

# IgnCoilAnalyzer

Ignition Coil Analyzer Application  
Users Manual

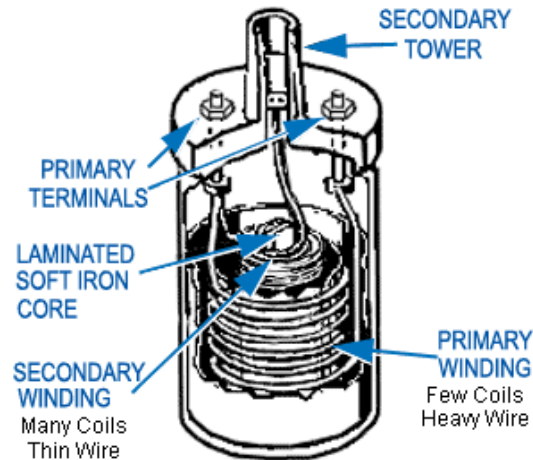
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## Introduction to IgnCoilAnalyzer

- The IgnCoilAnalyzer application is designed to assist in the characterization of automotive ignition coils.
- By taking a small set of electrical measurements (resistance and inductance), important parameters of an ignition coil can be determined, including:
  - Energy Storage
  - Discharge Voltage and Current
  - Primary Charge Time
  - Spark Discharge Time
- These parameters can be used to compare different ignition coils in order to assist in proper selection with respect to application.

The IgnCoilAnalyzer is a PC Application that uses a simple set of measurements of an induction-type ignition coil to determine several key factors. The measurements take about 5 minutes to complete and are sufficient in ignition coil characterization.

## How Ignition Coils Operate

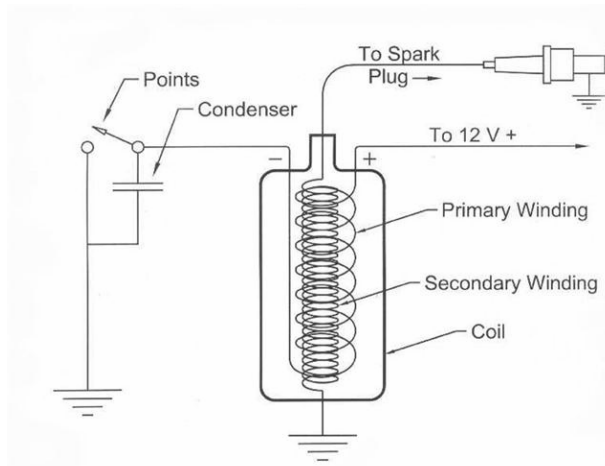


An ignition coil, also known as an induction coil, is really a simple transformer that steps up voltage. A transformer consists of two windings, a primary winding and a secondary winding, wrapped around a metal core. A voltage is applied to the primary winding, in the case of an automotive ignition coil a voltage around 12 volts or so. The current in the primary winding will build up over a period of time (depending on the resistance and inductance of the primary) which imposes a magnetic flux on the metal core. After a period of time the current will equalize, with the energy now stored in the metal core as a magnetic flux.

When the primary voltage is removed, the sudden collapse of the magnetic flux in the metal core imposes a back voltage to the primary winding in an attempt to maintain the current flow. The voltage in the primary radically increases in value for a very brief instant, up to 300 volts or more. When this occurs a voltage is induced in the secondary winding that is proportional to the ratio of the primary to secondary turns. In an ignition coil, the turns ratio is usually 50 or greater, this effectively multiplies the voltage to a value of many thousands of volts. This high voltage induces a spark on the secondary circuit (if there is a suitable gap).

It should be noted that while the turns ratio increases the voltage, it also decreases the current from the primary to secondary by the reciprocal of the turns ratio.

