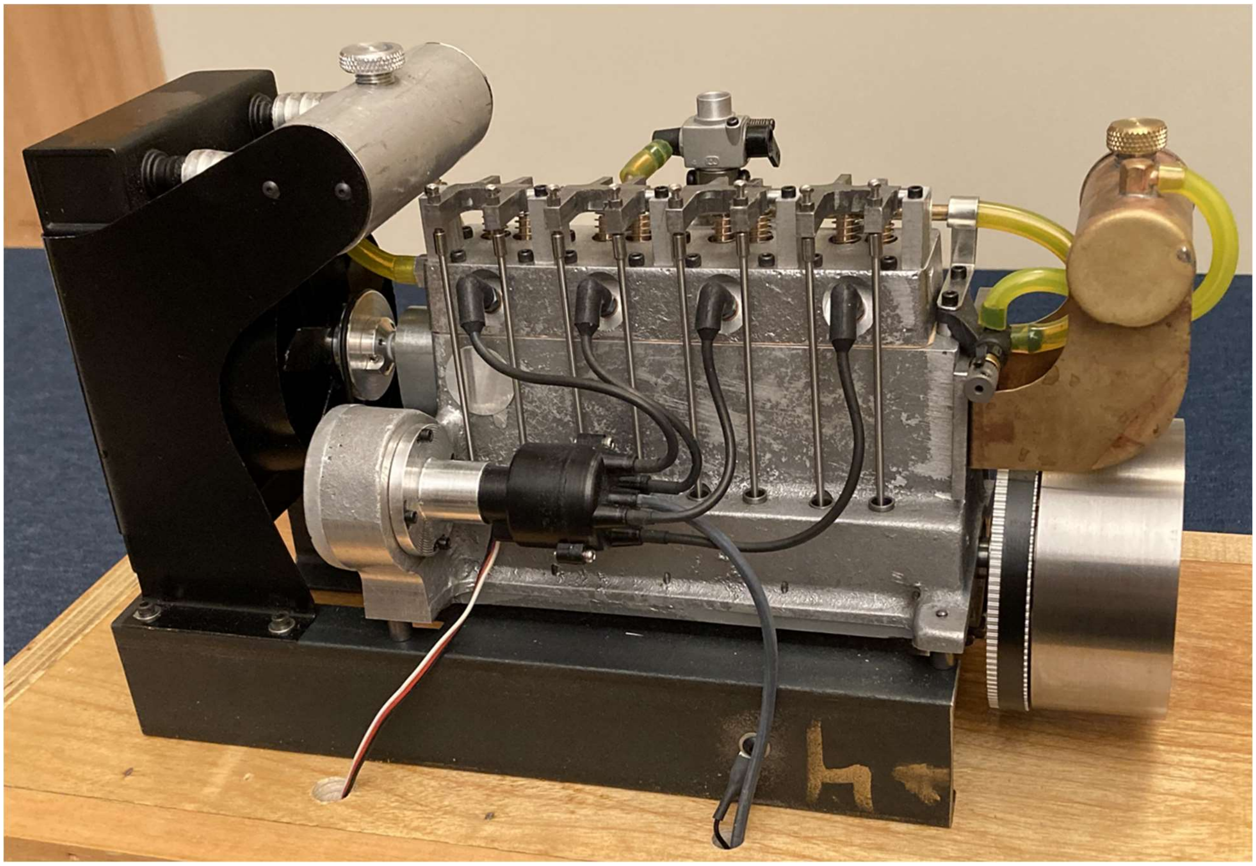
Testing Model Engine Ignition Systems

Statement of problem



Starting point: 4-cylinder original design engine that barely runs. Engine is Atkinson cycle nominally designed with 5:1 compression ratio, 10:1 expansion ratio, 1.8 cubic inch displacement (27 cc.), with a 0.19 model airplane engine carburetor. Engine will run briefly on one or two cylinders but will not continue for more than a few seconds. Extreme mixture sensitivity suggests weak ignition. Equipped with S/S CDI module with an S/S distributor, Hall-effect ignition timing, subminiature Rimfire Z3 10-40 spark plugs.

Objectives

1. Test a number of CDI modules available on the market.
   a. Compare to determine whether the original CDI module had a failure.
   b. Measure energy output from a range of other available CDI modules.
2. Evaluate alternatives such as inductive coil ignitions systems available on the market.
3. Publish test results on HMEM and other forums for critique by others.

Methods

Spark energy is measured by sampling voltage and current at the spark plug and multiplying the two to calculate the power delivered into the spark at each instant. Multiplying that calculated power by the length of time for each sample gives the total energy for that sample, and summing all these bits of energy for all samples gives the total energy delivered to the spark.

