Tesla Coil Reconstruction

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1 Introduction

1.1 Purpose of this document.

This document is intended only as a brief history of the large Tesla coil constructed and located at Arkansas State University, Jonesboro, Arkansas. The information included in this document is not meant as a *make your own Tesla coil* project. It should be noted that a Tesla Coil is an extremely dangerous piece of equipment, and should be treated as such. The high voltages reached in the Tesla Coil can not only cause severe burns but can also prove to be lethal. A sign as in figure 1 should be posted on or around the Tesla coil. A sign should also be posted on all entry points leading to the room where a Tesla coil is in operation.

Figure 1

1.2 The Tesla Coil

A Tesla coil is a high frequency air core transformer. The Tesla Coil was invented by Nikola Tesla in 1899. Tesla is considered by some to be the greatest inventor of the modern electrical age. He is best remembered for his fascinating wireless power-transmission experiments, using his famous Tesla coil. Tesla used a Tesla coil to successfully transmit electrical energy over 25 miles, without wires, to light a large number of incandescent lamps.

The Tesla coil that will be described in this paper will be the standard Tesla coil, that has been designed for educational and experimental purposes. Tesla coils can be used to generate extremely high voltages, up to the one million volt range. These high voltages can be used in experiments where high voltages are needed.

2 General Theory

2.1 General Theory and Schematics

A Tesla coil is a high-frequency, high voltage resonant transformer. A Tesla coil primarily consists of just a high voltage transformer, spark gap resistor, high voltage capacitor, primary coil, and secondary coil. This Tesla coil uses an in line operated, step-up transformer, to generate the high voltage needed for the primary circuit. As seen Figure 2, the input to the Tesla coil is 117 Volts AC that is then ran through a step up transformer and increased to about ten thousand volts at thirty milliamps. An RLC circuit is then used to establish a resonance frequency. By changing the resistance of the Sparkgap resistor (i.e. the length of the arc) The resonance frequency is changed. The Tesla coil is tuned by adjusting the spark gap.

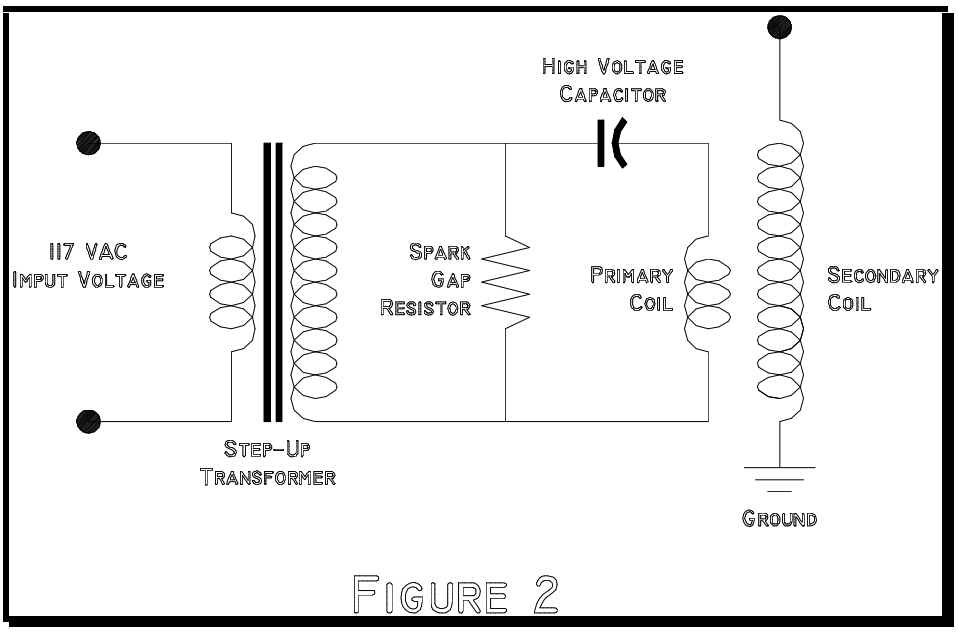

FIGURE 2

3 Tesla Coil calculations

3.1 Output Voltage Calculations

When a Tesla coil is driven in resonance, the output voltage can be approximated by equation 1.

