Part 3 – Sizing Condensers Correctly
(When you Don't Know the Original Value!)

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If you have read the prior 2 installments in this Technical Series on Condensers, you will know that when you are doing a complete "rebuild" of an old motor, you almost always have to replace the condensers. They are a VERY high failure rate part, and we have explained in the prior 2 articles why this is the case. So, you are highly likely to have to replace the condensers in almost every motor that hasn't run in several decades.

However, as you probably are aware, if the manufacturer of your motor went out of business 40 years ago or more, you might have serious problems finding functional replacements. Yes, there are people that sell old (supposedly "unused / new") condensers on e-bay and in other surplus marketplaces. But, if you have had any experience buying old condensers like this on the "surplus market", you will know the low success rate you can expect when you do this. As I explained in Part 1 of this Technical Series, these wax paper and film condensers will get old, break down and fail with time. (Just be cause an old condenser was never used, that doesn't mean it's good!) In recent years, companies like General Electric have stated that **these types of "film capacitors" should be considered to have no longer than a 10 year shelf life,** before they are purchased and put into use. (They don't have "sell-by dates" on condenser boxes, of course. But, this statement from GE should be used as a clue that 40+ year-old, UNUSED condensers on the surplus market are likely to NOT be a very wise purchase, no matter how "clean" they may appear.)

This puts your antique outboard mechanic in a serious bind. Yes, you CAN buy old "tested / guaranteed" condensers from suppliers that you know. But, it should be obvious that a recently manufactured condenser his highly likely to be **much** more reliable than any decades-old, surplus condenser. The downside, of course, is if you cannot find a recently manufactured condenser in the capacitance value **and case size** you need for your specific antique motor. Many old condensers haven't been built for more than 40 years, so what can you do?

Well, in Part 4 of this Technical Series, I'll explain how you can "rebuild" old condensers, if you absolutely have to. However, that only handles the "CASE SIZE" issue. The other thing you must know about any condenser is its VALUE (in microfarads). If the condenser in your old outboard is COMPLETELY SHORTED, you won't be able to determine this. However, quite often you CAN measure the capacitance of your old condenser, as most capacitance meters only put a volt or two across the condenser during testing. This will get you the condenser's VALUE**. It's extremely wise to do this test BEFORE you do any "Condenser Insulation Breakdown" test** (or actually attempt to run the motor), both of which will put high voltages across your condenser, and will immediately destroy it if it's in bad shape. If you tried to run the motor first (and failed), film capacitors still might be able to be measured with a low-voltage capacitor tester. It's still smarter to try and measure a condenser's value FIRST, if you possibly can.

Let's say, however, that the condenser in your "project motor" is COMPLETELY SHORTED (or perhaps the condenser was simply MISSING when you got the motor!) Now, this is a completely different class of problem. Now you are faced with having to somehow figure out the VALUE of the condenser that will work correctly in your magneto. As you might expect, figuring out this “match" is likely to be a bit of a challenge. After all, if you measure a random sample of condensers, you’ll find a wide range of capacitance values. (See Fig. 1, below).

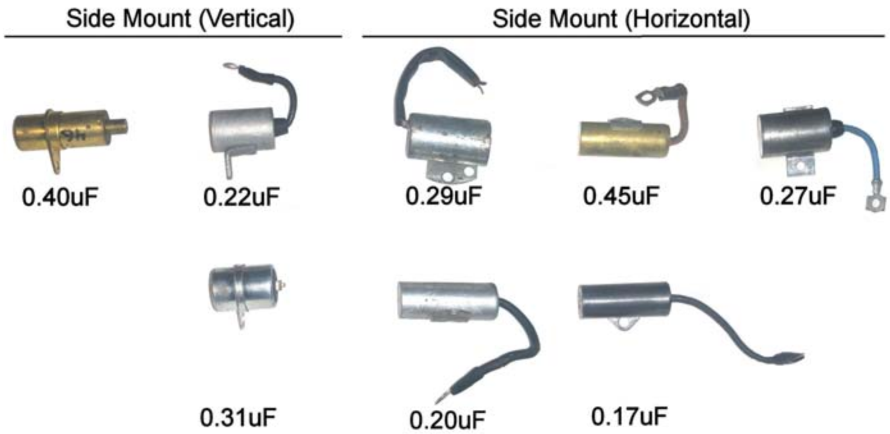

Fig. 1 - Miscellaneous Condenser Values

I personally have measured old outboard condensers from 0.1 uF all the way up to 1.5uF. So, how do we go about “sizing" a condenser for an old motor when the original value is not known? And, (an even more interesting question**), just how critical is this “match"? Is “close enough” OK, or not?** Are there any “rule of thumbs" we can apply in this evaluation?