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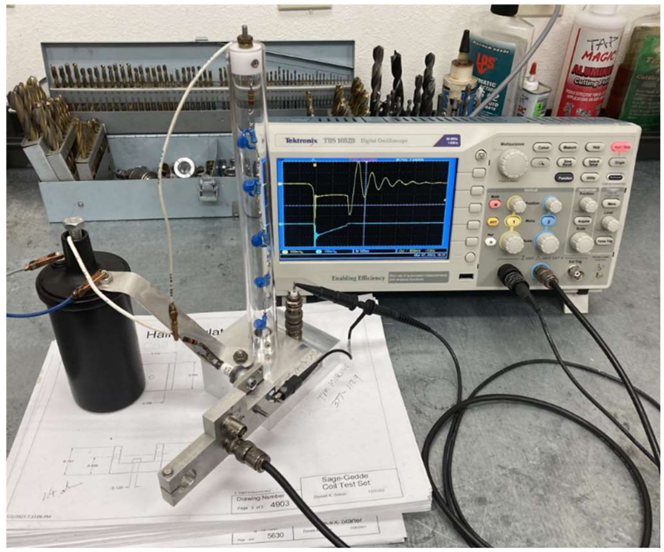
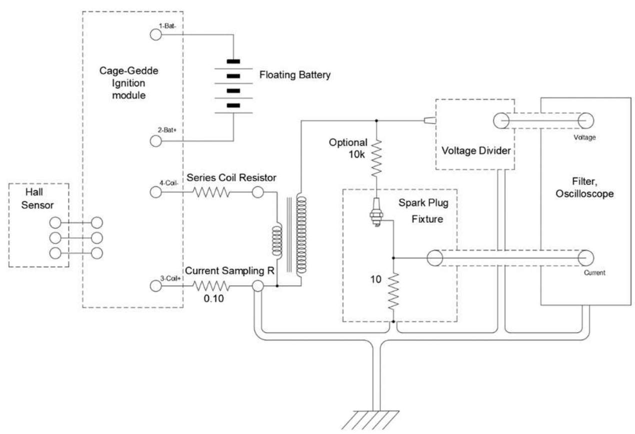


These measurements require an instrument capable of recording the spark voltage and current during a single spark. This is done using a two-channel digital sampling oscilloscope, a Techtronix 1052B, capable of capturing and storing 2500 samples per sweep in each channel. The maximum sample rate is 1 GHz, one sample every nanosecond.

The spark plug voltage will peak in the tens-of-thousands of volts, so it is necessary to use a voltage divider to scale down the voltage input to the scope. The photo above shows a shop-made 1000:1 voltage divider. The scope 10:1 divider probe is used also to bring the measured voltage within the range of the scope input.



The spark plug base is insulated from the fixture but is grounded to the spark plug fixture by a 10-ohm current sensing resistor.

The schematic at right shows the setup for measurements of an inductor coil ignition, but the same setup is used for CDI measurements with no essential change.

All samples collected by the scope for a given sweep are downloaded into an Excel program. That program not only calculates the energy per spark but also produces charts that can show analysis of the spark event from a number of different viewpoints, including charts of the voltage and current waveforms to compare with the scope display.

Spark plug discharges do generate an abundance of spurious noise in wiring, at frequencies up into the VHF or even UHF range. Good system grounding is vital to minimize the effect of this noise. The spark plug fixture is directly bolted to the 1000:1 voltage divider and is bonded with a wide strap the coil or ignition module. A coaxial cable connects the current sensor in the spark plug fixture to the scope. Even with these precautions it has been necessary to impose some low pass filtering into both the voltage and current measuring circuits to avoid saturating the scope with noise pulses.

Progress

CDI testing was reported on HMEM in post #1 of this string. The following (edited) paragraphs are copied from that post:

Conclusions

All CDI modules—except those with failures—were able to drive spark plugs with a range of 0.46 to 1.47 millijoules total energy per spark. In my experience, spark energy below 1 mjoule is marginal for reliable operation of model engines. Follow-on tests will be required to determine if coil-based systems deliver their stored energy into the spark more efficiently.

