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Tesla's coil. A toy or useful thing in the life of radio engineering?

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Аннотація.
У цій статті, подан опис такого приладу як Котушка Тесли. Наведені її характеристики, принцип роботи, історія створення та значення в сучасному житті. Також описані процеси створення власноруч та розсуди про практичність даного виробу у реальному житті.

Ключові слова: Котушка індуктивності, висока напруга, Нікола Тесла, радіотехніка, електрична дуга.

Abstract.
This article contains a description of the device as a Tesla coil. These characteristics of the principle of history and value creation in modern life. Also describes the process of creating his own judge and practicality of this product in real life.

Keywords: Inductor, high voltage, Nikola Tesla, radio, electric arc.

I.Introduction

Perhaps in the life of every student comes a time when it begins to be interested in their field. In some it comes in the first year, someone on last. At the beginning of the 3rd year I finally decided to solder something with their hands. The choice immediately fell on Tesla coil. But is this thing so important, whether it is only a toy, which is impossible to do anything useful? Let us know about it.

II. Summary

The Tesla coil is an electrical resonant transformer circuit designed by inventor Nikola Tesla around 1891 as a power supply for his "System of Electric Lighting".It is used to produce high-voltage, low-current, high frequency alternating-current electricity. Tesla experimented with a number of different configurations consisting of two, or sometimes three, coupled resonant electric circuits.

Tesla used these circuits to conduct innovative experiments in electrical lighting, phosphorescence, X-ray generation, high frequency alternating current phenomena, electrotherapy, and the transmission of electrical energy without wires. Tesla coil circuits were used commercially in sparkgap radio transmitters for wireless telegraphy until the 1920s, and in medical equipment such as electrotherapy and violet ray devices. Today their main use is for entertainment and educational displays, although small coils are still used today as leak detectors for high vacuum systems. [1]

III. History of appearance

Tesla invented his "Tesla Coil" around 1891 while he was repeating and then expanding on Heinrich Hertz' experiments that had discovered electromagnetic radiation three years earlier. Tesla decided to power his setup with the high speed alternator he had been developing as part of an improved arc lighting system but found that the high frequency current overheated the iron core and melted the insulation between the primary and secondary windings in the Ruhmkorff coil originally used in Hertz setup.[3] To fix this problem Tesla changed the design so that there was an air gap instead of insulating material between the primary and secondary windings and made it so that the iron core could be moved to different positions in or out of the coil Tesla also found he needed to put the capacitor normally used in such setups between his alternator and the coil's primary winding to avoid burning out the coil. By adjusting the coil and the capacitor Tesla found he could take advantage of the resonance set up between the two to achieve even higher frequencies.

In Tesla's coil transformer the capacitor, upon break-down of a short spark gap, became connected to a coil of a few turns (the primary winding set), forming a resonant circuit with the frequency of oscillation, usually 20–100 kHz, determined by the capacitance of the capacitor and the inductance of the coil. The capacitor was charged to the voltage necessary to rupture the air of the gap during the input line cycle, about 10 kV by a line-powered transformer connected across the gap. The line transformer was designed to have higher than normal leakage inductance to tolerate the short circuit occurring while the gap remained ionized, or for the few milliseconds until the high frequency current had died away.

The spark gap is set up so that its breakdown occurs at a voltage somewhat less than the peak output voltage of the transformer in order to maximize the voltage across the capacitor. The sudden current through the spark gap causes the primary resonant circuit to ring at its resonant frequency. The ringing primary winding magnetically couples energy into the secondary over several RF cycles, until all of the energy that was originally in the primary has been transferred to the secondary. Ideally, the gap would then stop conducting (quench), trapping all of the energy into the oscillating secondary circuit. Usually the gap reignites, and energy in the secondary transfers back to the primary circuit over several more RF cycles. Cycling of energy may repeat for several times until the spark gap finally quenches. Once the gap stops conducting, the transformer begins recharging the capacitor. Depending on the breakdown voltage of the spark gap, it may fire many times during a mains AC cycle.

A more prominent secondary winding, with vastly more turns of thinner wire than the primary, was positioned to intercept some of the magnetic field of the primary. The secondary was designed to have the same frequency of resonance as the primary using only the stray capacitance of the winding itself to ground and that of any "top hat" terminal placed at the top of the secondary. The lower end of the long secondary coil must be grounded to the surroundings.

The later and higher-power coil design has a single-layer primary and secondary. These Tesla coils are often used by hobbyists and at venues such as science museums to produce long sparks. The American Electrician gives a description of an early Tesla coil wherein a glass battery jar, 15 × 20 cm (6 × 8 in) is wound with 60 to 80 turns of AWG No. 18 B & S magnet wire (0.823 mm^2). Into this is slipped a primary consisting of eight to ten turns of AWG No. 6 B & S wire (13.3 mm^2) and the whole combination is immersed in a vessel containing linseed or mineral oil.

