Spark Plug Voltage Requirements

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Once again, we will address another electrical topic where there isn't a lot of solid information available to most people. This time, we will be addressing the topic: "How do I test an outboard motor for adequate electrical spark"? Well, what most people do is simply pull out their spark plugs, attach the spark wires, and hold the plugs against the engine block…..and crank the motor over. If they see a bright spark, they assume that the electrical system is good, re-install the plugs, and then move on. However, as we will soon see, this isn't a very good test at all. It does tell you if the ignition system is completely dead or not. However, just because your spark can jump across a plug in open air doesn't mean your ignition system can fire that same plug when installed in your engine! This isn't obvious, but let's look at some physics here and find out why.

1) **HOW MUCH VOLTAGE DOES IT TAKE FOR A SPARK TO JUMP AN AIR GAP?**

It's a lot less than you think. In DRY AIR, at ONE ATMOSPHERE (14.7 PSI), it's about 75,000 volts to jump 1" of air gap.

Let's say you gap your plug to 0.035"....... 1" / 0.035" is 28.57. Simple math shows that **75,000V / 28.57 gives you 2,625 V to jump your 0.035" spark plug gap, in free air, at one atmosphere, between two SPHERICAL conductors. (Not across POINTED conductors!)** It does not matter that your coil can POTENTIALLY produce 40,000 V......as soon as the coil voltage hits 2,625V, it will jump the gap, and "short out" the coil. This limits the peak voltage across the gap to only 2,625V.....again, at ONE ATMOSPHERE, and going through DRY AIR. Not 20,000V, or 50,000V......only 2,625V. That's nowhere near an adequate test of the insulation in your plug wires and spark coil, as we'll soon see.

OK, let's start hauling in the other factors. Lots of things can alter this discharge voltage....including the SHAPE of the conductors on either side of the gap, air pressure (based on COMPRESSION RATIO), fuel / air temperature, and so on.
Here's a quick overview:
https://www.denso.com/global/en/products-and-services/automotive-service-parts-and-accessories/plug/basic/spark/condition.html

SO, how severe are each of these effects?

2) **ELECTRODE SHAPE**...... Well, POINTED conductors emit electrons more easily. FLAT conductors take higher voltage. ROUNDED OFF conductors are the worst .... (this is why when your electrodes on your spark plugs wear down and get "rounded off", it takes a higher voltage to jump this gap.)

However............my voltage calculations in section (1), above, assumed SPHERICAL conductors across the gap, which is the WORST POSSIBLE CASE already. If you file one of the conductors to a needle point, it can greatly lower the voltage needed to jump that gap, from 2,625 V down to maybe 1,500V or even less. So, let's assume ROUNDED OFF electrodes, to keep it at our maximum 2,625V to jump our 0.035" spark plug gap.

4) **Fuel / Air mixture.** That 2,625V assumes that you have DRY AIR in the spark gap. When mix liquid fuel into the air, that just about doubles the voltage needed to jump the gap, to about 5,000 V (or a bit higher). Don't ask me why; according to experts, it just does.

5) **AIR PRESSURE / Compression Ratio** As you know, the pressure in your cylinder when the spark plug fires is also based on PRESSURE, and this is directly proportional to the COMPRESSION RATIO of your engine. And, here's where things start to get really interesting!

See this online spark gap calculator:

http://www.mazdamaniac.com/spark_gap_calculator.htm

NOTE: The spark gap in all of these examples was set to 0.035" The atmospheric pressure was set to 101.3 kPA (kilo Pascals, which equals 14.7 PSI, or ONE standard atmosphere) The intake air temperature is 35 degrees C (inlet air temperature does have some effect on voltage needed to jump the spark gap, but not a lot. Experiment with this online calculator and see for yourself.)

I entered every compression ratio from 1.0:1 to 12.0:1 and here's how that affects the spark voltage: Note: "PSI" is Pounds per Square Inch, and is what you would read on your compression tester, to check conditions of cylinders, pistons, and rings.

Compression Ratio	PSI	Voltage to jump this Spark Gap	Recommended Min. Octane Rating	
1.0	14.7	5,673V		<-- This is your plug firing in open air
2.0	29.4	7,053V		
3.0	44.1	8,433V		
4.0	58.8	9,806V	64	<-- Engines don't run well, if at all, at compression test of less than this!
5.0	73.5	11,174V	69	
6.0	88.2	12,559V	74	
7.0	102.9	13,932V	79	<-- 1970's vintage smog motors... or, your average low-performance outboard
8.0	117.6	15,309V	84	<-- Typical "grocery getter" car, unleaded gas, today
9.0	132.3	16,689V	88	
10.0	147.0	18,064V	93	<-- Looking at "performance engines" here!
11.0	161.7	19,421V	97/98	<-- This is tough to find.....
12.0	176.4	20,803V	104	<-- Remember 104 octane Sunoco 260, and Super Shell? Ah, yes, the good old days!
(20.48)	300 PSI	32,458V	<-Cyl. Peak Pressure after ignition, at IDLE	
(47.61)	700 PSI	69,764V	<-Cyl. Peak Pressure after ignition, at FULL POWER (Standard Engine, or outboard)	
(68.02)	1000 PSI	97,763V	<-Cyl. Peak Pressure after ignition, at FULL POWER (High performance engine, "boosted")	