## Ignition Coil – Kettering Points Configuration

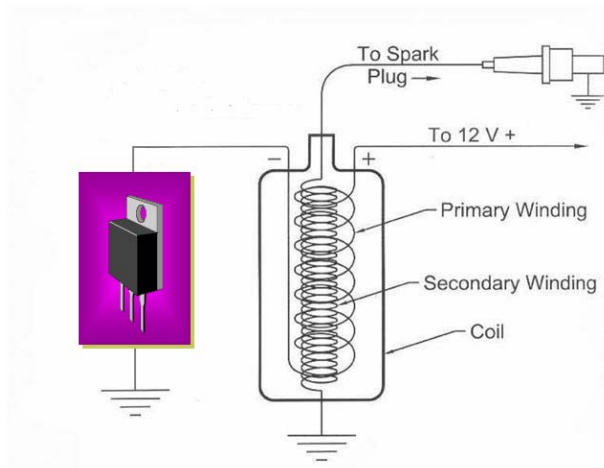


Here is a diagram of the Kettering ignition system which was used for years and years before the advent of electronic ignition. Operation is very simple.

First, the points are closed for a period of time in order for current to flow in the primary windings. Since the ignition coil primary is really an inductor, it takes time for the primary current to build up to a final value, generally 3 - 6 milliseconds. The circuit of the conventional points ignition setup usually employs a series resistor (not shown) which limits the final current flow. Generally, this resistance is switched out of the circuit during engine cranking in order to deliver more current to the ignition coil.

When the time is right for the ignition coil to “fire” a spark, the points are opened. This results in a collapse in the magnetic field in the ignition coil. This collapse causes a current to flow in the primary windings through the capacitor (which acts like a short circuit for a brief moment in time). The voltage induced on the primary winding can range to 300 – 500 volts (limited by the primary and secondary winding resistance, inductance, and capacitance). The change in voltage is multiplied by the turns ratio of the secondary to the primary windings, thus producing 12,000 to 40,000 volts on the secondary and initiating spark.

## Ignition Coil – Electronic Driver Configuration



This diagram is almost like the previous one, with the notable difference that the mechanical points are replaced by a semiconductor switch. This switch is activated by an external trigger, like a Hall, Variable-Reluctance (VR) or most likely from a Engine Control Unit (ECU). The operation of the ignition circuit is the same otherwise.

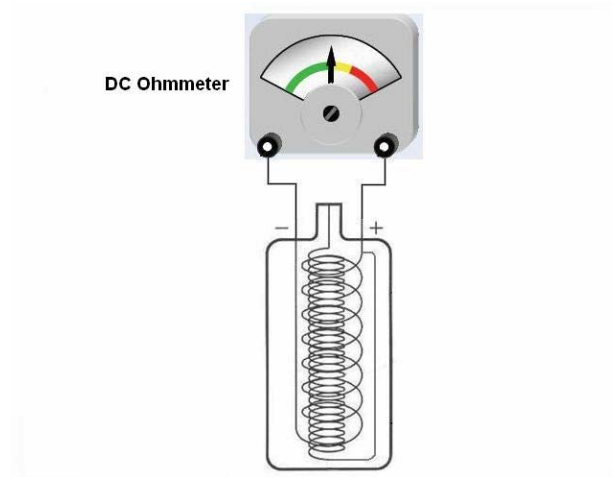
The ignition coil still requires a period of “dwell” where there is primary current flowing in order to impart energy, or “charge up” the coil. The dwell time is provided by the driver circuit which controls the semiconductor switch.

One thing different about the semiconductor switch is that there is a maximum voltage that it can withstand, and if this voltage is exceeded the device will be destroyed. This maximum voltage can range from 300 to around 450 volts, depending on the construction of the semiconductor switch. Voltages that equal or exceed this value during the primary flyback transient are clamped by a zener circuit, which limits the voltage to the maximum.

## Ignition Coil Measurement – The 5 Steps

- With the help of the IgnCoilAnalyzer application, the important parameters of an ignition coil can be determined from 5 simple parameter tests:
  - Primary Resistance Measurement ( $R_{pri}$ )
  - Primary Inductance Measurement ( $L_{pri}$ )
  - Primary Inductance Measurement with Shorted Secondary ( $L_{pss}$ )
  - Secondary Resistance Measurement ( $R_{sec}$ )
  - Secondary Inductance Measurement ( $L_{sec}$ )
- These values are entered into the IgnCoilAnalyzer to obtain key operational parameters of an ignition coil, which can be used for comparison purposes.

