Testing Your Ignition System

Introduction

Measuring Ignition System Output

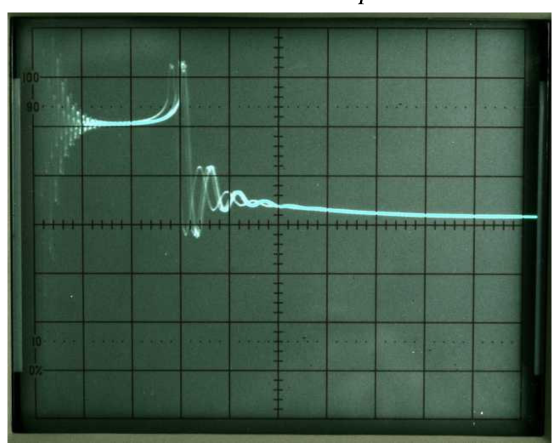
The time–honored ignition test is to take the wire off the spark plug and turn the engine over to see if the spark jumps from the lead to the engine frame. If you can see it (nice and blue), hear it (big snap), and maybe smell the ozone, you know it's good. If, as often happens, the spark takes a shortcut through the hand that holds the lead, estimating the spark quality becomes a good deal more subjective (usually expressed with great passion in colorful language, but often over–estimated).

In any case, the hand-held spark jump method is a pretty good way to tell if you have a big, strong spark. However, it's not a very good way to tell if a relatively smaller spark from a scaled–down model engine coil is "good enough." Moreover, it can be risky. The coil is physically small, so it may not have a lot of margin for overvoltage. Internal flashover can ruin a coil in very short order if one tries to make a spark jump across too big a gap.

In this article we'll describe a calibrated spark gap that can be constructed as a measurement tool to measure your ignition system. With that tool you can test model ignition systems with much more confidence. Use caution, however, when testing for higher energy sparks with larger gaps. Trying to get too much out of a small coil can still damage the coil by internal flashover.

Low Energy Spark Instability

Low–energy sparks are flaky. Sometimes they jump and sometimes they don't. This randomness is a fact of life. If you want a reliable engine, you need enough spark energy to fire the plug consistently. In a nutshell, that means generating a spark with enough energy to form and maintain a *stable plasma* between the plug electrodes for the duration of the spark.



Stable Plasma

If you've ever seen pictures of the waveform of a good spark on an ignition analyzer, you've seen that the spark begins as a very high frequency oscillation, and converges to a smooth line for a period of time. This line may dip downward a bit at first, then curves upward, and finally breaks into another burst of oscillation as the spark comes to an end. The *stable* part of *stable plasma* refers to the decay of the initial burst of oscillation into the smooth line. Without pursuing this all the way into some physics textbook, it means the arc path becomes hot enough to have an abundance of ionized gas. That reduces the resistance of the electrical path and damps out the initial oscillation. Hot is good. It lights our fire, so to speak. And hot comes from sufficient *energy* in the spark itself.

Energy: Voltage, Current, and Time

How do you measure the *energy* of a spark? It's not hard to understand how to measure voltage or current. Even measuring time can be as simple as observing a waveform on an oscilloscope. But *energy* is all of the above. It's (voltage) x (current) x (time)—if everything is constant. Problem is, if voltage and current are both oscillating, then how do you measure anything that you can use to determine *energy*?

Sidestepping that question for just a moment, we also have a second question: how much *energy* do we need to reliably fire the spark plug in our engine? In what is to follow we describe making a tester from a standard automotive ignition system. We can calculate the amount of available *energy* by knowing the *inductance* of the automotive coil, and knowing the current flowing at the time the points open. Using that test device, we test a collection of spark plugs modified in various ways. That will roughly show how much *energy* is needed for different shaped plugs under different conditions.

Then we can come back to the first question. We'll discuss how to construct a calibrated spark gap to test for the level of spark *energy* we think our particular engine and spark plug will need. There is a calibration chart for that spark gap, created using the same test methods used to measure the spark plugs.

Spark Plugs Tested

All spark plugs tested in this project were NGK CM-6 from my own collection. It would have been better to also test other sizes and gap shapes, but for now these were what I had. It feels intuitively that creating a sharp edge on one or both electrodes should enhance the electric field and initiate voltage breakdown more easily. One of the objectives of the testing was to measure how effective such modifications might be. The data shown later in this report confirm some beneficial effect, but much less than I would have guessed.