Let’s get started!

If you have been inside many old motors, you'll know that there are several "generations" of magnetos, with VERY DIFFERENT internal construction. The very oldest (from the 1910s up to the early 1930s) had massive steel magnet structures, and very large coils and condensers to match. Fig. 2 (below) shows two VERY DIFFERENT generations of magnetos:

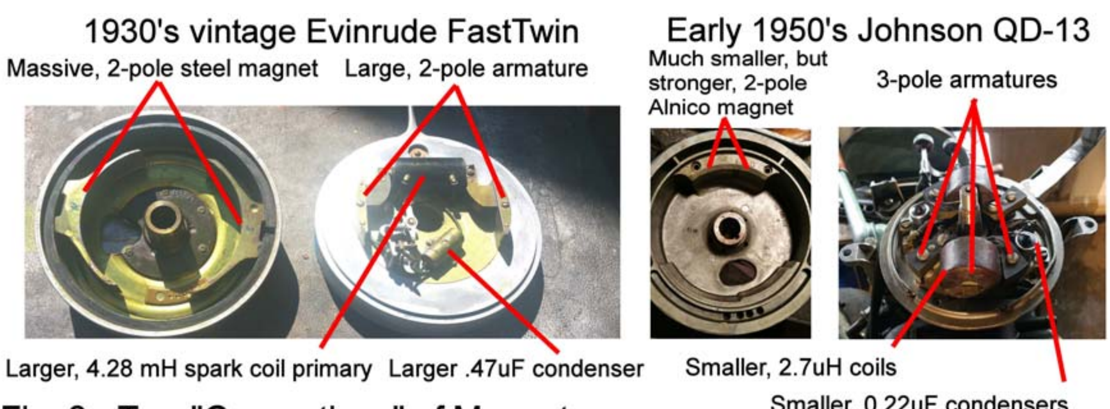

Fig. 2 - Two "Generations" of Magnetos

In my earlier Technical Articles on Magnetos, I described how the earliest magnetos (1910s to early 1930s) used heavy steel magnets, with low field strength (about 200 gauss, or less). The flywheels had 2-pole magnet structures, and the spark coils were mounted on 2-pole armatures. This combination didn't lend itself to producing high voltages, so physically larger **4mH primary coils** were used in the spark coils to generate enough current to produce a good spark. These physically large coils usually were matched with larger condensers (**on the order of .47uF to .68uF**). These systems were physically massive, and heavy. But, they did produce a wicked spark, even at low RPM.

In the later 1930s, magneto designers figured out the "2 pole magnet / 3-pole armature" trick, that effectively doubled the voltage generated in the spark coil's primary windings. Engine designers could now get away with either ½ size magnets, or ½ size spark coils. So, there were several generations of magnetos designed in the later 1930s that were….well.....one of a kind. Coil and condenser sizes varied quite a bit during this time period.

In the mid 1940s, another major development was invented; the Alnico magnet (which had over twice the magnetic strength of the older steel magnets….typically 400 Gauss or more). These magnets could be made much smaller than their old, heavy steel predecessors. These stronger magnets, combined with the 2 pole magnet / 3 pole armature structures, allowed even more decreases in spark coil size (and a similar reduction in the size required of the condensers.) So, once again, we had several generations of magneto evolution, in a relatively short span of time.