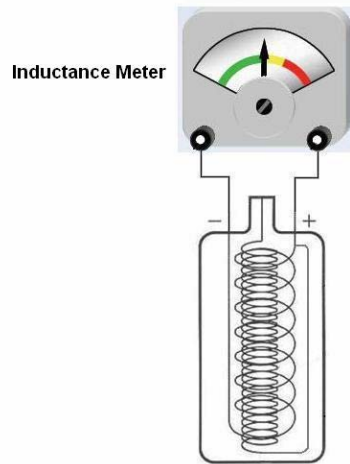
## Ignition Coil Measurement - Step #1 Measure Primary Resistance



The first measurement to perform is a DC resistance measurement of the ignition coil primary circuit (the low voltage winding). This is done using a standard ohmmeter. Note that this is a DC measurement, avoid the use of a LCR or other bridge measurement device that measures reactance. Just use a standard ohmmeter to obtain the reading.

The range of resistance can be from 0.5 ohms to 2 ohms, depending on the ignition coil. Record the value as **Rpri** to indicate the resistance of the primary.

## Ignition Coil Measurement - Step #2 Measure Primary Inductance



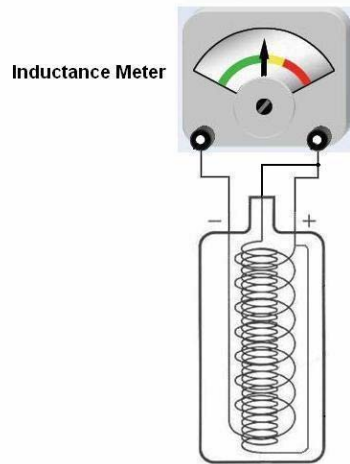
The second step to knowing your ignition coil is to measure the inductance of the primary winding. What is inductance? It is the property of a circuit element that opposes a change in current flow, measured in henries. Inductance in the ignition coil's windings is the reason it takes time to "charge up" a coil. Without inductance, the current flow within an ignition coil would reach a maximum immediately. The inductance of the coil resists changes in current.

To measure the inductance, an inductance meter is used, in a similar manner as the ohmmeter. Just attach across the primary winding, leave the secondary winding open.

An inductance meter may have different test frequencies, if so use the 1KHz mode for the inductance tests if possible. Also, allow the reading to stabilize before taking the final reading. You should see a value in the millihenry (mH) range. Save this reading a **Lpri** for the inductance of the primary.



### Ignition Coil Measurement - Step #3 Measure Primary Inductance w/ Shorted Secondary



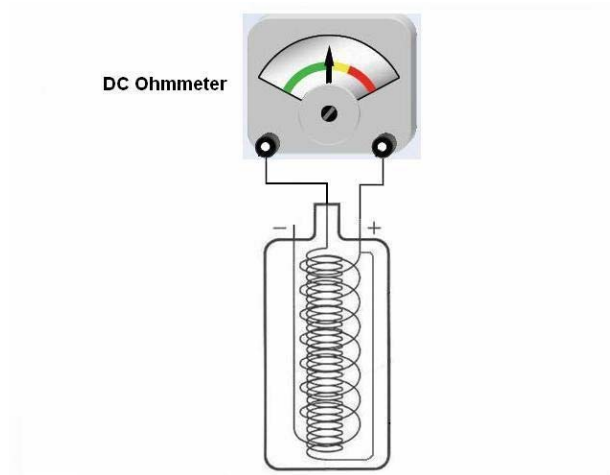
This is step 3, which is almost the same as step 2, with the addition of a shorted secondary winding. What you do is use a wire and short the secondary winding together. What this does is change the inductance of the primary winding and is used to determine the electrical coupling between the windings.

