area designers had been investigating for some time was the effect of ignition rise time. This is the time it takes for the system to go from zero up to sufficient volts to jump the plug gap. Different types of ignition systems were found to have quite different rise times and effect on low speed fouling.

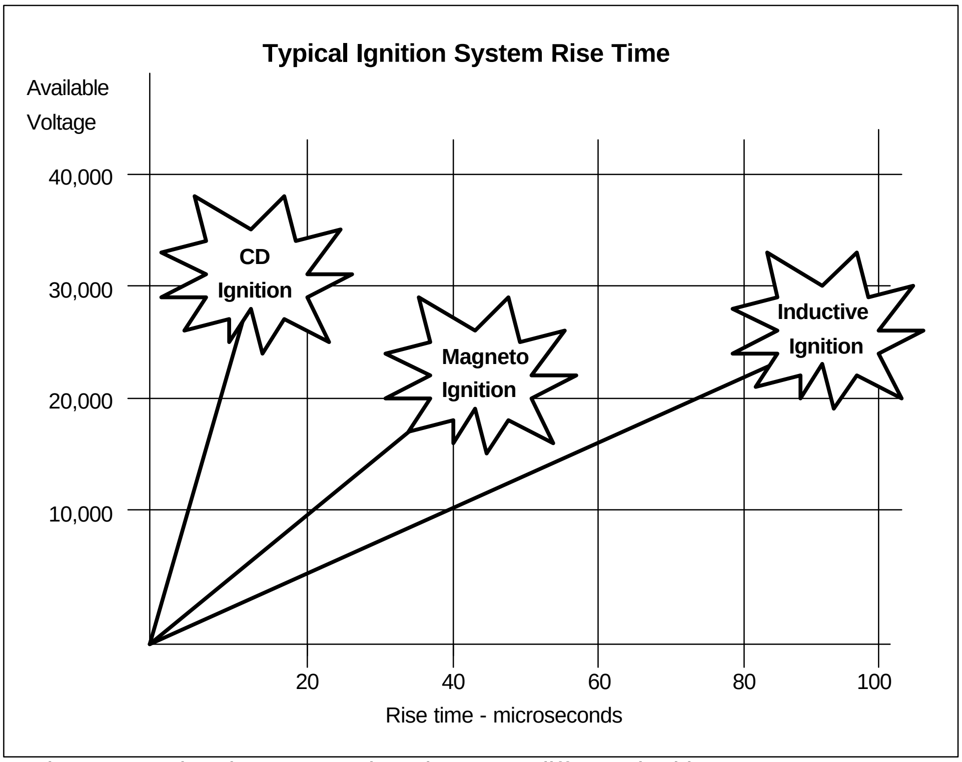

Figure 3. - Rise time comparison between different ignition system types.

Figure 3 shows some typical examples. The very common (at that time) inductive system which used a battery, coil and points had a rise time around 100 - 125 microseconds (millionths of a second). It's hard to think of something measured in microseconds as being slow, but for ignition systems this one is.

Even a well fouled spark plug is usually not a short circuit from centre electrode to ground. Rather it's more like a slow leak that bleeds off the electrical energy as it is being built up to the level required to jump the gap. The longer it takes to build up voltage, the more time there is available for it to leak away through the nose insulator deposits. Hence slow rise time ignition systems are more prone to plug fouling problems.

Magneto systems were better with a typical rise time around 50 microseconds. Motors using magneto's had less plug fouling, and for this reason they were always popular for small outboards (one or two cylinders) and on all sorts of motors modified for racing.

CD, or capacitor discharge, ignition had been experimented with on aircraft engines in the 1950's, but it had been difficult make and keep reliable, especially at high altitude. It had the advantage of very fast rise time, typically down around 10 microseconds, but the disadvantage of being hard to construct. When transistorised electronics became commonly available in the late 1950's, then plastic encapsulating compounds in the early 1960's, a means of both mass production and protection from the environment existed and CD ignition started to appear on production outboards.

