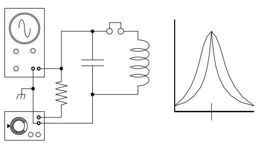
Tuning

With any Tesla coil, tuning is required for maximum output. Adjustments are made to bring primary and secondary resonant frequencies together, allowing maximum energy transfer. The degree of coupling, which is a factor of the *mutual inductance*, also affects coil performance, and may require adjustment.

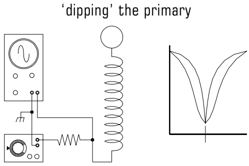
Tuning is a *dynamic* process, requiring coil operation to evaluate performance. However, several measurements may be taken before power need be applied. These *static* measurements allow the builder to check both primary and secondary resonant frequencies, mutual inductance, and even the degree of coupling.

The first involves finding the exact resonant frequency of both the primary and secondary. From previous discussion, the secondary circuit is a series resonant system, and will draw maximum current at resonance. The primary is a parallel circuit, and draws minimal current at resonance. We can exploit this phenomenon through a procedure known as *grid dipping*. Also, if the builder has access to an *inductance bridge*, the coupling coefficient may also be determined and adjusted.

Coupling coefficient is obtained as follows:



'dipping' the primary



'dipping' the secondary

Grid-Dipping

This term derives from a piece of test equipment called a grid-dip meter. Used to tune oscillators and RF circuits, the meter monitors grid current in it's internal oscillator tube.With an external tuning inductor, the meter induces oscillation into the circuit being measured. When the meter circuit oscillates at the resonant frequency, grid current will 'dip' due to increased loading by the circuit under measurement.

For Tesla coil work, a grid-dip meter isn't used, but the principle is.

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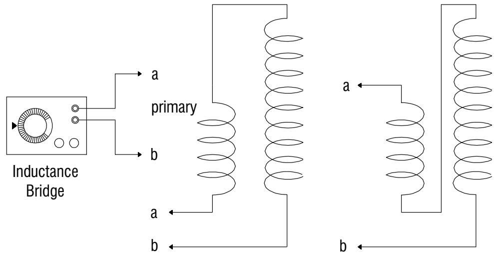
A resistor becomes the sensing device. When the generator nears the resonant frequency, more current is drawn in the case of the secondary, or in the case of the primary, less current. The secondary is at resonance when the voltage bottoms, and the primary is at resonance when the voltage peaks.

Rough tuning is accomplished by finding the secondary's resonant frequency, then adjusting the primary's inductance until the primary's frequency matches that of the secondary.

By plotting the voltage across the resistor as a function of the frequency, the result is a response chart.Bandwidth and 'Q' are indicated by 'narrowness' of the curve, and the resistance is indicated by how far the curve drops.



setup for measuring mutual inductance

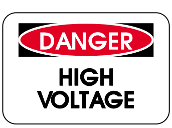
$$M = \frac{\left(L_p + L_s\right) - \left(L_p - L_s\right)}{4}$$

To determine coupling coefficient:

$$k = \frac{M}{\sqrt{L_p \times L_s}}$$

For most Tesla coil systems, a value of between 0.1 and 0.2 (or 10 - 20%) is optimal. Under-coupling leads to weak output. Over-coupling overloads the system, forcing the secondary to resonate at several different frequencies.

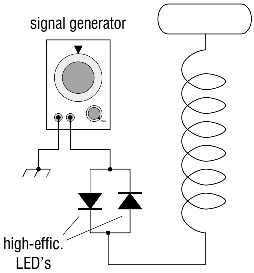
Fine Tuning



Fine-tuning requires that power be applied to the Tesla coil. Always check the wiring and follow the safety steps. *Do not touch any part of the Tesla coil while it's running!*

Once static parameters have been determined and roughed in, fine-tuning must be performed. ***NOTE: This procedure involves applying voltage to the coil. Safety precautions must be followed, as hazardous and lethal voltages are present. Make all adjustments with the power cord unplugged, and evaluate coil performance (with the coil energized) standing at least 10 feet away from the coil.***

Start by setting the primary tap (adjustable connection) to the point where the resonant frequency matches the secondary's. Open the spark gap to approximately ¼". While standing at least 10 feet away, apply power



Quick F_r Measurement

A fast and accurate way to find the (free) resonant frequency of a secondary is to connect (2) ultra-bright, high-efficiency red LEDs together with one connected 'backwards' to the other. Place these LED's in series between the output of a good, calibrated signal generator and the base (ground) connection of the secondary.

Set the output level to maxium and the frequency for maximum LED brightness. Lower the output level slightly and re-adjust the frequency. Eventually you find the exact resonant frequency (when the LED's are brightest) of the coil. Using a frequency counter will provide enhanced accuracy.

and note effects. If the coil has been designed and constructed properly, the spark gap should produce a bright, bluish-white arc that makes snappy, crackling sounds. There should also be noticeable bluish corona discharge from the secondary terminal. Remove power and unplug the power cord.

Widen the spark gap until the gap will no longer fire reliably. As each adjustment is made, step away a safe distance and re-energize the coil. Look for any arcing in the secondary, or anywhere in the primary system other than the spark gap. If it occurs, unplug the coil and check for wiring errors, or try to insulate the point of arcing if everything is wired correctly.