Sharpened Ground Electrode

One fairly easy modification is to file the ground electrode to a point, leaving the center electrode unmodified. See the taper filed on the ground electrode on the spark plug on the left.

Truncated Ground Electrode

Another easy modification is to cut off the ground electrode so that it ends in a sharp edge a little short of the center line of the center electrode. That modification is seen on the center spark plug.

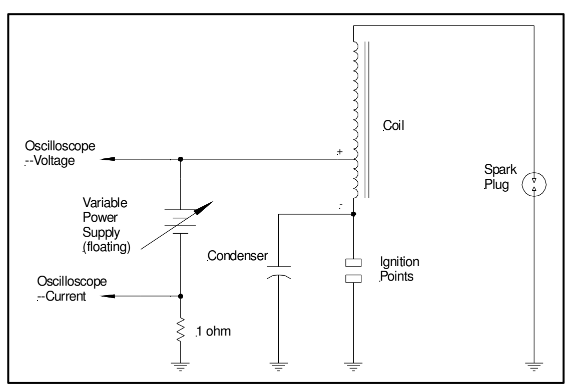
Double-Pointed Electrodes

This modification is a lot harder to do. John Vietti first showed me plugs that he modified, and mine are a copies of his. The ground electrode is cut off completely. Then the center electrode is filed to as sharp a cone as possible. (Author's note: I tried to cut my first one by chucking a plug in a fixture on the lathe. Despite great care to take light cuts, it took about ten seconds to break off the insulator.)

A new ground electrode is made from a sharpened loop of music wire silver soldered into a small hole in the threaded base. A double–pointed plug is shown on the right in the picture.

Test Equipment

Spark Generator



The spark generator is simply an ordinary automobile ignition coil, condenser, and breaker point set. I mounted the breaker point set on a fixture attached to a lathe tool holder, and made a breaker cam from a piece of 1/2 inch drill rod. This cam runs in a collet on the spindle. A floating dc power supply provides the ignition power. The power supply voltage is adjusted to control the energy of the spark output.

Testing Your Ignition System

A 1 ohm series resistor is required for calibrating the spark. Peak current is measured with an oscilloscope. To calibrate your own spark generator to measure energy delivered, you will also need to measure the low frequency inductance of the coil. Details of the method I used and a formula for the required calculation are described in the appendix.

Coils and Condensers

I have run a few experiments using a couple different coils and different condensers in this generator, and have found (as I had hoped) that amount of *energy* it takes to fire a given spark plug is pretty much the same, no matter what size coil or condenser, within a reasonable range. The trick is to compare *energy* required, rather than voltage or current.

Energy Calculations

How can you determine spark energy delivered by this setup? You simply calculate it from peak current in the coil just before the points open. A fraction of that energy will be dissipated in various kinds of losses without ever making it to the spark plug. I have chosen to ignore those losses for these tests, so my energy required numbers should be interpreted as a little on the high side.

Peak current is measured with an oscilloscope by observing the voltage across a 1 ohm series resistor. (1 volt per amp.) Knowing the current, you can calculate the energy stored in the coil from the relationship:

$$W = \frac{1}{2} L i^2 .$$

{*Energy* (*W*) is *Inductance* (*L*) times *Current squared* (i^2) divided by 2.}

{*Energy in Joules, inductance in Henrys, and current in amperes.*}

Spark Plug Tests

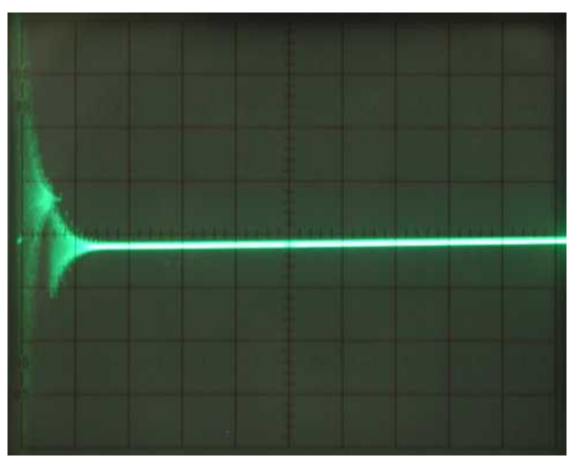
Using the test generator, I slowly increased the spark energy until I reached the threshold level for the effect desired. In many cases the threshold was not abrupt or clear-cut, and subjective judgment was required. I found it necessary to repeat tests over and over. I tried to practice the test until I could develop a feel for recognizing threshold effects that would give repeatable results.