For a standard tower ignition coil, one side of the primary and secondary are tied to the same post, the (+) terminal. In this case short out the high tension tower post to the (+) terminal, and measure the primary winding like before.

For wasted spark coils the secondary posts are usually isolated. Just short the two secondary posts together.

When the secondary is shorted, the inductance of the primary will drop significantly, usually in the microhenry (uH) range. Record this value as **L<sub>pss</sub>** for inductance of the primary with shorted secondary.

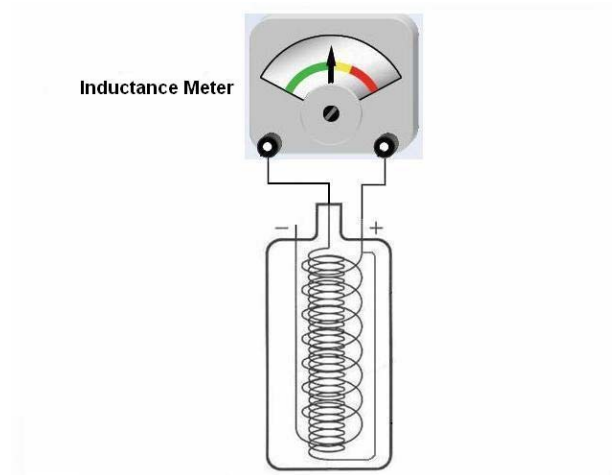
## Ignition Coil Measurement - Step #4 Measure Secondary Resistance



Step 4 is easy, just a DC measurement of the secondary winding, in a similar fashion as step #1. Use the DC ohmmeter for this.

You should expect a reading in the kilohms (K) range. Record this as **Rsec** for resistance of secondary.

## Ignition Coil Measurement - Step #5 Measure Secondary Inductance



Finally, the last step! This is an inductance measurement of the secondary winding (with primary winding open). This is similar to step #2 but working on the secondary.

You should expect a large reading, in the henries (H) range. Record this as **Lsec** for inductance of secondary.

This is all of the measurements required. With the help of the IgnitionCoilAnalyzer application you will now characterize the ignition coil.

Measurement Example  
Mitsubishi Wasted Spark Coil  
Step #1 – Measure  $R_{pri}$



Here is the sequence of tests for a wasted spark coil, which are the same as the standard tower ignition coil. The coil under test is a Mitsubishi wasted spark ignition coil, which is a good representative test case.

Note that the ohmmeter and inductance meter values in the photos above may not have settled, so the final value used in the calculation may be different.

Measurement Example  
Mitsubishi Wasted Spark Coil  
Step #2 – Measure Lpri



Measurement Example  
Mitsubishi Wasted Spark Coil  
Step #3 – Measure  $L_{pss}$



Measurement Example  
Mitsubishi Wasted Spark Coil  
Step #4 – Measure Rsec



Measurement Example  
Mitsubishi Wasted Spark Coil  
Step #5 – Measure Lsec





# Measurement Example

## Loading Data into IgnCoilAnalyzer

IgnCoilAnalyzer V1.01 by Bowling & Grippo (C) 2006

Input Parameters

Ignition Coil Type: Mitsubishi/Neon Description: 1997 2.0L non-turbo, number 05263670

Primary Coil Parameters

Winding Resistance: 0.7 Ohms Winding Inductance (Open Secondary): 6.7 mH Winding Inductance (Shorted Secondary): 753 uH

Secondary Coil Parameters

Winding Resistance: 11.93 Kohms Winding Inductance (Open Primary): 41.6 H

Driver Parameters

Supply Voltage: 13.0 Vce Drop (Volts): 1.2 Resistance (Ohms): 0.0 Zener Avalanche Voltage: 350.0 Current Limit (Amps): 8.0

Spark Plug & Wire Parameters

Spark Plug Gap: 0.030 Inch Resistance (Ohms): 1000.0 Capacitance (pF): 25.0

Engine Parameters and Empirical Values

Number of Cylinders: 8 Engine Stroke: 4 Cylinder Pressure (Bar Absolute): 12.0 Cylinder Temperature (Degrees C): 300 Spark Burn Voltage (kV): 1.2