Close the spark gap setting in small increments until it fires repeatedly and reliably. This may require several attempts. With the gap set at optimal width, note the discharge from the secondary terminal — it should be considerably longer and noisier.

Move the primary tap approximately ½-turn in either direction. Re-energize and note discharge length. If it increased, continue to move the tap in the same direction in small increments. If a decrease in discharge occurred, move the tap in the opposite direction. Continue until maximum output is reached, and clamp or otherwise fix the connection at that point.

Coupling sometimes requires adjustment. If corona occurs anywhere on the secondary other than off the top windings, the coil is most likely over-coupled. Coupling is adjusted by raising or lowering the secondary with respect to the primary. Elevate the secondary until corona occurs only off the discharge electrode and top secondary winding.

Output voltage may be determined by placing a *grounded* metal object near the secondary discharge terminal. Energize and see if the discharge arcs to the object. De-energize and increase distance. Continue until a point is reached where the arc will just strike. Using the rule of thumb of 100,000 volts per 6 inches, the coil output voltage can be calculated.

Problems

Occasionally a coil will not work, despite good design and construction. Most likely a defective component is to blame. Capacitors can develop weak spots which arc or short, or simply change value. The transformer can have a bad winding, or has formed a carbon track in the tar. The electrode can be too big which prevents energy from escaping.

Check capacitors with a high-quality ohmmeter and capacitance meter (always short a high-voltage capacitor before making measurements). Transformer windings can be checked, but only for open windings. Specialized equipment is needed for voltage measurements, and the builder should take a neon transformer to a local neon shop. (Most shops will quickly test a transformer for only a dollar or two, and often for free.)

Some of the more common problems that can occur with a spark-gap Tesla coil include gap firing difficulties, tuning problems and coupling.

A spark gap that fires with a flaming, humming arc indicates that no high-current RF oscillations are being generated. If the circuit was wired correctly, most likely the primary capacitor is at fault. Try using a different capacitor. If the gap doesn't fire at all, at any setting, and the transformer is humming, the capacitor is shorted, or is breaking down internally at the high voltage. It is also possible that the transformer secondary winding has shorted. Try testing the

Spark gaps & Neon Transformers

With neon transformers, never run the spark gap at it's maximum setting for normal operation. A wider gap allows more energy into the coil, but it will also force the transformer to run at maximum voltage. Due to resonance voltage rise in the primary circuit, the transformer can be subjected to voltage levels exceeding it's design, resulting in a burned-out transformer. Close the gap down a bit and make your transformer last longer.

'Magic' k values

k's of 0.105, 0.117, 0.133, 0.153, 0.180 and 0.220 are 'magic' values. These numbers derive from the time it takes energy in the secondary to peak based upon integer values of the beat frequecy envelope. Coil builders report that these coupling numbers appear to give optimal performance. Details can be found in the Advanced Topics section.

transformer as mentioned in the Advanced Topics section under Neon Transformers. If the transformer is OK, try replacing the capacitor.

Secondary problems include issues related to overcoupling and breakdowns. An overcoupled coil will exhibit corona discharges from windings *below* the top windings of the secondary. Sparks may also 'race' down the length of the secondary coil, or jump from the secondary coil to the primary. (*D'Arsonval breakdown.*)

To eliminate over-coupling, simply raise the secondary up out of the primary, or increase the primary diameter and distance between the primary and secondary.

Occasionally the secondary coil will suffer an internal breakdown. Usually this occurs whenever the output discharge length exceeds the coil form length. It most often occurs where the secondary winding passes through the coil form. If the form is not damaged, try insulating the thru-hole points with a large dab of silicone rubber (RTV). Alternately, you can glue a bulkhead into the middle of the coil form. The purpose is to add a barrier to the high-voltage discharge path.

Overcoupling results in breakdown discharges that 'jump' down the secondary windings. Running the coil with lower coupling will reduce this, as will a larger, high-inductance primary. Notice in this photo that the breakdown occured in the lower part of the secondary. When it jumps to the primary, it's known as D'Arsonval breakdown.

Ideally, a properly designed coil will literally 'sing' when it's in tune. If the coil sounds 'rough', or is firing somewhat erratically, more tuning and adjustments are necessary.

Improvements

One critical area is the spark gap. Try adding a few more gap sections. This will enhance the quenching, which will remove some of the coil's 'harshness'. There is a synergistic relationship between the spark-gap design, the size of the primary coil, and the coupling. Any one of these parameters can severely affect coil performance.

Once the coil is running, performance can, at times, be increased via tinkering.

The spark gap is one area for experimentation. Significant coil improvement often results from switching to a higher-efficiency gap. If a fixed-electrode gap is currently used, consider a different gap type. Replacing the line transformer with a bigger unit is a quick way to increase performance, but always check to see if the voltage rating of the primary capacitor(s) is not exceeded. Additional primary capacitance can also be added, but will require re-tuning.

Try adding a discharge electrode, or switch to a larger one. Additional inductance or more primary capacitance will be needed to balance the tuning. A large electrode will prevent secondary discharge until the voltage has built up. The added size also increases the capacitance, which can enhance the energy level in the discharge spark.

Some coil builders report that Tesla coils with high-inductance primaries are particulary well-behaved. Try using a smaller capacitor and a larger primary. The spark length may not increase, but the discharges can be heavier and more abundant.