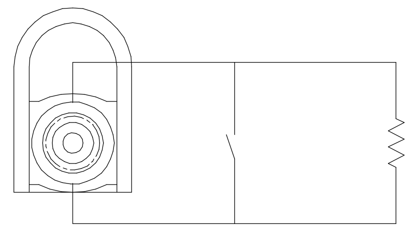
Measuring Magneto Energy Output and Inductance

Revision 1

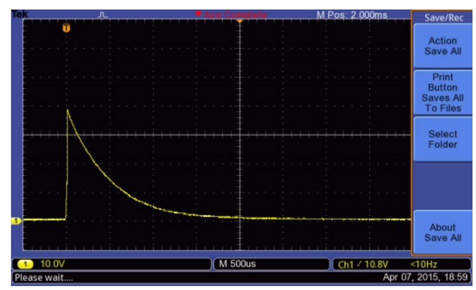
Introduction

A magneto is fundamentally an inductor that is mechanically charged with an initial current value. That initial current is produced by movement of the rotor while the primary coil is shorted by mechanical (or electronic) ignition points. Inductors tend to maintain current flow, so when the points open, the stored inductive energy discharges into a spark gap, igniting a combustible fuel mixture. Inductor current steadily decreases as energy is delivered to the spark from its magnetic field.



Low Tension Magneto with resistor load

During the spark the output voltage is determined by the nature of the spark; it does not depend upon the magneto itself. Spark discharge voltage is wildly variable, difficult to measure or to characterize. The instantaneous output voltage does determine the rate of change of output current. Neither current nor voltage are well enough behaved to easily measure the output energy directly.



One method for measuring output energy is to connect an appropriate resistor load across the spark gap to suppress the spark and absorb the output energy. The discharge will then occur in a predictable and easily measured manner. This works well under many conditions, but there are complications that will be discussed below.

Measurement Method for Low Tension Magneto

Ideally, output energy of a low-tension magneto would be measured by the following method. Connect the magneto coil to quick-opening interrupter points that are synchronized with the rotor. Time the points to open at the instant of maximum short circuit current while the rotor turns at the desired operating rotor speed. Connect an appropriate resistor to divert the coil current so that there is no spark discharge at the contact points. Record a table of samples of the RL discharge pulse with a recording oscilloscope. Output power and total energy are calculated:

$$P = \frac{v^2}{R} \quad and \quad W = \int_0^\infty P dt, \text{ or } W \cong \sum_1^N \frac{v_n^2}{R} \Delta t_n$$

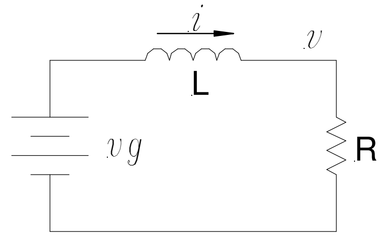
The summation form is used to calculate the integral numerically from the table of sampled data.

This method has two practical problems that must be dealt with. First is that the output voltage transient will be sufficient to induce a spark anyway if the rotor speed is high or if the resistor is large. The method is thus limited to low speed testing with relatively small resistance loads.

Second, the turning rotor generates some voltage during the discharge period, and that voltage becomes the dominant part of the output voltage near the end of the RL transient decay. The method must therefore be refined to separate the rotor-generated voltage from that produced by the inductor-stored energy. The schematic diagram below shows the discharge circuit after the points open with rotor-generated voltage, vg, included.

$$P_L = (v - vg)\,i = \frac{1}{R}(v - vg)\,v$$

$$W_L = \int_0^{\infty} P_L\,dt, \text{ or } W_L \cong \frac{1}{R}\sum_1^N \left[v_n \left(v_n - vg_n \right) \right] \Delta t_n$$



The variable tables containing v_n and vg_n samples are recorded in two separate data runs with a digital sampling scope. v_n is measured with the switch operating. vg_n is the open circuit magneto-generated voltage measured on the same time scale, using the ignition points to trigger the measurement so the measurement periods are coincident. The two data files are linked directly to software in an Access program that calculates the energy using the equations above. See the author for details about the Access program implementation.