Surface Gap Spark Plugs

As shown in Figure 3 the three types of commonly available ignition systems are all capable of providing the 20,000 + voltages required, for normal engine operation. In fact examples exist of all three types which are all capable of over 40,000 volts. Output is not the reason for selection, but fast rise time. With the advent of CD ignition on production engines, very cold spark plugs were now used to ensure no likelihood of pre-ignition and a type of spark plug which has no nose insulator length or ground electrode was developed. These are the "Surface Gap" spark plugs as shown in Figure 4.

Surface gap plugs have a very short heat path and therefore a very cold heat range. They don't even appear on most heat range charts because they are off the bottom of the scale (down in the fouling zone) across the whole speed range. Having the spark gap formed between the centre electrode and body or shell of the plug also gave a very large spark area, which meant a longer life before the gap would wear large enough to cause problems. Some outboard manufacturers even advertised that surface gaps would "last the life of the engine"!, and they were not far from the truth. Tests conducted with high usage customers in the 1970's showed it was possible to get over 500 hours out of surface gap plugs. When most recreational use engines rarely exceed 50 hours per year that meant over 10 years was possible.

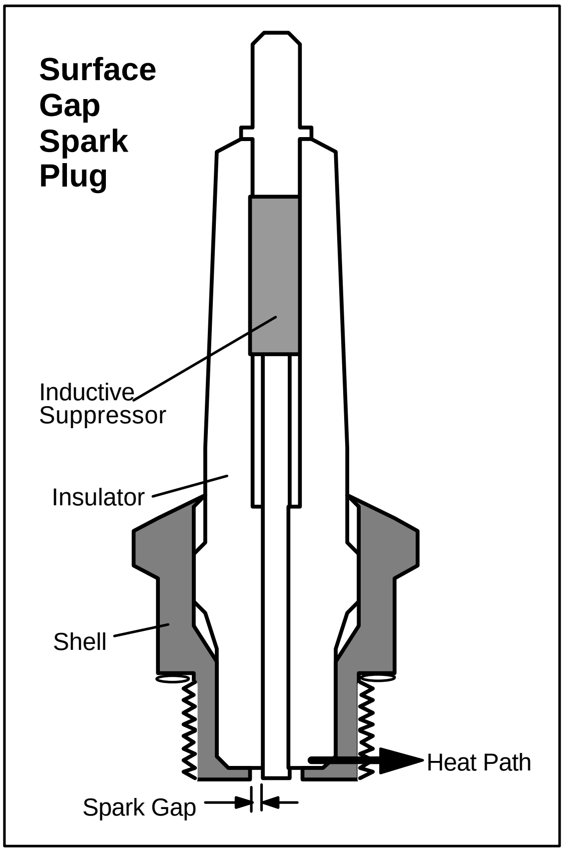

Figure 4 - Construction of a surface gap spark plug.

Early CD ignition outboards used a distributor cap and rotor in the high tension circuit, just like most cars still do. However in a marine environment any sparks outside the combustion chamber are more of a safety concern, so in the 1970's manufacturers started moving towards solid state distribution, that is, one ignition coil per cylinder and no more distributor.

Auxiliary Gaps

This move had an undesirable effect on rise time. The distributor system had two spark gaps, one from rotor to cap, and one at the spark plug. The gap between distributor rotor and cap meant that no spark energy got to the spark plug until first it had overcome the rotor gap. This in fact shortened the rise time, as seen at the spark plug electrodes. Without the distributor rotor gap, fouling started to occur again. The solution was simple, add back the extra gap, but put it inside the spark plug. This is the Auxiliary gap spark plug. Figure 5 shows where the gap is located.

Having a gap inside the spark plug insulator means that a small amount of ozone gas is created each time a spark occurs. Pressure builds up in the auxiliary gap making it more and more difficult for the spark to jump the gap, so a vent is required (distributors also have a vent for the same reason). This is a small hole through the spark plug terminal at the outer end of the plug, as shown in Figure 5.

The amount of ozone created is very small and it usually has no trouble getting out past even a tight fitting rubber cap, but if the spark plug cap, or boot, is retained by a tie strap or a clamp, then trouble is not far away. If you've ever had a motor fitted with auxiliary gap plugs start to misfire after a couple of hours, and then miraculously recover as soon as you pulled off the plug boots, build up of ozone in the auxiliary gap is very likely the problem. Using grease to make the cap slip easily over the pug can also cause this problem when it blocks the vent hole. Motors using auxiliary gap plugs and fitted with tie straps or clamps around the plug boots (in an attempt to make them more waterproof) would sometimes develop enough pressure to actually blow the plug boot off the plug!