NOTE: The Octane recommendations (above) were from:
https://www.energy.gov/eere/vehicles/articles/fotw-1043-august-20-2018-engine-compression-ratio-and-gasoline-octane-rating

Remember that modern cars have "knock sensors" and computers that retard the timing to prevent "ping" and "detonation" if you put garbage gas in vehicles that require higher octane. Old outboards don't have sensors and ignition computers to do this, so use sub-standard octane fuel at your own risk! If you are worried, you should back off your timing a bit to prevent "ping" and potential engine damage with slightly sub-standard gas.

Reviewing this table (above), we saw our "5,000V gap" jump up to 20KV, just because of compression ratio. **So, now our "20KV" ignition requirements are beginning to make sense.**

OH....also note that the voltages in the table above are MAXIMUMS at full throttle. If you throttle back, you start pulling a vacuum, so the PSI peak pressure goes dramatically DOWN (as does the voltage required to jump your spark plug gaps) when running the engine at low speed or idle, and not under heavy load.

6) **Screwy spark plugs (Non-resistor, resistor, "Pulse", "Capacitor Gap" and other oddities)**

Let's deal with the "resistor vs. non-resistor plugs" issue first. As you will recall, our old outboards used SOLID CORE wire, and NON-RESISTOR plugs. Here's what happens when you use "resistor" plugs:

The resistor plugs reduce Radio Frequency interference by damping the oscillating electrical waves jumping across your spark gap.

The average current through a spark plug at 1 mS is approx. 250 mA or 0.250 Amps.

A resistor spark pug has a resistance of less than 10,000 ohms. (Typically 5K ohms, but let's use the larger number to note the impact)

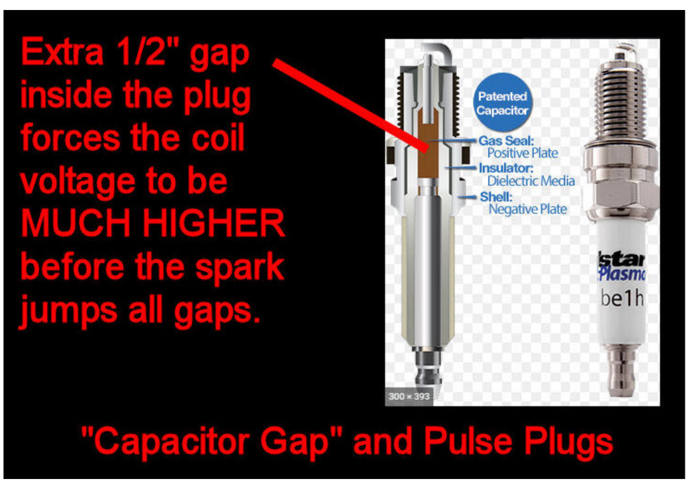
So then, the voltage drop across the resistance cylinder (slug) in the spark plug is therefore about 2,500 volts.

For an ignition system with a coil secondary voltage of 25,000 volts, this drop represents a 10% drop in voltage, or a drop in the bucket compared to the coil voltage.

OK, what about resistor WIRE? Modern ignition wires are around 10,000 to 12,000 ohms PER FOOT. Figure 1 to 2 feet of spark wire, and this adds another 6,000V drop to your ignition requirements.

So....20KV, plus 2,500V for the resistor plug and 6,000V for 2' of wire, and you can hit 28,500V. That's 30KV......for an ignition system with high compression, and resistor plugs AND resistor wire all included. If the insulation in your plug wires or coil is marginal, this can cause arcing and ignition system failures.

What about oddball plugs, like "Pulse" plugs and "Capacitor Gap" plugs? Well, I looked at the pictures of several of these plugs, and most looked a lot like the plug picture below:



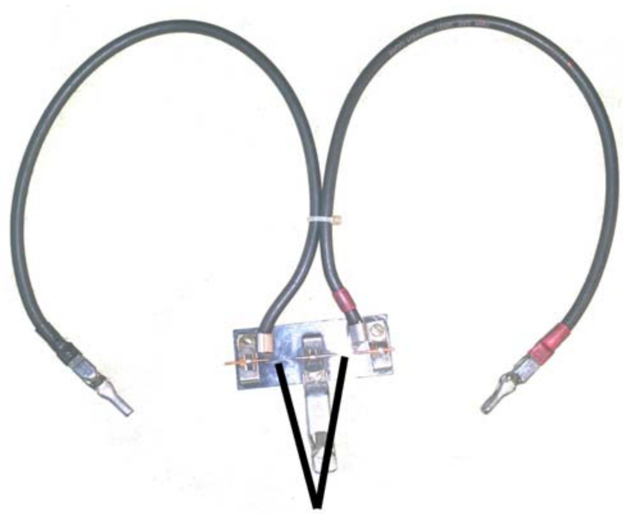
Yes, I read some of the patents, and they make lots of claims that I don't think are very valid (if at all). Unless I'm misreading the patent literature, most of these plugs just add a large arc gap inside the plug (of about 1/2"), which will add another 25,000 to 30,000V requirement on your coil, before ALL of the spark gaps in the entire circuit can be jumped. **This can EASILY boost the requirements on your coil to > 50,000V, before all of the arcs in the series circuit can be jumped.** This gives you a "hotter spark".... but also puts INCREDIBLE STRESS on your wires, plugs, distributor cap (if used). If thre are any flaws, you'll get sparks jumping to places OTHER than across the gap in your plug. (e.g. arcing from the coil and wires to the engine block, and NOT jumping the gap in the plug). I STRONGLY suggest you NOT use these in your old outboards!