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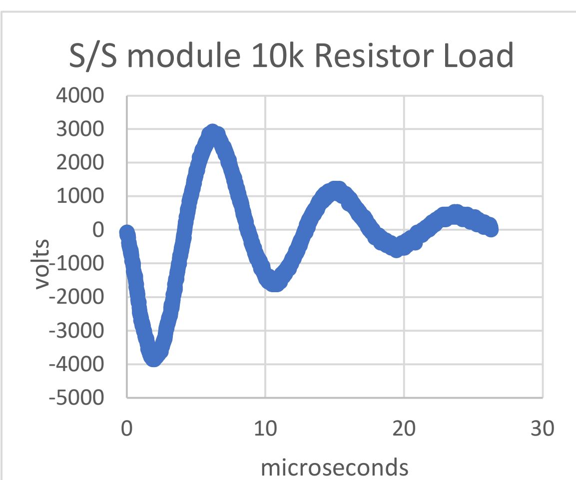
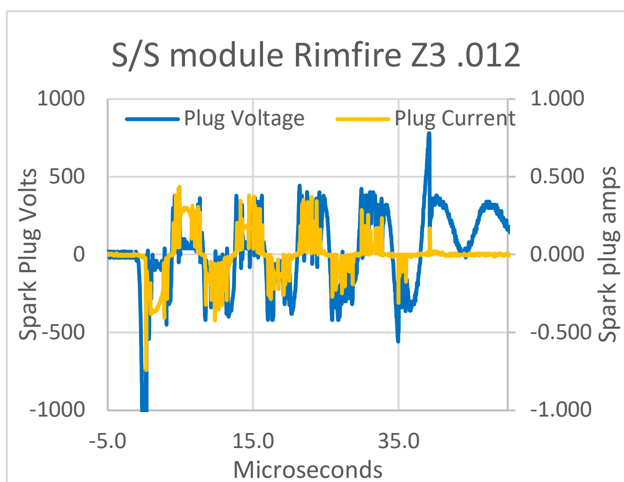
Tests of Model Engine CDI Ignition Modules

				Measured Energy - millijoules				
Module ID	Type	Owner	Pulse +/-	10 kΩ res load	CM6 0.025	Viper Z3 0.012	Input Volts	Notes
AVE	S/S 2	Grimm	-	4.5	1.3	0.65	4.5	As installed on original engine
ATKD	S/S 2	Grimm	-	5	1	0.85	4.6	
Otto Langen	S/S 1	Grimm	+	14.2	1.03	1.1	5	1K series R in HV pulse output line
Loaned Unit	CH	Knapp	-	3.07	-	-	4.5	returned without spark plug tests
Dual RCEXL	CC	Vietti	-	1.68/1.98	-	-	4.5	returned without spark plug tests
Single, large	CC	Vietti	-	4.53	-	-	4.5	returned without spark plug tests
NFSTRIKE #1	G-01	Grimm	-	10.6	1.25	0.875	9.75	
NFSTRIKE #2	G-01	Grimm	-	11.7	1.16	1.1	9.75	
Cison #1	none	Grimm	-	3.4	1.47	0.47	9.6	
Cison #2	none	Grimm	-	3.2	1.14	0.46	9.6	
RCEXL	A-02 vers 2	Berry	-	6	1.05	1.03	9.5	Unique circuit—unipolar pulse out
S/S	RCEXL kit	Grimm	-	4.8	0.7	0.74	5.1	1K series R in HV pulse output line

Discussion of Results

These tests consistently showed that the spark energy delivered to the spark is only a fraction of the total energy available from the CDI module. That result was not unexpected. CDI ignitions deliver a very short spark, typically around 40 µsec. Once flashover occurs (initiated by very high voltage) the spark voltage itself drops to a relatively low value. In fact, the higher the current, the lower the voltage[1]. You can clearly see this happening in the sample spark plug waveform below. Low spark voltage limits the rate at which energy can be transferred to the spark (volts x amps.). Energy is volts x amps x time; if both volts and time are limited, you just can't get a lot of energy transferred.