Calculate

Calculation Results

Secondary Voltage (kV): 30.3 Secondary Current (ma): 95.7 Secondary Energy (mJ): 190.3

Turns Ratio (Ns/Np): 73 Coupling Coefficient: 0.94 Spark Break-down Voltage (kV): 12.3

Primary Current Charge Time (ms): 6.2 Spark Burn Time (ms): 2.3 Maximum RPM to Maintain Charge Time: 2435

Exit Program

**IgnCoilAnalyze Equations**

Vp = Primary voltage (V)  
Rp = Primary resistance (W)  
Lp = Primary inductance (H)  
Lpss = Primary inductance with shorted secondary (H)  
Vs = Secondary voltage (V)  
Rs = Secondary resistance (W)  
Ls = Secondary inductance (H)  
Vz = Primary flyback voltage (V)  
a = Load Coefficient (assumed 1.1)  
Vb = Battery Voltage (V)  
Vce = Driver collector-emitter voltage drop (V)  
k = Coupling coefficient between primary and secondary  
a = Turns Ratio (Ns:Np)  
Rl = Load resistance (W)  
Cl = Load capacitance (F)  
Ip = Primary current (A)  
Is = Secondary current (A)  
Ep = Primary energy (J)  
Es = Secondary energy (J)  
Fs = Secondary resonant frequency (Hz)  
Vbd = Spark breakdown voltage (V)  
Vburn = Spark discharge voltage (V)  
D = Spark gap (mm)  
T = Cylinder temperature (K)  
P = Cylinder pressure (Bar absolute)

This is the variable definition list for the equations used in the IgnCoilAnalyze application. The units are volts, amps, ohms, farads, joules, and Hertz.

The Lpss variable is the primary inductance measured with the secondary winding shorted. This value is used to determine the coupling coefficient between the primary and secondary windings.

Load coefficient is assumed as 1.1, but can vary from 1.0 to 1.2. The program uses a value of 1.1 for calculations.

The Vce variable represents the voltage drop of the ignition coil driver device. For a bipolar junction transistor in darlington configuration, the voltage drop ranges from 1.2 to 2.2 volts. For a MOSFET or IGBT driver the value is the Vds or Vce(on) saturation voltage at the current limit value, see the device datasheet for information.

Vz is the zener voltage flyback limit, normally from 300 to 450 volts. This value is determined by the avalanche rating of the power darlington, MOSFET, or IGBT, see the device datasheet,

$$\begin{aligned}
(1) \text{ Secondary Voltage: } & V_s = \alpha \cdot V_z \cdot a \\
(2) \text{ Secondary Current (max): } & I_{s\_max} = k \cdot \frac{N_p}{N_s} I_p = k \cdot \frac{1}{a} I_p = k \sqrt{\frac{L_p}{L_s}} \cdot I_p \\
(3) \text{ Secondary Energy: } & E_s = k^2 \cdot \frac{L_p \cdot I_p^2}{2} \\
(4) \text{ Primary Current vs. t: } & I_p(t) = \frac{V_b - V_{ce}}{R_p} \cdot \left[ 1 - \exp\left(-\frac{R_p}{L_p} \cdot t\right) \right] \\
(5) \text{ Coupling Coefficient: } & k = \sqrt{1 - \frac{L_{ms}}{L_p}} \\
(6) \text{ Secondary Current vs. t: } & I_s(t) = I_{s\_max} - \left( I_{s\_max} + \frac{V_{burn}}{R_s} \right) \cdot \left( 1 - \exp\left(-\frac{R_s}{L_s} \cdot t\right) \right) \\
(7) \text{ Spark Breakdown Voltage: } & V_{bd} = 1000 \cdot \left[ 4.3 + 136 \cdot \frac{P}{T} + 324 \cdot \frac{P \cdot D}{T} \right] \\
(8) \text{ Secondary Resonant Frequency: } & F_s = \frac{1}{2\pi \sqrt{L_s \cdot C_l}}
\end{aligned}$$