By the early 1950s, magneto evolution stabilized into what we now identify as our "modern" magneto: small Alnico 2-pole magnets, **small (2 to 3 uH primary) spark coils** on 3-pole armatures, matched with **approximately 0.22 uF condensers.** Almost every outboard after 1950 was built with general configuration. And, it appeared that any condenser from .15 uF to .47uF could be used, with no apparent penalty in engine performance…...with .22uF being the "average". And so, mechanics developed the "rule of thumb" that .22uF condensers are the size to use if you don't know the value of the original condensers. The question at hand now is, IS This "rule of thumb" valid? Just how critical IS the condenser size, anyways? For that matter, what does the condenser DO in the circuit, anyhow?

Condensers in Magnetos – Condensed Theory. (Sorry, bad pun).

All the time your flywheel is revolving, the magnetic field (created by the magnets in the flywheel) will be moving past the pole pieces, and the all the windings in your spark coil. As we all know, any time you have a changing magnetic field (either changing in STRENGTH, or MOVING PAST a conductor), you get a voltage produced in that conductor. **(RULE: The faster the CHANGE in the magnetic field, the HIGHER THE VOLTAGE PRODUCED in any nearby conductors!)** Now, initially our points are closed, so the flywheel magnet creates a large (4 to 5 amp) current in our primary windings. This current produces another magnetic field of it's own.....let's call this the Primary Winding Field. Right about when the current (and the Primary Winding Field) are at their absolute maximum, the points open up. This attempts to take the primary current to zero amps, in ZERO TIME. As the current in the primary is RAPIDLY CHANGING toward zero, this causes the Primary Winding Field to RAPIDLY CHANGE as well…..which generates a VERY LARGE voltage in both the Primary and Secondary windings. This causes a large voltage (many hundreds of volts) to be generated in the Primary windings, and a considerably higher voltage (many thousands of volts) to be generated in the Secondary windings. This is just fine for the secondary, as we WANT to have thousands of volts generated, to arc across our spark plug. But, we do NOT want any arcing in the Primary circuit, as any arcing there will jump across our points, overheating them, and greatly shortening their life.

Without any condenser in the circuit – when the points open up, the large voltage induced in the primary windings will rise to enough voltage to force the current to continue to 'arc' across the points, overheating and burning these contacts into early failure. This high voltage can easily exceed several hundred, to a few thousand volts.

With a condenser in the circuit – when the points open up, the condenser gives the current in the primary winding somewhere to go….OTHER than arcing across the points. This allows the current to approach zero at a slightly slower rate, which reduces the voltage generated in both the primary AND secondary windings. This lowers the primary voltage "kick" to about 100 to 200 volts peak - (200 to 400 volts peak-to-peak), preventing the points from arcing and burning out.

Here's the "sizing problem" in a nutshell – If the condenser is TOO SMALL, it won't have much effect. You will have a VERY hot spark, but will also have lots of arcing across your points, dramatically shortening their life. If your condenser is TOO BIG, it will lower the voltage in both the primary and the secondary by too much. You won't have any arcing across your points (so they will have a long lifetime)…..but you won't get enough voltage in your secondary to actually arc across your spark plug, either. So, our challenge here is to find the "sweet spot" that is a compromise between contact / points life, and still getting an acceptably intense spark across your plug.

So, how difficult is it to find this "sweet spot"? Does this take extremely careful tuning to get everything right, or is "good enough" just fine? To answer this question, we turned back to our lab equipment, so we could DIRECTLY TEST the effect of the condenser size on both primary voltage (with it's potential arcing), and the effect on the secondary voltage. To measure both of these effects at the same time takes some slightly specialized equipment. (See Fig. 3, below):