[1] Electric arc - Wikipedia

Testing Model Engine Ignition Systems

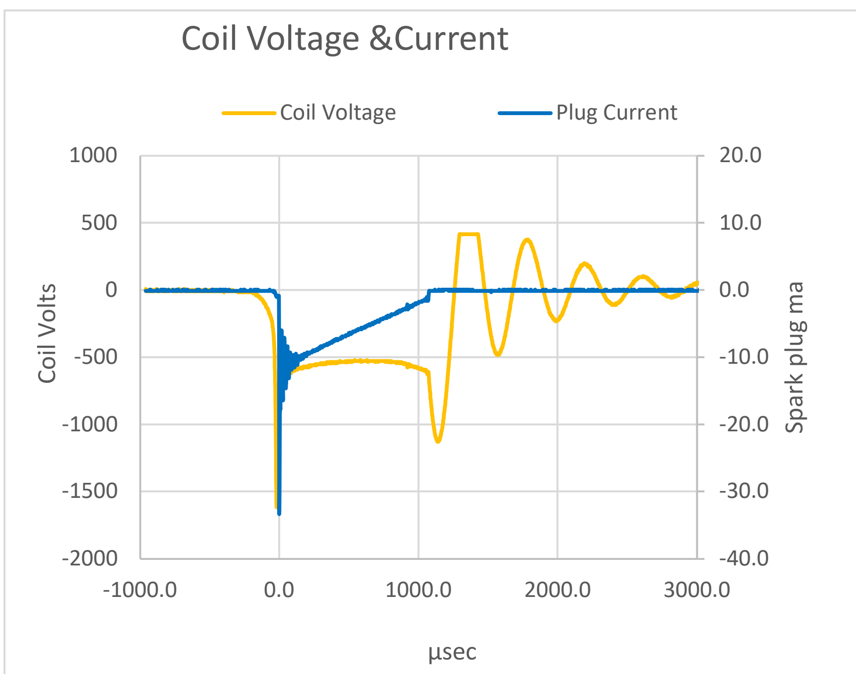
Tests of Automobile Coil with Sage-Gedde driver

It's taken a few weeks of experimentation to iron out a repeatable standard test to be used to evaluate inductive ignition systems. As of now, that standard includes the following:

1. Supply voltage is a nominal 6v sealed lead cell battery.
2. Series resistors are used to set the amount of coil current for each test.
3. A supply current sampling resistor of 0.10 ohms is used in the positive coil lead to measure the coil current at the point of firing.
4. A 10k resistor is used in series with the spark plug lead to limit the peak avalanche current at the initiation of spark (discussed below).
5. Voltage, current, and time base controls on the scope are set (limited by noise spike saturation) to maximize the (undistorted) size of the spark display on the scope.
6. 2500 samples voltage, current, and time are recorded for one single spark and copied unto a USB drive to be transferred to the Excel processing software.
7. The Excel spreadsheet creates graphs showing voltage and current waveforms, and the energy buildup over time for the sparkplug and for the series sparkplug resistor. An expanded waveform for the spark initiation transient is also produced.

Sample Results

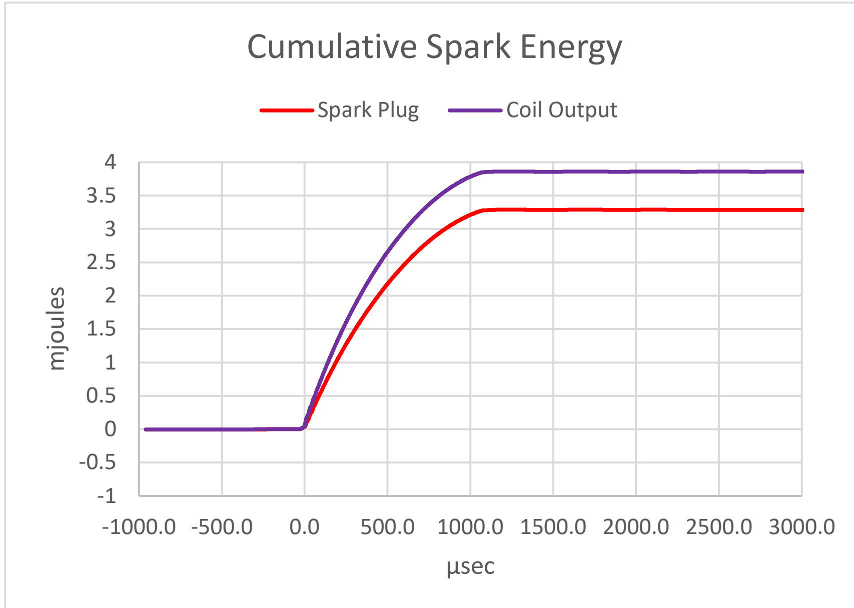
The following example test results were obtained from an automobile coil tested at 1.2 amps current with a 10k resistor at the spark plug:



Comments: the voltage trace is the classic ignition analyzer scope picture, negative because the test setup is positive ground. The initial negative spike is actually a high frequency burst. The arc stabilizes for a little over 1 msec and then abruptly rings out at a little over 2 kHz (the self-resonant frequency of the open-circuit coil secondary.) Note the first half-cycle of the ringout is clipped by the scope.

The current starts with a short, high-amplitude, high-frequency burst, stabilizes at about 10 milliamps, and decreases linearly t to about 1 milliamp, at which point the arc de-stabilizes and abruptly extinguishes (which triggers the voltage ringout beginning at that point).