This is the equations used in the IgnCoilAnalyze program. They were obtained from the following references:

1. Heywood, J.B., *Internal Combustion Engine Fundamentals*, McGraw-Hill, 1988.
2. Pashley, N., Stone, R., and Roberts, G, *Ignition System Measurement Techniques and Correlations for Breakdown and Arc Voltages and Currents*, SAE Paper 2000-01-0245
3. Pischinger, S., *Effects of Spark Plug Design Parameters on Ignition and Flame Development in an SI-Engine*, MIT Thesis, 1989

## Ignition Coil – Targets for Best Design

- Maximum energy storage in ignition coil (equation 3) by maximizing primary inductance and primary current. Also dependent on coupling coefficient between primary and secondary.
- Maximum primary current dependent on primary resistance, battery voltage, voltage drop across the ignition driver circuit, and opportunity time for charge, which is dependent on engine RPM, primary inductance, and number of ignition events per crank revolution (equation 4).
- Voltage transferred from primary to secondary depends on coupling coefficient and primary flyback voltage and turns ratio (equation 1)
- Current transferred from primary to secondary depends on coupling coefficient, primary current, and the inverse of winding turns ratio (equation 2).

The design of an ignition coil is based on a lot of compromises. The goals are to maximize energy, voltage, and current but it is not possible by virtues of the physics involved. The best ignition coil is a compromise of many parameters, and not just the secondary voltage – secondary energy and current also affect spark burn time.

To maximize primary coil energy the primary current (which is squared) must be as large as possible – however there are limits to driver current control and heat generated. The primary inductance also should be as large as possible, with the downside of slowing the primary current charge time and reducing the turns ratio.

The voltage from the primary to secondary depends on the flyback voltage, which is determined by the driver electronics, With the semiconductor devices available this value is nominally 350 volts. The voltage also depends on the turns ratio of the secondary to the primary, which is equivalent to the square root of the secondary inductance divided by the primary inductance.

The maximum current transferred from the primary to secondary depends on primary current and the reciprocal of the turns ratio. The higher the turns ratio the lower the secondary current – this decreases the burn time, increases the likelihood of spark blow-out, and deteriorates low-temperature engine starting.

## Ignition Coil – Targets for Best Design

- Some of the best compromises in ignition coil and driver design are the following:
  - Higher secondary energy
  - Higher driver flyback voltage
  - Lower turns ratio
  - Higher primary current
  - Higher secondary energy

## Representative Test Results

Coil Type	Rp	Lp	Lpss	Rs	Is		Vs	Is	Es	a	k	T <sub>ip</sub>	T <sub>burn</sub>
	(ohms)	(mH)	(uH)	(Kohm)	(H)		(kV)	(mA)	(mJ)			(ms)	(ms)
UC12 <sup>(1)</sup>	1.5	3.2	809	8.9	60.9		53.1	24.4	18.2	138	0.86	5.1	1.1
HEI	1.1	3.7	400	7.3	31		35.2	82.5	105.6	92	0.94	4.6	1.7
GM-DIS	0.5	3.2	345	5.9	25.8		34.6	84.2	91.4	90	0.94	2.6	1.5
Ford EDIS	0.7	6.3	632	13.4	51.1		34.7	84.3	181.4	90	0.95	5.8	2.5
Mitsubishi	0.7	6.7	753	11.9	41.6		30.3	95.7	190.3	79	0.94	6.2	2.3

Analysis performed with supply voltage = 13.0V, Vce drop = 1.2V, Driver resistance = 0 ohm, Driver avalanche voltage = 350V, Current limit = 8.0A,  
 Plug gap = 0.030in, Plug wire resistance = 1Kohm, Plug capacitance = 25 pF

<sup>(1)</sup> - UC12 ignition coil analysis performed with external resistance of 1.5 ohms, current limit of 3.9 amps