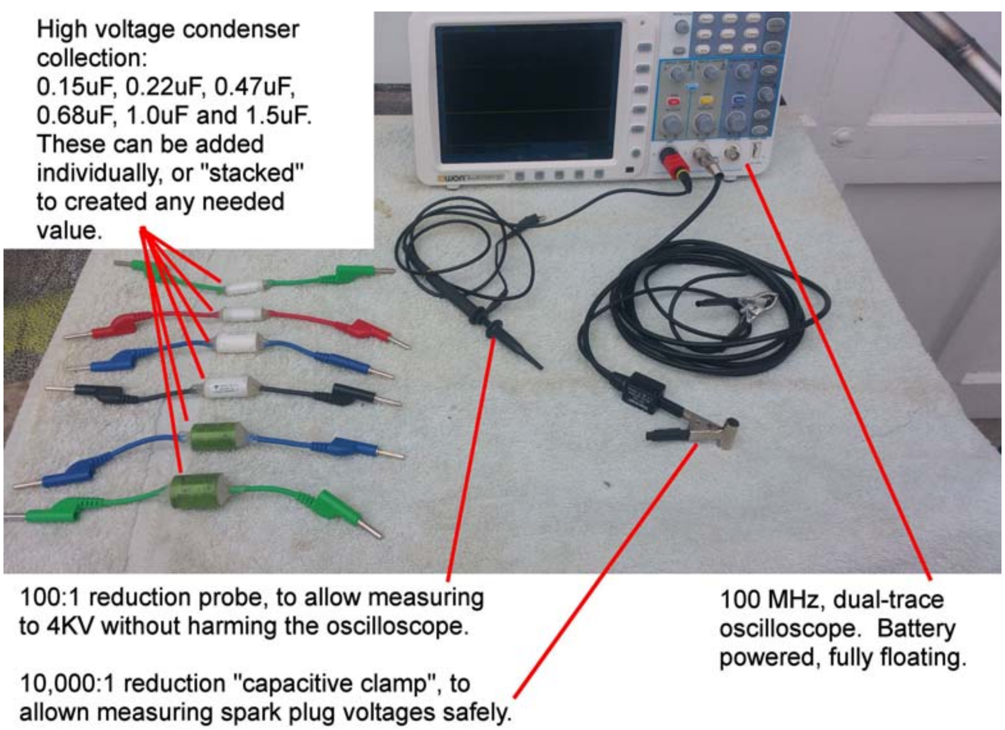

Fig. 3 - Equipment Needed for Test

And, of course we need a old motor to test with. So, we selected a 1958 Evinrude 7.5 HP Twin. This motor is of the “1950 or newer" generation, so it has Alnico Magnets, small spark coils and small condensers. Specifics are shown in Fig. 4, below:

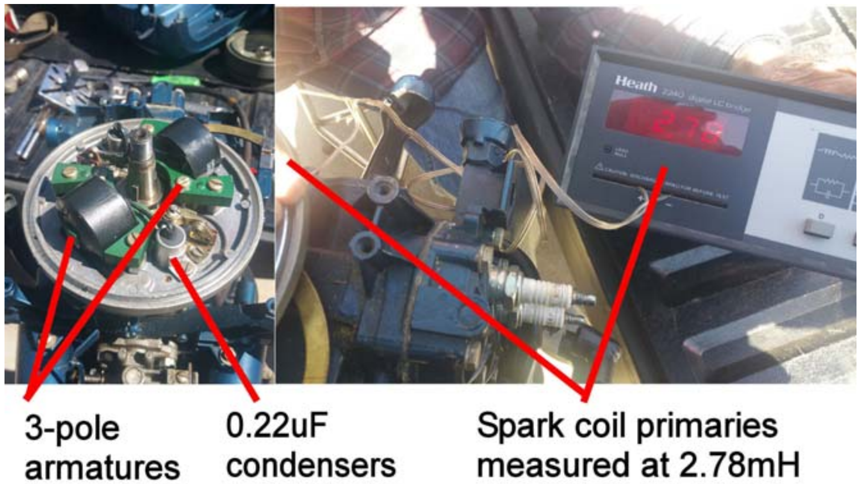

Fig. 4 - Key Components In Test

Here are details on the actual test setup, and the connections made. Note that with the points wire brought outside the flywheel / mag plate housing, we were free to substitute any value of condenser we wanted, from 0.1uF to about 4 uF in size. Our goal here was to see what size was “optimal”, what primary voltages were “optimal”, and what secondary voltages we could expect to see. See Fig. 5 below, for details:

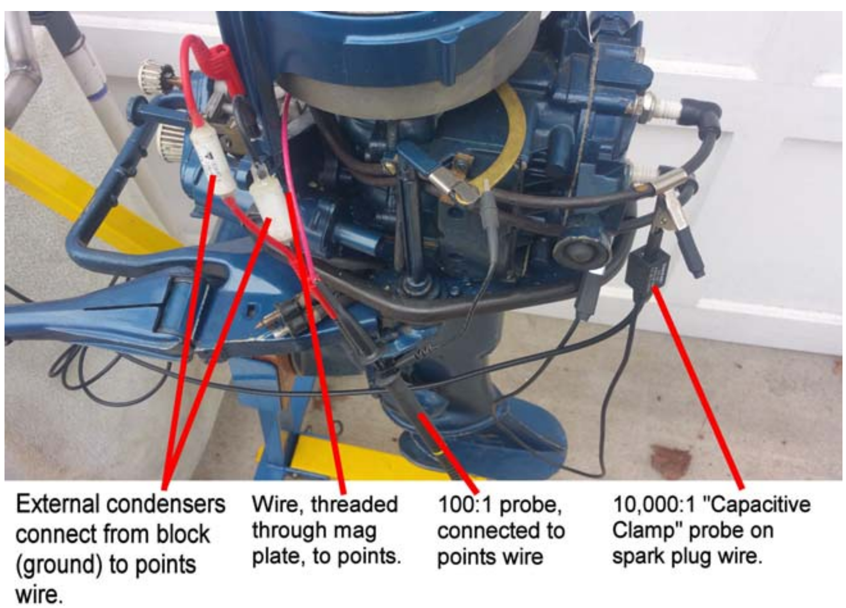

Fig. 5 - Our 1958 Evinrude "Test Setup"

The pictures on the next page show our test results! See Fig. 6, next page:

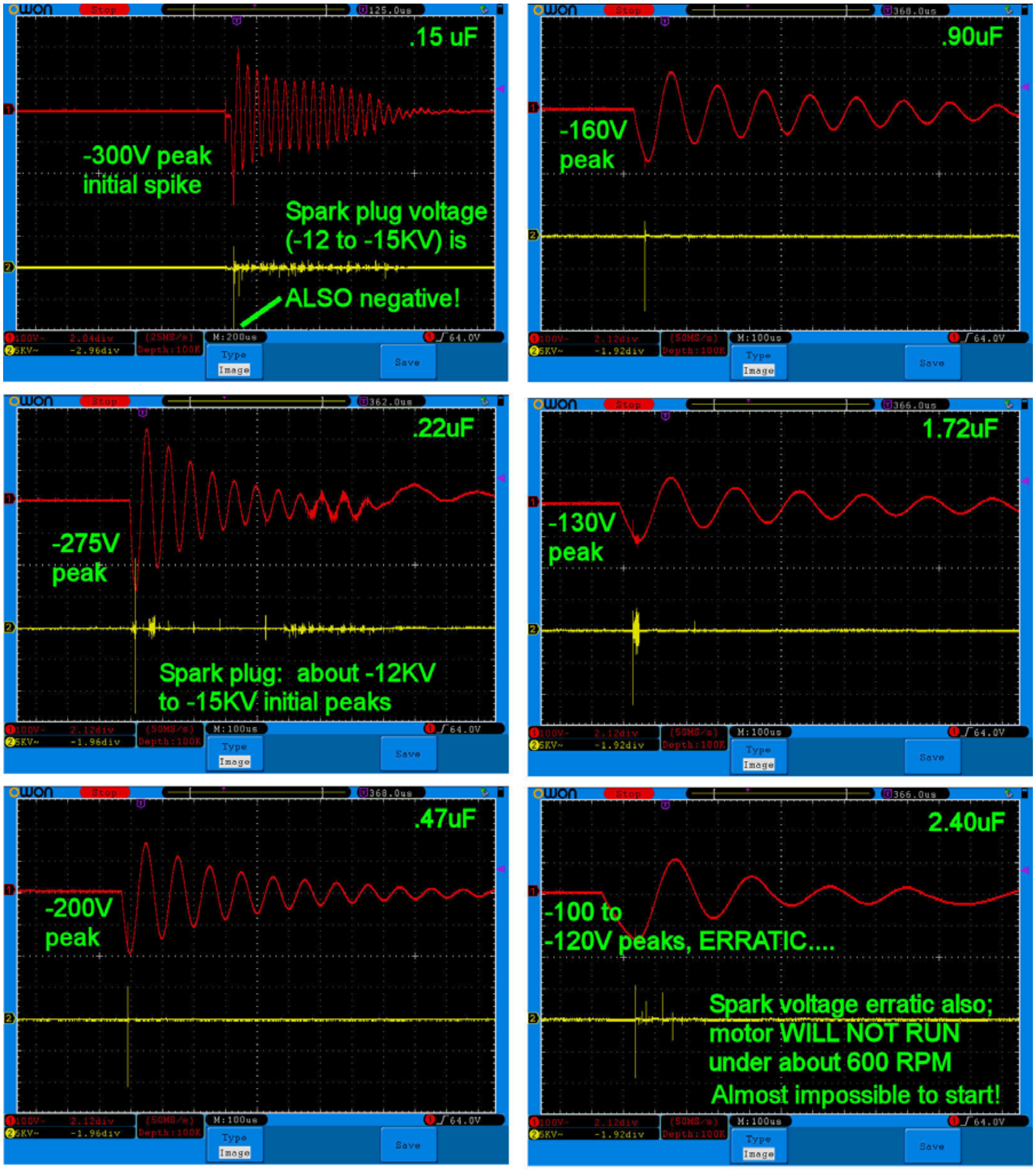

Fig. 6 - Summary of Results

OK, now what did we learn? Here's what these results imply:

1) **Ideally, this motor was sized for 0.22uF**. This produced an initial voltage spike across the primary windings of –275V…..along with a very hot spark.
2) Cutting the condenser back to 0.15uF resulted in the initial peak reaching –300V, and arcing could be seen across the contacts. **NOT SEVERE, but obviously not ideal.**
3) Doubling the condenser size to .47uF reduced the primary voltage peak to –200V. No apparent change in spark intensity.

4) Increasing the condenser size all the way up to **2.40uF (more than 10X the "ideal" size)** resulted in the initial primary voltage spike being reduced to close to –100V peak. At this point, the secondary had troubles producing spark unless the engine was running well over 600RPM….it would not idle down without stalling. Hand-starting with this large of a condenser was almost impossible.

SO………for a given engine, you can DECREASE the condenser size by half without much effect (but not much more than that!)……and you can INCREASE the condenser size by slightly more than 10x too large before completely killing your engine's ignition. So, the conclusion here is that the condenser size is FAR from critical; anything large enough to quench the arcing across your points is all you need. Putting in a condenser that's slightly too big is the safer way to go!

I believe we can make the following generalizations and recommendations:

Motors, 1900s – (MASSIVE steel magnets, 2 pole / 2 pole construction, absolutely HUGE spark coils)….use a .68 to 1.0uF condenser. Error on going too large, to protect the insulation in your antique spark coil if possible…as long as your motor can be started easily.

Motors 1910s through 1920s (STEEL MAGNETS, 2 pole / 2 pole construction, very large spark coil)….use a .47uF to .68uF condenser. Again, error on going larger than this, as long as you can start the motor easily!

Motors 1930s and 1940s (Steel Magnets, typically 2 pole / 3 pole construction, "medium" size spark coils)….use a .3 to .47uF condenser.

Motors 1930s and 1940s, (Alnico Magnets, 2 pole / 3 pole construction, smaller size spark coils)….use a .22 to .47uF condenser.

Motors 1950s and newer (all)….just use a .22uF. It REALLY isn't at all critical, apparently! Also note that almost all 12V "Battery and Points" ignition systems seem to use something close to 0.22uF as well, so this is sort of your 'universal replacement' value.

Hey, while we are at it, doing the "Mythbusters" thing…..there's a assumption in outboarding circles **that "magnetos are better than battery / points systems at higher RPMs. Because the magneto's power is created by (essentially) a generator, the faster you run your engine, the hotter the spark with magneto systems!"** Or, at least that's the story you often hear. But, is it true? While the motor IS spinning faster, and a magneto primary WILL generate more voltage….but the TIME you have to get the current going in the Primary coil goes DOWN at approximately the SAME RATE. (This is why battery / points systems have less spark intensity at higher RPMs, and THIS is a known fact.) So for Magnetos, at higher RPMs, do you get a less intense spark like Battery / Points systems, or a MUCH HOTTER spark, or does the spark intensity just stay the same? Is the old saying about "magnetos being better at high RPM" true or not?