This residual generated voltage, vg_n undoubtedly contributes some energy to the spark output above and beyond the stored inductor energy. That incremental output energy is not calculated here. Unless one can characterize the time-voltage behavior of the spark, it is not possible to calculate the magnitude of the contribution. For most situations it appears to constitute a small bonus energy of relatively insignificant value, although exceptional cases have been seen, especially with high-tension magnetos having large coil turns ratios that greatly step up the rotor-generated voltage.

Calculating Low Tension Magneto Inductance and Inductance-stored Energy

Analysis of the initial part of the RL discharge pulse can provide additional information, including a measurement of the magneto inductance and an independent calculation of stored inductor energy.

$$v - vg = -L\tfrac{di}{dt},\ \ i = \frac{v}{R}, \text{ and } \tfrac{di}{dt} = \frac{1}{R}\tfrac{dv}{dt}$$

$$v - vg = -\frac{L}{R}\tfrac{dv}{dt}, \text{ so}$$

$$L = R\frac{vg_1 - v_1}{\left(\tfrac{dv}{dt}\right)_1} \text{ at } t = T_1$$

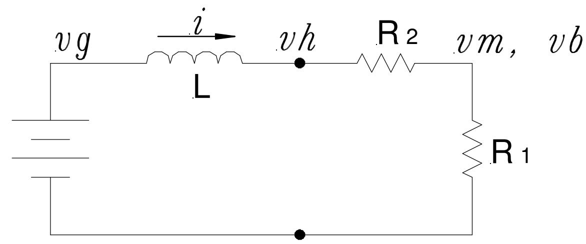
$$W_1 = \frac{1}{2}Li_1^{\,2} = \frac{1}{2}L\left(\frac{v_1}{R}\right)^2$$

$$W_1 = \frac{1}{2R}\frac{(vg_1 - v_1)v_1^{\,2}}{\left(\tfrac{dv}{dt}\right)_1} \text{ at } t = T_1$$

Voltages v_1, vg_1, and the slope of the discharge curve, $\left(\tfrac{dv}{dt}\right)_1$, can all be obtained from the early part of the data sample tables recorded by the oscilloscope as above. $\left(vg_1 - v_1\right)$ and $\left(\tfrac{dv}{dt}\right)_1$ will both be negative, so the results will be positive. Be aware that noise on the sampled data will give unreliable results to these quantities unless the samples are appropriately smoothed over time. Eyeball estimates of these quantities from oscilloscope pictures can give useful results. From one or two examples so far, L appears to be fairly constant for values of t throughout the discharge interval.

High Tension Magneto Measurements

Voltage delivered to the spark plug by a high-tension magneto generally exceeds the breakdown voltage of standard oscilloscope probes. Using a high voltage probe with sufficient range, the measurement methods developed above can still be applied. However, as a practical matter, standard instruments and probes may be used with a resistive voltage divider connected as shown in the diagram. An attenuation ratio in the order of 100:1 combined with typical hardware voltage limits of 300 volts will accommodate transients up to 30kv.



Magneto points operating:

$$vm = \frac{R_1}{R_1 + R_2} vh, \text{ so } vh = \frac{R_1 + R_2}{R_1} vm$$

Magneto points open:

$$vb = \frac{R_1}{R_1 + R_2} vg, \text{ so } vg = \frac{R_1 + R_2}{R_1} vb$$

As with the low-tension magneto measurements, two data files are recorded. The symbol vm in the equations at right represents the operating magneto output, and vb represents the open circuit voltage with the coil open. Both files are synchronized by the magneto ignition points so they have the same time base. The equations shown assume the attenuator consisting of R_1 and R_2 is in place for both measurements.

$$P_L = (vh - vg)\, i = \left(\frac{R_1 + R_2}{R_1^{\,2}} \right) (vm - vb)\, vm$$

$$P_L = \left(\frac{R_1 + R_2}{R_1^{\,2}} \right) (vm - vb)\, vb$$

$$\frac{1}{R_{eq}} = \left(\frac{R_1 + R_2}{R_1^{\,2}} \right), \text{ or } R_{eq} = \left(\frac{R_1^{\,2}}{R_1 + R_2} \right), \text{ so}$$

$$P_L = \frac{1}{R_{eq}} (vm - vb)\, vb$$

$$W_L = \int_0^\infty P_L\, dt, \text{ or } W_L \cong \frac{1}{R_{eq}} \sum_1^N \left[vm_n \left(vm_n - vb_n \right) \right] \Delta t_n$$

Software developed for data reduction described above may be used directly by calculating the value of an "equivalent load resistor," R_{eq} as shown at right. Actual measured voltage readings are processed in the program. No further scaling is required.