Spark Threshold

This tests for the lowest energy level that will produce a spark of any kind. Because low threshold sparks are very random, I tried to judge the current setting that would make a spark about half the time. This requires a dark room. With a little practice, it is possible also to recognize when a spark jumps and when it doesn't by observing the primary voltage waveform.

Stable Plasma Threshold

It takes a little more practice to be able to judge the threshold of plasma stability, but it actually turns out to be quite repeatable for most test conditions. We look for the initial burst of oscillation to converge and mostly decay by the time the spark ends. There may still be randomness, but try to set the current to get most of the bursts to decay. This scope photo shows a number of sparks superimposed.



This stable plasma energy level represents the absolute minimum required for reliable engine operation.

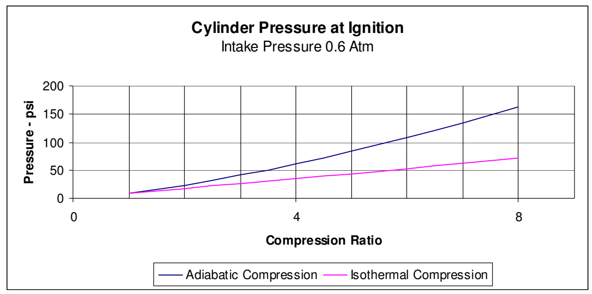
Testing Your Ignition System

Positive vs. Negative spark

There's a published theory that negative sparks work better than positive for IC Engines. Supposedly at high temperature the center electrode of the spark plug will emit a thermionic cloud of electrons, as the cathode of a vacuum tube does. Those free electrons will accelerate toward the ground electrode in the high field when a negative ignition voltage is applied, and that will reduce the amount of energy required to initiate the spark. I have no particular quarrel with that theory. If true, though, it would logically apply to a warmed up engine under load, perhaps not so much to a model engine running without load.

If you examine the results in this paper, you'll see variations both ways, but no predominating evidence of any difference between positive and negative sparks. That's not surprising, because these tests were run at room temperature. No high temperature; no thermionic effect.

Compression Pressure



Compression pressure is a major factor in determining how much energy it requires to fire a spark plug. For your particular engine you can calculate or estimate the maximum pressure, based on the compression ratio, the degree of heat loss during compression, and the intake pressure drop due to throttling and flow losses. I chose an example for the chart at right, and showed the maximum possible (adiabatic compression) and the minimum (isothermal compression) assuming no leaks and an intake pressure of 0.6 atmosphere. I'm guessing for my Red Wing at 500 rpm, with atmospheric intake valve (and a second one in the mixer) it would be about 4:1 compression, and roughly 50 psi compression. I used 100 psi for all pressurized spark plug tests in this article.

I cannot speak from personal knowledge about effects of fuel mixture on spark plug firing. I'm guessing the effect is small compared with compression pressure, but I know that Bob Shore's book says the effect is more important. I'd be happy to hear from anyone who has specific information.