So, while we had the test setup running, we took two more measurements….at a normal idle (about 600 RPM, I would guess) and with the engine racing a bit (probably 3,000 RPM or slightly higher.) Look at Fig. 7 on the next page to find out!

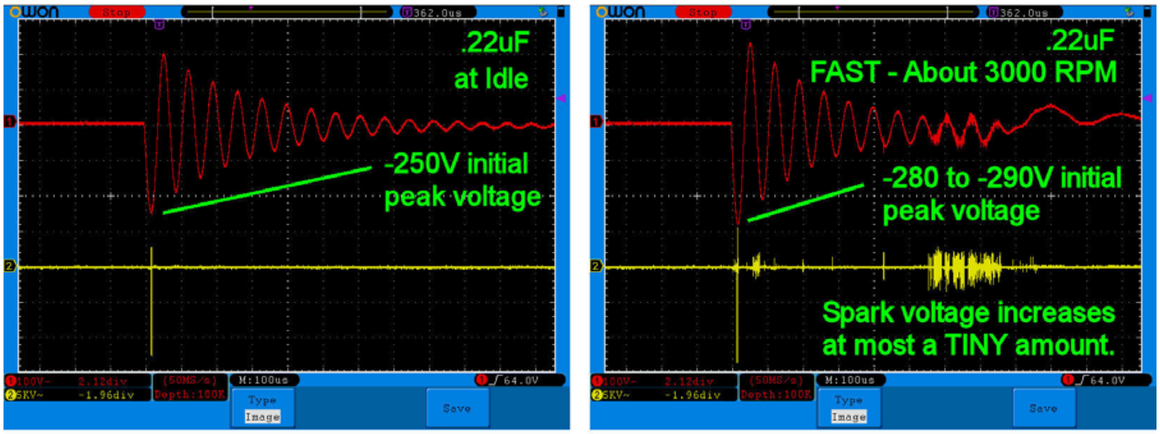

Fig. 7 - The "mageto hotter spark, or not?" Test.

Well, our test indicates that running a magneto MUCH FASTER produces a SLIGHTLY hotter spark. The primary winding energy is SLIGHTLY higher, but not by much. In contrast to battery / points systems (where the spark energy goes DOWN with RPM, and rather dramatically), with magnetos in our outboards, the spark energy MOSTLY STAYS THE SAME, or very slightly increases. It does not “greatly increase with RPM” the way many people think it does….but it IS better than battery / points systems at higher RPM.

While we are doing the "mythbusters" thing here, there's another assumption that I’ve seen in almost every discussion of Magnetos and also Battery / points ignition systems. Specifically, there's a belief that your spark plug actually arcs over several times in a row, during the “ring wave” on the Primary. And, YES, when I initially measured spark voltages, that's what I saw as well. (See Fig. 8, below, for a picture of that Evinrude 7.5, the spark plug restriking many times during the “ring wave")