I'm sure there are other things plug manufacturers do that wind up raising the voltage required to jump across the "gap" in their plugs.....but series gaps and / or resistor elements are the most obvious.

Conclusions:

When we test old outboard ignition systems, we should probably test them with about a 1/2" air gap, because that more closely simulates the voltage demands seen when that coil will be firing a plug, with a 0.035" gap, in a outboard engine cylinder, with a 10 to 1 compression ratio on the fuel-air mixture. This is probably the "Rule of Thumb" we should be using. It will cause more coils to fail and "arc over" internally than we would see with about a 0.035" spark gap setting, but it's probably better we that find these flaws BEFORE we assemble a motor, and then ASSUME the spark is good.

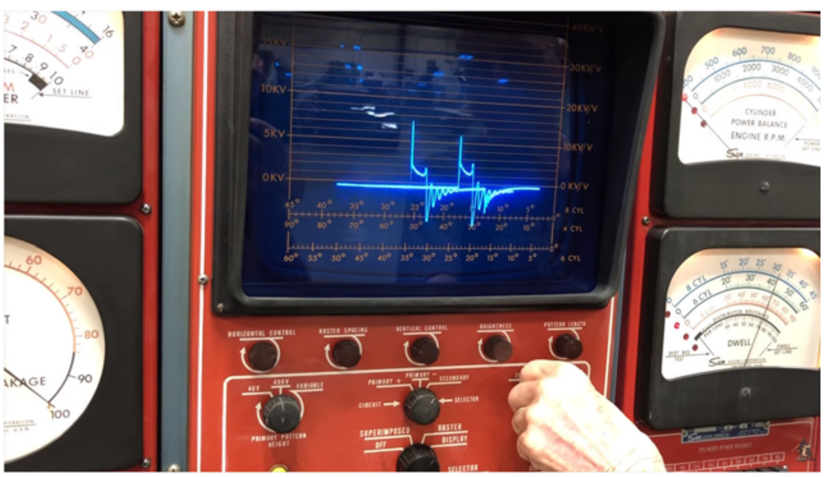
See the picture below for a typical “spark gap tester”. Set yours to about a 1/2" gap, and this will stress your coils and spark wires to about 18,000V. This should be a really good test for most outboard ignition systems. If your ignition system can jump this gap (and not arc over elsewhere or inside the coil), your ignition system is in really good shape and should perform just fine under load.



Set the point gaps to 0.5", for 18KV test.

Fig. ZZ - Spark Gap Tester

One last odd point: **how could someone measure these voltages, to be absolutely sure?** Well, in the good old days, you could get your SUN Ignition Analyzer out, (essentially a big oscilloscope), and you could directly measure the voltages at the spark plug wires. But, relatively few people have access to such a piece of test equipment today.



Note: if your old outboard's raw ignition system is causing radio interference with the electronics on your boat, you can switch to resistor WIRES or resistor PLUGS, **but NOT BOTH,** as the higher voltage demands of doing both might overwhelm the ability of your magneto to produce enough spark voltage to work correctly. EITHER of those solutions individually will solve your RF interference problems, and doing both at the same time really is overkill.

Oh, hey, while we are at it.......the question **PEAK CYLINDER PRESSURES** is a related topic of some interest. With our compression tester, we can see how much pressure the piston / rings / cylinder produce with NO SPARK. But, what does the pressure go up to when OPERATING? **Well, at IDLE or low speed, most small internal combustion engines will develop peak cylinder pressures of about 300 P.S.I. Standard engines peak at about 1000 P.S.I. when running maximum power (throttle plates wide open, under load). High performance, high compression piston engines can reach about 1,500 P.S.I. at max power levels.** (This is with a carburetor. Turbos and superchargers can GREATLY increase these peak pressures!) However, crossing 2,000 P.S.I requires forged pistons, stronger rods / rod bolts, etc, etc, etc, and even then, piston damage is very common when a turbo is cranked up to too much boost, on too low of octane fuel. This is great fun to watch as a spectator, but not so much fun if you own the engine in question.

I hope this information is helpful. And, don't forget to keep the blue smoke flowing!

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