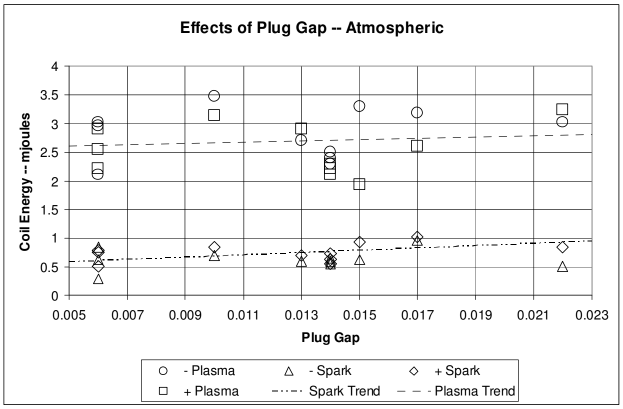
Results

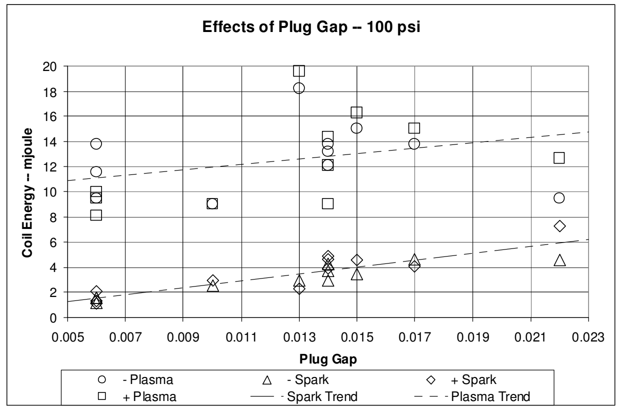
For this series of tests I gathered eleven spark plugs. Three were stock plugs and eight had modified electrodes as previously described: a) three with sharpened ground electrodes; b) three with truncated ground electrodes; and c) two with double-pointed electrodes.

The first thing you'll notice is that the data presented in the charts below show a fairly wide dispersion. While acknowledging that there is some subjectivity in reading the scope pictures, I did go back a repeat many of the tests showing the widest variation. I was surprised to find that those variations did repeat, even re-testing on different days, and even when switching back and forth between condition to get A/B comparison results. My guess is that this is not just a random effect, but it shows that minor variations in things like electrode shape and surface imperfections do have significant influence.

Test results are given below as charts called histograms that plot all of the individual data points. These are a little like a Rorschach ink blot test for engineers who stare at them and try to see (or imagine to see) patterns and trends. They are actually quite helpful when looking to separate out effects of different variables, as we are doing here for plug gap and electrode shape.

Effects of Spark Plug Gap



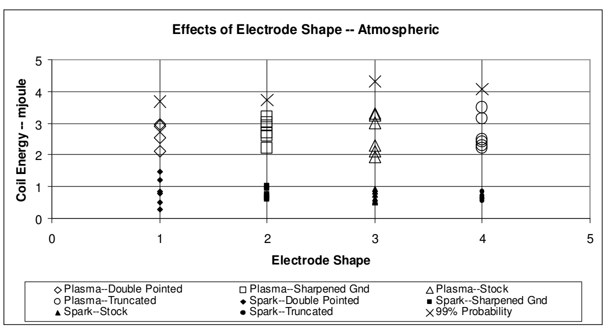


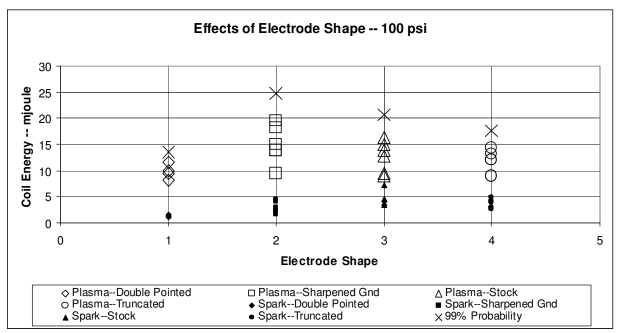
I lumped all spark plugs with all shapes of electrodes together for this test. That makes the data appear a little wild, but it's useful to look at it this way. Even if you don't trust every one of the data points, you can still have some confidence that *trend lines* will show the effect we are looking at. The trend line is calculated as the best fit to the data points on the chart, measured by a method called "least square error."

In these charts, the trend lines show how much the required energy will change if you change the plug gap. For example, if you look at the trend lines on the atmospheric pressure chart, reducing the gap on a plug from 0.023 down to 0.005 will cut down the energy required to just spark over the plug by about 40%, but it will only cut the energy to create a plasma by about 6%. On the 100 psi chart, the corresponding reductions are about 77% for the spark threshold and 25% for the plasma threshold.

I was frankly surprised that the plug gap effect is this small. I have to admit, though, that when I have had trouble getting an engine to run with a small magneto, reducing the spark gap seemed to help some, but not as much as I expected. According to this data, reducing the plug gap over 4:1 will typically decrease energy to establish a stable plasma in the gap only 6% to 25%.