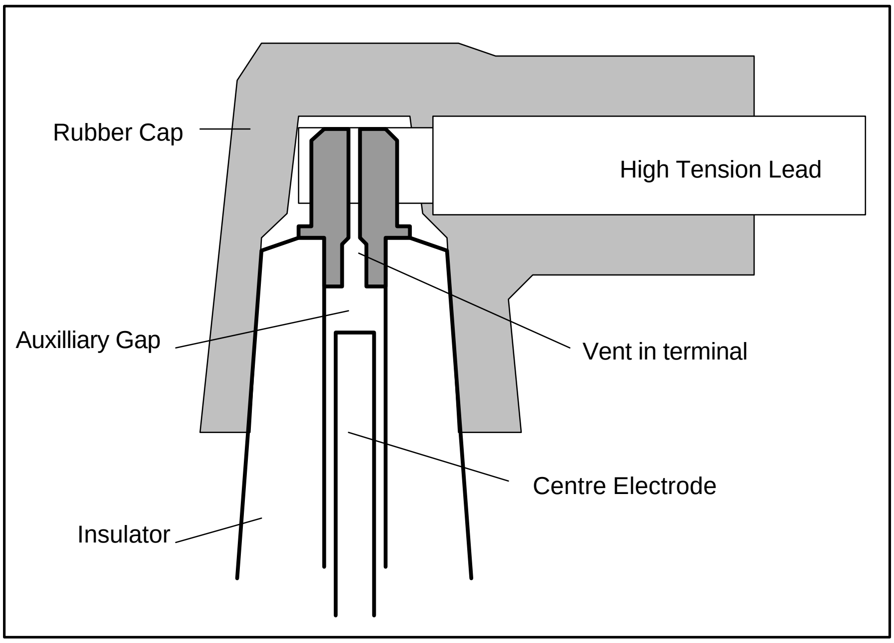

Figure 5 - Location of the auxiliary gap and gas vent.

You can also get a similar result sometimes on a running motor without auxiliary gap plugs. If a plug is fouled, then slowly removing the plug boot while the motor is running creates an auxiliary gap that can often start the fouled plug firing again. Some old timers may well remember that auxiliary gaps came out in the 1950's to fix fouling caused by worn rings and oil burning in some cars of the time. One of the "bush fixes" was to cut the high tension wire and put the ends through the holes in a shirt button, thereby creating an auxiliary gap!

Today with our unleaded fuels of generally lower octane than was common 20 years ago outboard motors now use lower compressions ratios and consequently combustion chamber temperatures are lower, so surface gap plugs are no longer so essential (although many older, high compression, models must still use them). This, together with todays greater emphasis on economy and lower emissions, has seen a move back to more conventional type electrode shapes (as in Figure 1) with extended nose insulators to ensure the spark occurs in the most favouravble location inside the combustion chamber.

EMI or RFI?

Another important area for outboard motor spark plugs is Electro-Magnetic Interference (EMI) or as it used to be called, Radio Frequency Interference (RFI). Any device that creates rapidly moving magnetic fields, like an ignition system, also creates interference with surrounding electronics. How much interference depends on how much is radiated by the ignition system and how susceptible the surrounding electronics are to small electrical currents.

Just as the magnetic force lines move through the ignition coil secondary windings to create the spark, the also move through any other wires (or printed circuits) in the vicinity and create undesirable currents. Back when the lowest voltage in engine systems was 12 volts, it took a lot of EMI to cause problems. More often it was only the radio or depth sounder that suffered, because they both have antenna or receiver systems tuned to respond to tiny voltages.

Today there are digital integrated circuits and microprocessors even in the simplest of engine and surrounding systems. These systems may be powered by the same old 12 volt battery, but internally they operate on much lower voltages, typically 5 volts, with some of the latest type using under 3 volts. Smaller voltages mean less heat generation and therefore the components can be reduced in size and eventually cost. Unfortunately, smaller operating voltages also mean the system is more susceptible to interference by magnetic fields, so suppression of EMI is now an important part of every modern engine and is required by legislation in an increasing number of countries.