Equation 1: $$V_{OUT} = \frac{C_1 V_{IN}}{C_2} \quad [1]$$

where:

V_{OUT} = Output Voltage
C_1 = The primary capacitance
C_2 = The secondary capacitance
V_{IN} = The input voltage

3.2 Output Voltage Measurements

The maximum output voltage can also be approximated by the maximum arc length of the discharge. By using the length of the arc, and the breakdown voltage constant for air, the following equation can be used to find the voltage:

Equation 2: $$V_{OUT} = LV_{AIR}$$

Where:

V_{OUT} = Output Voltage
L = Length of Arc
V_A = Breakdown constant of dry Air ≈3 x 10^6 V/m

By using this method, the output voltage was found to be approximately

V_{OUT} = (.290m)(3 x 10^6 V/m) ≈ .87 MV

3.3 Resonance Frequency Calculations

The resonant frequency of the primary coil can be calculated with the equation :

Equation 3: $$f = \frac{1}{2\pi\sqrt{LC}}$$ [2]

where:

f = The frequency in **Hz**
L = The inductance of the secondary coil in **H**
C = The Primary Capacitance in **F**

The frequency of the secondary can be approximated by the following method, if the ratio of height / diameter is in the range of 1-3. The frequency is determined by the inductance of the secondary and by the inner winding capacitance of the secondary as well as by the capacitance of the output terminal. [6]

The Frequency is calculated by:

Equation 4: $$f = \frac{c}{\lambda}$$ [3]

and $$\lambda = s * l$$ [4]

and $$s = 3.485 * \frac{h}{d}^{-0.304}$$ [5]

where

f = The frequency in **Hz**
L = The inductance of the secondary coil in **H**
C = The Primary Capacitance in **F**
s =Shape factor
l =Length of the wire
h =Height of the coil
d =Diameter of the coil

The shape factor is originally from a table. A polynomial approximation was made to make calculations easier. See Reference [6] for more information.

3.4 Resonance Frequency Measurements

The frequency of the Tesla coil can also be measured experimentally. This is done by placing a small coil of wire (i.e. about five turns) several feet from the Tesla coil. **DO NOT CONNECT TO THE COIL.** Then connect the coil to an oscilloscope. When power is applied to the Tesla coil, the frequency can be observed on the oscilloscope. The frequency of the Tesla coil was measured by using this method, and found to be 1 MHz during a solid arc discharge. A second frequency was observed to be 440 KHz when a corona discharge was used.

4 The Components

4.1 The Setup

The Tesla coil located at Arkansas State University was malfunctioning. When power was applied to the Coil a resonance frequency was reached, but no discharge was observed. Restoration on the coil was started in 1993 and completed in fall of 1994. The age of the Coil has been estimated to over twenty-eight years old.

4.2 The Primary Coil

The primary coil was replaced with a complete new coil. The old coil was made of uninsulated copper tubing. The tubing was replaced

with 4 mm copper wire insulated and rated at ten thousand volts. The wire was donated by Jonesboro City Water and Light.

4.3 The Secondary Coil

The secondary coil was replaced with a complete new coil. The old coil was made of copper wire, insulated with a cotton covering. This wiring was replaced with a 22 AWG solid hook-up wire insulated for a maximum rating of one thousand volts. The secondary coil tube was replaced with a heavy duty cardboard tube of a diameter of 17 cm replacing the old cardboard tube that had a diameter of only 13 cm. The number of turns on the secondary was increased from 550 turns on the old coil to 575 turns on the new coil. The new secondary was wrapped on the lathe in LSE-112.

4.4 Primary Capacitor

The primary capacitor was not replaced or changed from the original design. The capacitor was cleaned of dust and dirt. The capacitor is rated at .025 muF and 50 KV.

4.5 Tesla Coil Output Terminal

The Tesla coil output terminal was not replaced or changed from the original design. The terminal was taken apart and vigorously cleaned.

4.6 Spark Gap

The sparkgap was not replaced. The gap was taken apart and vigorously cleaned. After the Tesla coil was completed, the spark gap was configured to give maximum discharge from the secondary coil.

4.7 High Voltage Transformer

The high voltage transformer upon initial power up displayed arcing from the primary to the secondary. The secondary winding

consisted of four, connected windings around an iron core. Each winding consisted of sixty layers of windings, separated by paper. Each layer of the winding consisted of one hundred turns of a fine copper wire. When arcing occurred from the primary to the secondary the insulating paper on one of the windings caught fire. This winding was removed from the iron core, and repaired, by rewinding the levels that were destroyed by the fire. A silicon rubber was then placed on the edges of each winding core. Each winding was then reattached and the transformer was placed back into the Tesla coil.

5 Cosmetic Improvements

5.1 Enclosure

An enclosure was built for the Tesla coil. The enclosure consisted of three side panels of particle board. The side panels were nailed to the frame of the Tesla coil, covering the transformer, capacitor, and the spark gap. The primary and secondary coils remain uncovered on top of the Tesla coil apparatus. Each side panel was spaced 2 cm away from the base and the top of the support structure, allowing free air flow. Free air flow will greatly inhibit the buildup of ozone that is created by the spark gap during operation.