Attenuator output measurements of the beginning of the output pulse from a high-tension magneto can also be used to calculate inductance and stored energy. The equations are derived at right, and are similar in form to those derived for low-tension magnetos in the previous section. As noted before, noise on the sample data files for vm and vb must be appropriately smoothed to get accurate results.

$$i = \frac{vm}{R_1}, \quad \frac{di}{dt} = \frac{1}{R_1} \frac{d(vm)}{dt}$$

$$(vh - vg) = -L \frac{di}{dt}, \text{ or}$$

$$\frac{R_1 + R_2}{R_1} (vm - vb) = -\frac{L}{R_1} \frac{d(vm)}{dt}$$

$$L_1 = \frac{(R_1 + R_2)(vb_1 - vm_1)}{\left(\frac{d(vm)}{dt} \right)_1} \quad \text{at } t = T_1$$

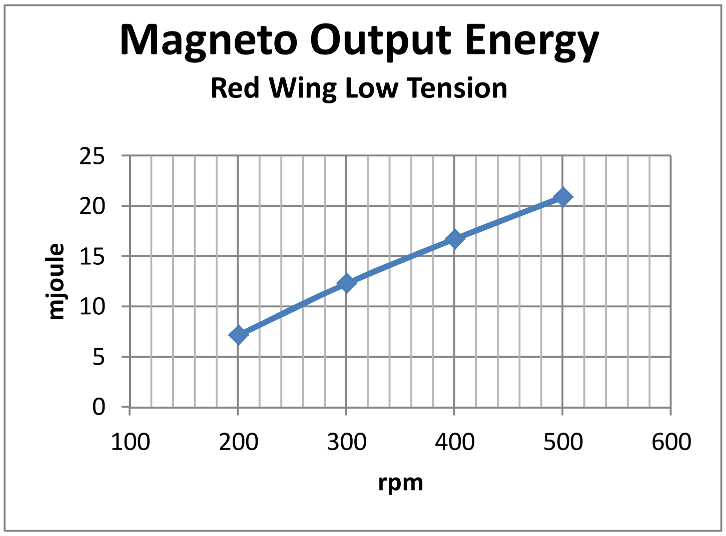
$$W_1 = \frac{1}{2} L i_1^{\,2} = \frac{1}{2} \; \frac{(R_1 + R_2)(vb_1 - vm_1)}{\left(\frac{d(vm)}{dt} \right)_1} \left(\frac{vm_1}{R_1} \right)^2$$

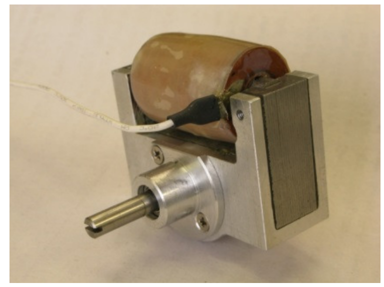
$$W_1 = \frac{(vb_1 - vm_1) vm_1^{\,2}}{2 R_{eq} \left(\frac{dv}{dt} \right)_1} \quad \text{at } t = T_1$$

Example Results from Recent Tests

Red Wing Low Tension Magneto

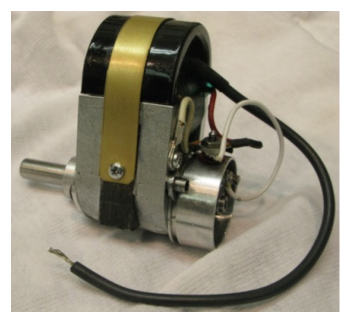
The waveform shown on page 1 is from a test of the low-tension Grimm Red Wing magneto described in *Model Engine Builder* magazine, Issue 25. The body of this magneto is 0.75" thick and 1.90" wide. The coil core is of octagonal cross section made from laminated transformer iron, with an area of 0.0672 in^2.