Marine engines like outboard motors need to have their electronics installed on the motor, and therefore in a location close to the source of any interference, so being aware of the measures taken for prevent EMI is essential for technicians. Reducing interference in the high tension part of the ignition systems is concentrated on the spark plugs and their wires.

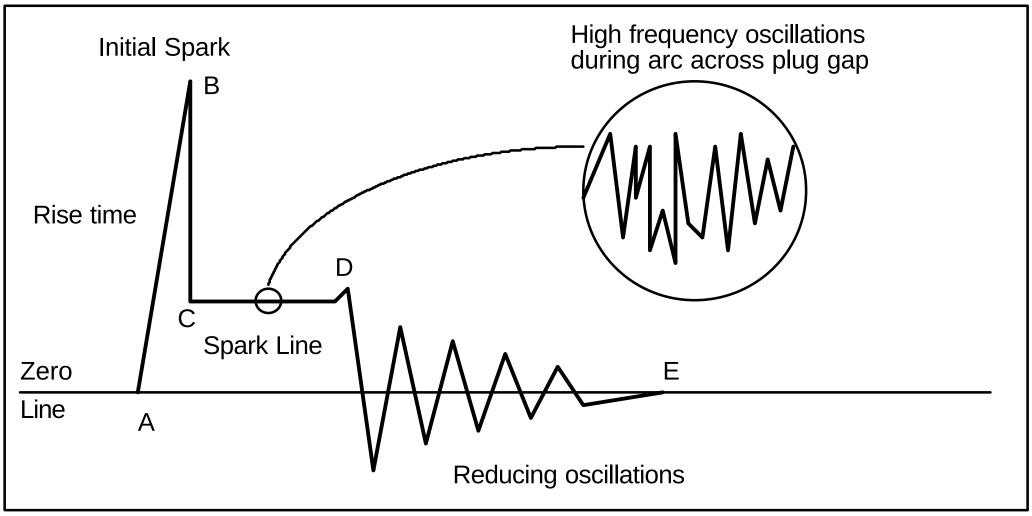

Figure 6 - Oscilloscope trace of ignition secondary voltage.

Figure 6 show a typical oscilloscope trace of an ignition coil output. The rise time from zero volts to initial spark is A to B, with point B being the beginning of the arc across the spark plug electrodes. B to C shows the drop in voltage once the arc is started and C to D shows the arc duration, a period when the arc is actually re-started several times due to high frequency oscillations occurring in the coil windings (as shown in the insert). At point D the arc ceases, but the oscillations continue and slowly diminish until finally stopping at point E. All of this, from A to E, only takes about a thousandth of a second, but that's for each cylinder, every time one fires, and at high rpm it's just about continuous.

Reducing the EMC effects typically requires reducing the number of oscillations. For inductive ignition systems we use either resistance type high tension leads or a resistor in the spark plug. These typically have a series resistance of around 10,000 ohms, which greatly reduces the number oscillations and shortens the arc duration. Shortening the arc duration is rarely a problem on inductive type systems because they naturally have arc durations much longer than needed. However, CD systems have quite short arc duration to start with, so placing 10,000 ohms in the system can reduce the arc duration by half, and lead to misfire problems.

What CD systems need is a low resistance suppressor called a high inductive reactance type. These measure less than 50 ohms so do not pose much of a resistance to high voltage DC currents, but their construction looks like a small coil of very fine wire and this poses a high resistance to AC currents. Figure 4 shows where they are located in the spark plug. These special suppressor plugs for CD systems are identified usually by the letter Q in Champion brand or Z with NGK.

Some CD ignition systems also use suppression high tension cables, but these are a special low resistance type (about 500 ohms per foot or 1600 per metre) and must not be substituted with conventional inductive system leads which measure about 7000 ohms per foot or 24,000 per metre.

Today with our modern electronically controlled engines, plus all our other electronic accessories (radio, phone, GPS, etc) these plugs are absolutely essential. Not using them in many current outboards can cause problems as diverse as false warning system activation or noisy radio (inconvenient) through to engines trying to run backwards during start up (deadly for starter motors).