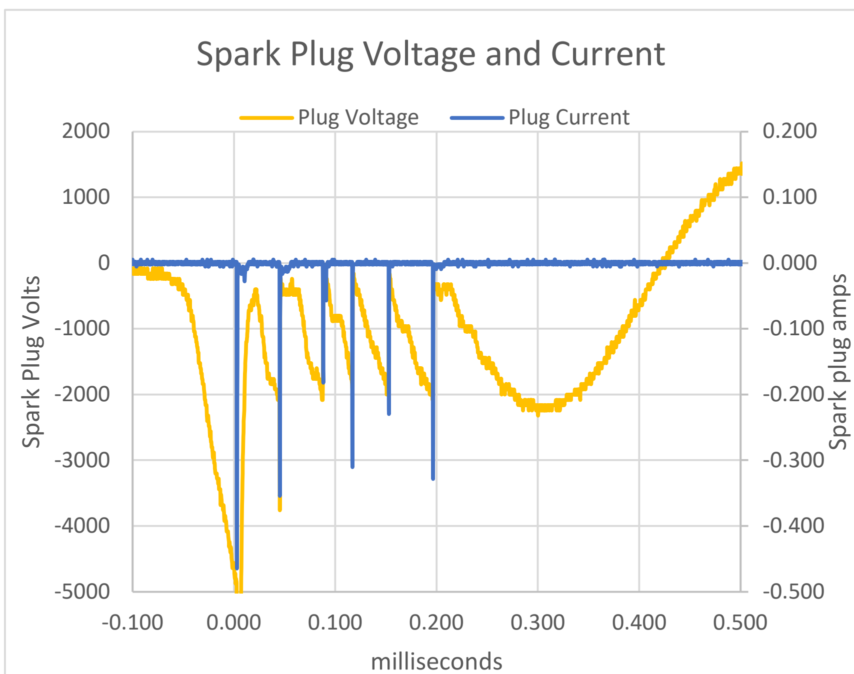
During the stable arc period the arc voltage remains almost constant at a little over 500 volts. This is an important aspect of a stable arc: the voltage is remarkably constant, actually decreasing as the current increases.



The Cumulative Spark Energy graph shows the energy delivered by the coil during the spark. The energy of the noise bursts and ringing are insignificant in the case where there is a stable arc for a period of 1 millisecond or more. If a series spark plug resistor is used the program calculates the dissipation in that resistor and subtracts it from the total coil energy. The second trace on this chart shows the net energy delivered into the spark itself.

Limitations of this method

It's hard to recognize that this waveform might have come from the same test setup, but it did, with only small changes to the test. Here the coil current was reduced to 0.86 amps, and the test was conducted without the series spark plug resistor.



Spark stability requires a certain minimum current to maintain the arc temperature; otherwise it will "flame out" until the current from the coil recharges the stray capacitance and strikes a new arc. The waveform here shows this repeated pattern very clearly. (They call this a relaxation oscillation.)

The measurement headache comes because here there is no stable arc period. The current spikes themselves are the dominant mode of energy transfer. Unfortunately, there are roadblocks that get in the way of measuring short spikes.

To measure instantaneous power as voltage x current, the measurements must arrive at absolutely simultaneously at the scope sampling circuits and must not be distorted by clipping or saturating. I am seeing gross errors in calculating energy for these short, high intensity pulses. These inaccuracies very large because they occur at times when the instantaneous voltage and current are at a very high magnitude. I now believe very short pulses are being distorted by the low-pass filtering I am using in each channel to suppress ringing noise from the wiring.

It doesn't help that the sample resolution of the scope channels is only eight bits – seven bits with sign. An example of that problem would be to set the scope gain to accurately sample a peak current of 0.5 amp. The least significant bit of the 8-bit sampler would be about 40 milliamps ($0.5a/2^7$). Because of this sampling resolution any current lower than that gets lost. That makes it impossible to calculate power for any stable arc that might exist during the spark event.

I can't afford an upgrade to test equipment that could deal with all this head-on, so I don't have an answer at the moment. My test set can accurately measure spark energy for relatively strong ignition systems, but not for weak ones.

Next Steps

1. Test run the original engine with the coil system describe in this paper.
2. Test inductive coil system at various current levels.
3. Test CDIs at various input voltages.
4. Obtain more ignition coils to evaluate and compare with the automobile coil.
5. Scan the literature and reader comments for additional suggestions.
6. Explore more arc conditions such as higher pressure, moving air, etc.
7. Spend less time writing papers and more time building engines.