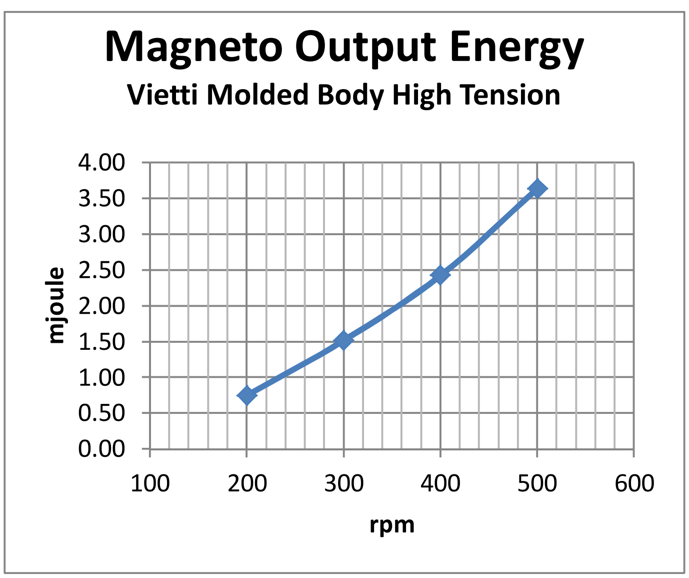


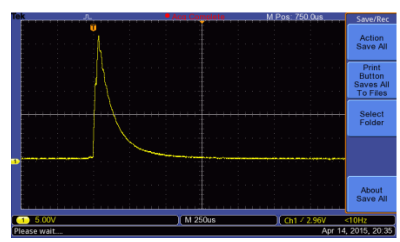
rpm	W mjoule
200	7.15
300	12.31
400	16.74
500	20.92

Vietti Cast Frame High Tension Magneto



Data from a recent high-tension magneto designed and built by John Vietti is shown here. The body of the magneto is 1.3" wide and 0.975 thick, with a coil core cross section of 0.049 in^2. Body stator thickness is 0.375". The waveform photo at right shows some evidence of spark plug or ignition point flashover during the leading edge of the pulse, reducing measured output energy into the load resistor.





rpm	W mjoule
200	0.75
300	1.52
400	2.43
500	3.64

Selecting Load Resistor Values

Determining the best resistor value for testing is more art than science. The length of the discharge pulse is controlled by the resistance of the load. High resistance increases the discharge voltage and shortens the pulse. Short pulse effects include susceptibility to flashover breakdown of the interrupter points or the spark plug* (high-tension magneto). Energy shunted into a spark discharge will deduct from the energy measurement. Short discharge pulses will also induce higher eddy current losses in the magneto iron flux path.

Lowering the load resistor decreases the pulse voltage and increases its duration. This allows measurements at higher rpm without sparking. The prolonged current flow does increase the copper loss in the magneto winding(s). Lowering the pulse voltage also makes the open circuit generator voltage of the magneto a more significant fraction of the total voltage, so compensation for this effect becomes more important.

The practical option, then, is to choose a resistance value that just suppresses sparking at the maximum rpm to be tested. It is not necessary to suppress all sparking. The single trace option of the oscilloscope can be used to select one good pulse out of numerous bad ones, given some patience and persistence. It seems best, however, to avoid reducing the resistance to the point where the output pulse becomes significantly longer than 1 *ms.* Most ignition sparks are shorter than that, and it is usually advisable to test the magneto with operating conditions as close to normal as possible. Most of my LT tests were made with a 55 ohm load, and HT tests were conducted with an R_2 value of about 270 kohm.

Conclusions

Theoretical bases for two methods for measuring magneto output energy have been described, along with one method of measuring inductance. Detailed implementation instructions are not provided here, but can be obtained from the author.

Other methods exist. See http://dtec.net.au/Ignition%20Coil%20Energy%20Testing.htm for an example. This tester discharges the output pulse into a Zener diode array that clamps the output voltage to a value near 1kv. Power is calculated by multiplying the pulse current times the clamped voltage, and then integrating over time to compute energy. It should give accurate results, but is not easily adapted to testing low-tension magnetos.

A commonly used analysis tool is the calibrated spark gap. One form is described in my working paper, http://www.dkgsite.com/index_files/Spark%20Testing%20Article%20062508.pdf, on page 6. This will give approximate values of output energy when properly applied.

Please contact the author with suggestions for improvements or information regarding other methods that may exist.

*Best practice is to keep the spark plug in place when testing a high-tension magneto to protect the coil from internal flashover if excessively high voltage spikes should happen to occur.