Effects of Spark Gap Shape





These scatter diagrams are a different form of the same data plotted in the previous diagrams. Rather than a trend line, though, these diagrams include a calculated 99% probability of producing a stable plasma for the various electrode shapes and compression pressures. With this small a sample, the statistical confidence level is not great, but still the idea is still useful. The 99% probability is calculated as 3 standard deviations added to the average for each data set. You can take the X on the chart as an estimate (good guess) of the minimum energy required for an ignition system for that particular electrode shape.

I was again surprised by how little difference the electrode shape makes at atmospheric pressure. At 100 psi the advantage of a double pointed electrode is the most significant.

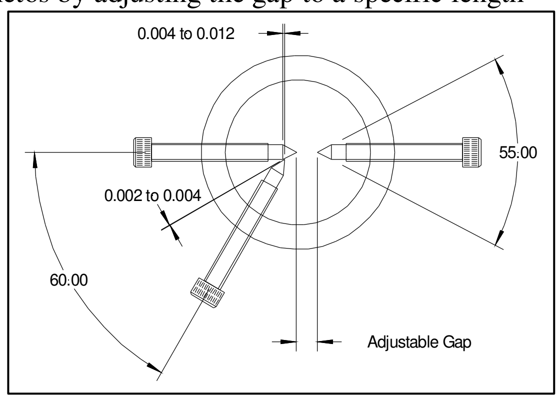
Calibrated Test Gap

Bob Shores Adjustable Air Gap

In his book, *Ignition Coils and Magnetos in Miniature*, the late Bob Shores describes an Adjustable Air Gap. His procedure is to connect this device between the spark plug lead and ground on a running engine. He instructs his reader to decrease the gap until it sparks over (and the engine therefore misses) every other cycle. Then you will have a calibrated spark gap equivalent to that of the spark plug under running conditions. I've not done this, but it seems to be a very common sense way of making and calibrating an ignition test device for a particular engine with a particular spark plug installed.

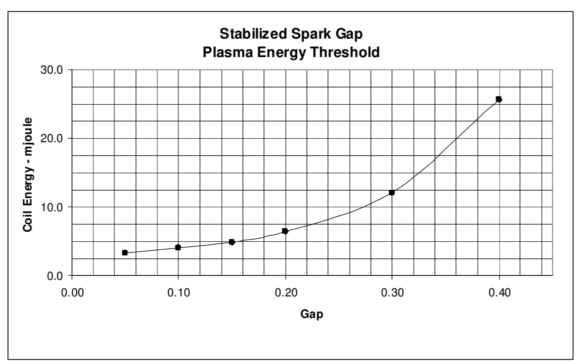
Ionized Spark Gap described in Motor Service Magazine, 1941

John Vietti loaned me his copy of a *Motor Service Magazine* series on magneto testing published in 1941. This report described an *Ionized Spark Gap* device, said to be provided by several different magneto manufacturers for testing their products. A sketch of the essential dimensions is included. Service technicians calibrated this device for testing various magnetos by adjusting the gap to a specific length using a gauge provided by the magneto manufacturer.



Apparently the third electrode serves to "seed" the developing spark with some ions early on as the spark voltage begins to rise. That helps reduce some of the randomness and make the results more repeatable. The ground should be connected to the adjustable electrode, and the spark lead to the fixed electrode (next to the diagonal electrode). The diagonal electrode is not connected to anything, but apparently conducts sufficient charge through stray ground capacitance to produce the few ions required to seed the main arc.

Building and Calibrating a Test Gap



If you make your test gap with the shape and dimensions of the drawing you should be able to use the Stabilized Spark Gap chart I have included here. My local altitude is about 900 feet. If you live where the altitude is above 2000 feet you'll need to re-calibrate the Test Gap for your location.

A polycarbonate ring provided the supporting structure, and 10-32 steel bolts formed the electrodes for my test gap. I polished the pointed electrodes to remove machine marks and rough spots. I kept the points as sharp as possible, but had no way to measure the actual tip radius. I set the auxiliary electrode gap using feeler gauges, and used a dial caliper to set the main gap to various lengths for testing.