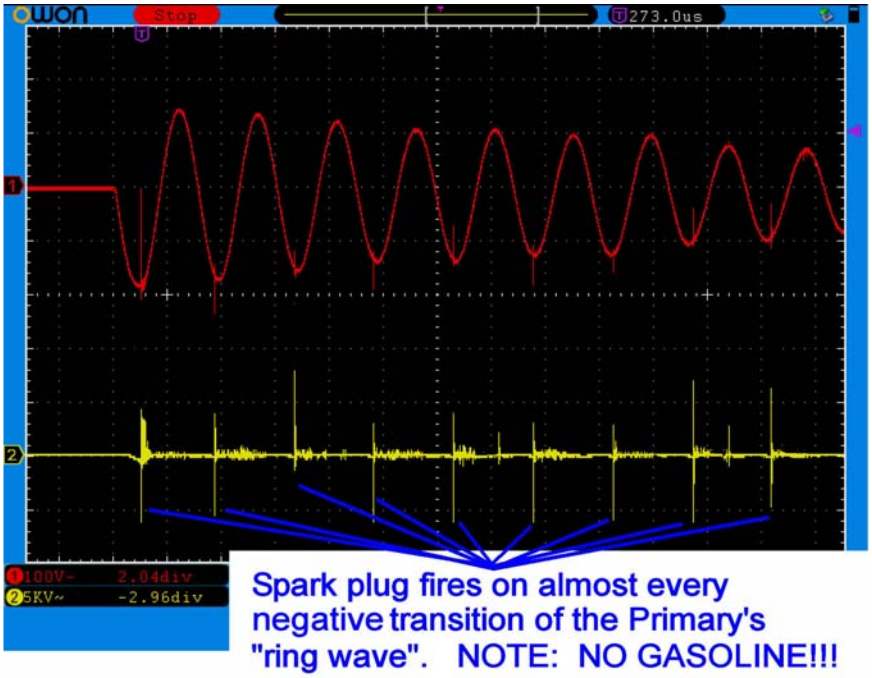

Fig. 8 - Spark Plug Firing Many Times During "Ring"

Literally, EVERY book on ignition systems I have seen makes this claim….that your spark plugs will arc over MANY times during the entire duration of the 'ring wave', and this is what reliably ignites the fuel/air mixture. And, (in Fig. 8, above), my initial testing seemed to indicate that as well. However, look at all of the pictures in Fig. 6 and Fig. 7, and you will only see ONE "spark", on the VERY FIRST peak of the "ring wave", AND NO MORE SPARKS other that the very first one. What gives?

Well, Fig. 8 was taken by just "pulling the motor over by hand". The spark plugs WERE installed in the cylinders, but….there was no GASOLINE line connected, so there was NO IGNITION. As a result, when the spark plug fired, the cylinder pressure was at about 100 PSI (for a standard 2-stroke outboard)…..and the cylinder pressure STAYED THERE, because there wasn't any fuel to burn. So, the spark coil didn't have any problems jumping the gap several times…...the initial arc was at about -12KV to -15KV, and subsequent arcs required a bit LESS energy, because the air got hotter from the "arcing" and the heat drove the voltage required to jump the gap lower.

HOWEVER….when you look at Fig. 6 and Fig. 7, the gasoline WAS connected, and the motor was RUNNING. NOW, when the first spark occurred, the gasoline in the cylinder ignited, quickly boosting the cylinder pressure from 100 PSI to about 300 PSI (at idle), and to about 700 PSI (at full throttle). The higher the pressure in the cylinder, the more voltage it takes to jump the gap. At 300 PSI, it takes about –32,000V to jump the gap…..and at about 700 PSI, it takes about –69,000V to jump that same gap. The magneto is "sized" to produce about -15,000V, which it reliably DOES DO when the cylinder pressure is at 100PSI (before the fuel is ignited). But, once the fuel burns and the pressure spikes up, the magneto simply cannot fire the spark plug a second time; it simply cannot generate the much higher voltage required to jump that gap a second time.

SO! Now the myth of “multiple strikes during the ring wave duration” is now officially BUSTED! In a magneto (OR BATTERY-POINTS ignition system), the spark plug only fires ONE TIME; the increase in pressure due to the burning fuel (and, hence, the sharp increase in the voltage required to fire the plug)…prevents any further ‘restikes’ from happening. MOST of the books on ignition systems get this wrong! But then, I don’t recall any of them taking a picture of the primary (points) and secondary (spark plug voltages) at the SAME TIME, on an engine while it was running. Mystery solved!

****(BACK TO OUR “CONDENSER SIZING” DISCUSSION)****

Now that we know how to size condensers for engines where we don’t know the original value (or even have the original condenser), we will now turn to the question of: What if NO condensers are available in the case size / value size I need? Is it possible to REBUILD or REPAIR an old condenser?

To that, the answer is “YES”….and we will look into this in Part 4 of this Technical Series on Condensers…..coming to you very soon!

A side note: for those readers that want more detailed information on how magnetos work, you can download a detailed article on that topic from the Western Reserve Chapter’s website. The article you will want is called:

“Articles_Ignition_Part_3_Magic_Of_Magneto.pdf"

See: https://wrcoutboards.org/magazine-articles/ ← And click on the download link!

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