Tips on Tesla Coil Design

By D.C. Cox   Resonance Research Corp.

The TCBA Newsletter and the internet groups have done a terrific job of providing the beginning coil builder with data to insure the coil will operate without a lot of trial and error experimental headaches. The purpose of this article is to provide insight into a few discrete areas of design that have not been previously covered in past articles.

New Jersey experimenter John Freau built a lot of small and medium size coils and developed some mathematical relationships between the amount of power extracted from the wall receptacle and the length of spark eminating from the secondary terminal of a modern design TC. In essence, John's work produced a simplified equation that relates power input directly to spark output assuming other parameters in the circuit are designed and constructed to modern standards, ie, efficient quenching of spark gap, good match between power transformer size and energy discharge capacitor, etc. John's equation tells us that the power level required to produce a certain size spark goes up as the square of the spark length in inches. If you want to double your present spark length then you must increase the input power level by 4 times.

I had over 30 previous designs for TC's so I columnized all the data from our commercial coils into a spreadsheet and plotted their power levels vs. output spark size and noted some differences exist which seem to be dependent on the size of the secondary coilform.

John's original formula is: d = k' * SQR p

Where d = spark length, inches
k' = a coefficient, usually 1.0
p = input power, watts

The input power level in John's equation is generally taken to be the metered input power level from the receptacle, ie, volts x amperes (indicated).

The k' designator was labeled k' (read k prime) to avoid confusion with k which is usually standardized as the coefficient of coupling between primary and secondary inductors. This is a form factor coefficient and is independent of coefficient of coupling values which usually fall in the range of 0.16 to 0.24 for most modern coil designs.

After reviewing all the data I noted variations in spark length vs. output power was coupled with the diameter of the secondary coilform, so I developed a series of values for k' that can be substituted depending on the size of secondary coilform diameter you are using. The following chart indicates the new and correct values of k' for various size diameter coilforms:

k' = 0.85 for sec diameters in the range 3-10 inches (small coils)
k' = 1.0 for sec diameters in the range 11-16 inches (medium coils)
k' = 1.3 for sec diameters in the range of 17-20 inches (large coils)
k' = 1.7 for sec diameters in the range of 21-36 inches (very large coils)
k' = 2.0 for sec diameters in the range of 37-48 inches (so called "super" coils)

These values can be directly incorporated into the d = k’ * SQR p equation to provide a good design starting point for producing a spark of any desired size within the ranges covered by k’ in the above chart. As an example, one of our larger coils, “Big Bruiser” features a 24 inch dia. secondary coil operating at a power level of 240 VAC and an average input power of 70 Amperes. This is 15,400 watts and has a spark output of 18 feet (216 inches). The k’ factor works out to 1.74 for this coilform diameter. This is in very close agreement with the 1.7 value for k’ in the chart.

This equation can also be solved, and reversed, for initial design considerations. For example, if you require a design with a spark output of 4 feet, ie, 48 inches, and you plan on using a secondary coilform with a diameter of 14 inches, then the equation becomes:

p = (d/k’) ^ 2

The value of 48 inches is substituted for d and from the chart, k’ for a coilform in the range 11-16 inches is 1.0, so substituting p = (48/1.0) , and solving produces a power level of 2,304 watts. Such a design would typically have a secondary toroid of 20 x 5 inches and be powered by neon sign transformers. A group of three 12 kV, 60 mA transformers connected in parallel producing 12 kV at 180 mA would equal 2,160 watts and provide a good power source to drive the capacitor bank.

Another area of modern design that isn’t discussed much is the linear relationships between toroid size and secondary coilform size. Many coils have been constructed with large toroids in the past 10 years and there is a tremendous amount of data available regarding the size of toroid used and the secondary coilform diameters employed. I compiled much of this data and started looking for ratios that match current modern design. The data suggests the high voltage terminal (toroid) diameter should be approximately 170% to 200% larger than the diameter of the secondary coilform. Two examples: Our model M-150 resonance transformer has a toroid terminal major diameter of 34.5 inches and the secondary coilform is 18 inches in diameter. This produces a ratio of 34.5/18 = 1.91. Our model M-100 resonance transformer has a 20 inch major toroid diameter and is fitted to a secondary coilform with a diameter of 12 inches, so 20/12 = 1.67. This value, of course, assumes you have enough primary power to drive the topload and a correct value of primary capacitance and inductance to bring the primary into resonance with the secondary system.

All of our system designs employ a secondary coilform height to diameter ratio of 4.5:1, a value which we optimized many years ago based on dozens of designs. Height to diameter ratios shorter than this value produce excessive secondary to primary arcing, and values with h/d ratios in excess of 4.5:1 have reduced output efficiencies per unit power input.

Another area of design consideration that adapts well to using ratio/proportion techniques is the major toroid diameter to minor toroid diameter (thickness) ratio. Again, using our model M-150 as an example, the toroid major diameter is 34.5 inches and minor diameter of the tube cross section is 8 inches, so 34.5/8 = 4.3. On our model M-100 unit we employ a 20 x 5 inch size toroid, so 20/5 = 4.0.

Using data from numerous other coil designs we have found an average value in the range of 3.8 to 5.0 for toroid major dia/toroid minor dia produces a good match for efficient operation and high output spark discharges per unit energy input.

Small coils usually have a value of 3.8 to 4.0, medium size coils (3-6 ft spark) seems to optimize around 3.8 to 4.0, and larger coils prefer values in the range of 4.0. Super coils producing spark lengths in excess of 20 feet optimize around 3.8 as an good working value. You can always stack on an incredibly large toroid and drive the hell out of the system, but these ratios suffice for most modern designs that are not excessive in any particular area.