Calibration tests were run using the same test methods used for the spark plugs. The stable plasma threshold was measured with the gap set at 0.050, 0.100, 0.150, and so on. The Stabilized Spark Gap chart shows data for both positive and negative sparks, but the point lie on top of each other, so they can't be seen separately.

Testing Your Ignition System

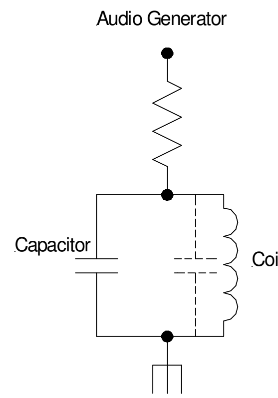
Testing Your Ignition System Output

To use the calibrated Test Gap to measure your ignition system energy output, observe the following:

1. Don't test with a large gap unless you are sure your coil won't flash over and be damaged. For my money, the yellow range is between 0.30" and 0.40" gap, and above that is definitely red for small coils unless you know the coil is designed to take it. (Some coils have a built-in protective gap that will flash over and protect the coil if the external gap is too large.)
2. Estimate how much energy satisfies your engine's needs using spark plug test data in this article, or conduct your own tests with your own spark plugs
3. From the Stabilized Spark Gap chart, find the gap that requires that amount of energy.
4. Set the Test Gap using a dial caliper or make a go/no go gauge that size.
5. Run your ignition system and verify you create a satisfactory spark in the Test Gap.

Look for a steady spark with essentially no misses. In a quiet environment, you should hear a definite "snap". In deep shade, you should see a blue spark that is at least a little wider than a wispy thread. These effects require a little interpretation, but once you've see a system that is working well and a system that is just on the edge, it's easy to tell the difference.

Measuring Ignition Coil Inductance



My method for measuring the coil inductance was to determine the self-resonant frequency of the coil and also the parallel resonant frequency of the coil with an external capacitor in parallel. The self-resonant frequency is determined by the stray capacitance of the coil windings, shown dotted in the drawing. With the external capacitor connected, the resonant frequency is determined by the sum of the external capacitance and the stray capacitance. We measure both frequencies to get enough information so that the formula below can compensate for that stray capacitance.

It's best to use a large external capacitor so the parallel resonant frequency quite a bit lower than the self-resonant frequency. A good choice would be about 10 μf. (A motor run capacitor from a surplus store should be ideal, but don't use an electrolytic capacitor.)

In both cases, drive the coil with an audio generator and a large series resistor of at least 22 kOhm and record the frequency where the coil voltage is maximum. Record both resonant frequencies. Subscript 1 refers to the resonant frequency $\mathcal{F}_{(1)}$ with the external capacitor connected. Subscript 2 refers self–resonant frequency $\mathcal{F}_{(2)}$ with the external capacitor disconnected.

Calculate the inductance using the following equation:

$$L = \left[1 - \left(\frac{\mathcal{F}_{(1)}}{\mathcal{F}_{(2)}}\right)^2\right] \times \left(\frac{1}{4\pi^2 \mathcal{F}_{(1)}^{\ 2} C}\right),$$

{*Frequency ($\mathcal{F}$) in Hertz (cycles per second); Capacitance in Farads; Inductance in Henries*}

If you are like me, you can sometimes get mixed up and use the wrong frequency one place or another in those equations. That will give some screwy answers. For my coil I calculated 5.06 mhy inductance (0.0056 Henry).

Testing Your Ignition System

Appendix

Photo Log

1. Primary Spark Waveform G1250177a.jpg
2. Spark Plug Modifications G6110483b.jpg
3. Minimum Stable Plasma P1090015.jpg

Drawing Log

1. C:\DKGFiles\Shop\Tools and Processes\3151 Mechanical Spark Generator.SKF
2. C:\DKGFiles\Shop\Ignition Studies\Spark Plug testing\3152 Ionized Spark Gap.SKF
3. C:\DKGFiles\Shop\Ignition Studies\Spark Plug testing\all by plug by test 062408.xls
4. ..\Calibration of Standard Spark Gap 051408.xls
5. C:\DKGFiles\Shop\Ignition Studies\Coil Analysis\5006 Ignition Coil Test Schematics.SKF