5.2 Observation Window

The fourth side of the Tesla coil was covered with a removable sheet of Plexiglass®. When in operation, the spark gap in the primary circuit generates large amounts of ultra violet light. Exposure to high amounts of ultra violet light is known to cause eye irritations. Upon testing of the Plexiglass® with a spectrometer, it was found that the Plexiglass® absorbed light in these regions. The Plexiglass® would then allow safe viewing of the circuit when in operation.

5.3 Painting

The enclosure, base and support post were then painted with a flat black spray paint. The choice of flat back was due to the fact that the paint would not draw attention to itself during operation, and draw attention to the corona discharge.

5.4 Labeling Components

Each part of the Tesla Coil was then labeled. The labels were printed via a laser printer and applied to the components with the aid of a rubber based cement. Parts labeled include: Input: 115 Volts, High Voltage Transformer, High Voltage Capacitor, Spark gap, Primary Coil and Secondary Coil.

6 Room for Improvement

Improvements can still be made on the Tesla coil. One possible improvement, is to provide a ground above the secondary coil. This would allow the display of a solid discharge arc from the secondary to the ground. If the distance from the secondary to the ground was adjustable, this would be a great advantage for two reasons. First, this would allow a total withdrawal of the ground, from the secondary, allowing a crona discharge. Second, the arc length would be adjustable to its maximum length, which would vary day to day according to water content in the air.

The second improvement that could be added is a rotating spark gap. A rotating sparkgap allows the spark gap length to change, without adjusting it. This will allow the Tesla coil to pass through the resonance frequency rather quickly, and makes the need for frequent tuning obsolete.

7 Standard Operation

Operation of the Tesla coil is to be accomplished with great caution, see warnings in section 1.1. There are two standard operation modes of the Tesla coil, corona discharge, and solid discharge. Corona discharge is the discharging of the secondary coil into the air, many small arcs that randomly extend from the output terminal. Solid discharge is the discharging of the secondary coil to a predetermined ground, allowing a solid arc to form, dissipate then reappear.

7.1 Corona Discharge Operation.

- Assure that no person can get close to the Tesla coil while it is in operation.
- Have very quick access to the power strip, so the coil can be turned off quickly
- Assure that the discharge will not arc to an undesired ground. Allow at least a two meter radius from the apparatus to be free of unwanted grounds.
- Connect the ground wire at the bottom of the secondary coil to a common ground.
- Assure that the Tesla coil platform is clear of foreign objects.
- Connect the UNPLUGGED power cable to the Tesla coil.
- Assure that the power strip is in the off position.
- Connect the UNPLUGGED power strip to the power cable
- Plug in the power strip.
- Switch the power strip to the on position.
- If nothing happens
    - Return the power strip to the off position
    - Unplug the power strip
    - Unplug the power cable
    - Adjust the Spark Gap resistor and repeat.
- Return the power strip to the off position
- Unplug the power strip
- Return everything to its proper location.

7.2 Solid Discharge Operation.

- Assure that no person can get close to the Tesla coil while it is in operation.
- Suspend a small conductive sphere above the Tesla coil with a insulating material (string).
- Connect the conductive sphere to a ground, via a wire.
- Run the other end of the string to the location where the operator will be standing.
- By pulling on the string the distance between the sphere and the output terminal will be increased thus increasing the arc length and allowing a longer, and brighter arc.
- Have very quick access to the power strip, so the coil can be turned off quickly.
- Assure that the discharge will not arc to an undesired ground. Allow at least a two meter radius from the apparatus to be free of unwanted grounds.
- Connect the ground wire at the bottom of the secondary coil to a common ground.
- Assure that the Tesla coil platform is clear of foreign objects.
- Connect the UNPLUGGED power cable to the Tesla coil.
- Assure that the power strip is in the off position.
- Connect the UNPLUGGED power strip to the power cable
- Plug in the power strip.
- Lower the sphere as close to the output terminal as possible.
- Switch the power strip to the on position.
- If nothing happens
    - Return the power strip to the off position
    - Unplug the power strip
    - Unplug the power cable
    - Adjust the Spark Gap resistor and repeat.
- Increase the arc length by pulling the string and raising the sphere higher. If the distance gets to large the arc will stop and a corona discharge will form. If this is undesirable lower the sphere until the arc reappears.
- Return the power strip to the off position
- Unplug the power strip
- Return everything to its proper location.

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9 For Further Information

Tesla Book Company
PO Box 121873
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