VI. Magnifying transmitter

Tesla built a laboratory in Colorado Springs and between 1899-1900 performed experiments on wireless power transmission there. The Colorado Springs laboratory possessed one of the largest Tesla coils ever built, which Tesla called a "magnifying transmitter" as it was intended to transmit power to a distant receiver. With an input power of 300 kilowatts it could produce potentials in the 12 to 20 megavolt range at a frequency of 150 kHz, creating huge 140 feet (42 m) "lightning" bolts. The magnifying transmitter design is somewhat different from the classic two-coil Tesla coil circuit. In addition to the primary and secondary coils it had a third "resonator" coil, not magnetically coupled to the others, attached to the top terminal of the secondary. When driven by the secondary it produced additional high voltage by resonance, being adjusted to resonate with its own parasitic capacitance at the frequency of the other coils.

The Colorado Springs apparatus consisted of a 53-feet (16 m) diameter Tesla coil around the periphery of the lab, with a single-turn primary buried in the ground and a secondary of 50 turns of heavy wire on a 9 feet (2.7 m) high circular "fence". The primary was connected to a bank of oil capacitors to make a tuned circuit, excited by a rotary spark gap at 20 - 40 kilovolts from a powerful utility transformer. The top of the secondary was connected to a 20 ft (6 m) diameter "resonator" coil in the center of the room, attached to a telescoping 143 feet (43.6 m) "antenna" with a 30-inch (76 cm) metal ball on top which could project through the roof of the lab.[2]

V. Description of work

A Tesla coil is a radio frequencyoscillator that drives an air-core double-tuned resonant transformer to produce high voltages at low currentsTesla's original circuits as well as most modern coils use a simple spark gap to excite oscillations in the tuned transformer. More sophisticated designs use transistor or thyristor switches or vacuum tube electronic oscillators to drive the resonant transformer.

Tesla coils can produce output voltages from 50 kilovolts to several million volts for large coils. The alternating current output is in the low radio frequency range, usually between 50 kHz and 1 MHz. Although some oscillator-driven coils generate a continuous alternating current, most Tesla coils have a pulsed output; the high voltage consists of a rapid string of pulses of radio frequency alternating current.

The common spark-excited Tesla coil circuit, shown below, consists of these components:

- A high voltage supply transformer (T), to step the AC mains voltage up to a high enough voltage to jump the spark gap. Typical voltages are between 5 and 30 kilovolts (kV).
- A capacitor (C1) that forms a tuned circuit with the primary winding L1 of the Tesla transformer
- A spark gap (SG) that acts as a switch in the primary circuit
- The Tesla coil (L1, L2), an air-core double-tuned resonant transformer, which generates the high output voltage.
- Optionally, a capacitive electrode (top load) (E) in the form of a smooth metal sphere or torus attached to the secondary terminal of the coil. Its large surface area suppresses premature corona discharge and streamer arcs, increasing the Q factor and output voltage.

VI. Resonant transformer

The specialized transformer used in the Tesla coil, called a resonant transformer, oscillation transformer or radio-frequency (RF) transformer, functions differently from an ordinary transformer used in AC power circuits. While an ordinary transformer is designed to transfer energy efficiently from primary to secondary winding, the resonant transformer is also designed to temporarily store electrical energy. Each winding has a capacitance across it and functions as an LC circuit (resonant circuit, tuned circuit), storing oscillating electrical energy, analogously to a tuning fork. The primary winding (L1) consisting of a relatively few turns of heavy copper wire or tubing, is connected to a capacitor (C1) through the spark gap (SG). The secondary winding (L2) consists of many turns (hundreds to thousands) of fine wire on a hollow cylindrical form inside the primary. The secondary is not connected to an actual capacitor, but it also functions as an LC circuit, the inductance (L2) resonates with (C2), the sum of the stray parasitic capacitance between the windings of the coil, and the capacitance of the toroidal metal electrode attached to the high voltage terminal. The primary and secondary circuits are tuned so they resonate at the same frequency, they have the same resonant frequency. This allows them to exchange energy, so the oscillating current alternates back and forth between the primary and secondary coils.

The peculiar design of the coil is dictated by the need to achieve low resistive energy losses (high Q factor) at high frequencies,[17]which results in the largest secondary voltages:

- Ordinary power transformers have an iron core to increase the magnetic coupling between the coils. However at high frequencies an iron core causes energy losses due to eddy currents and hysteresis, so it is not used in the Tesla coil.
- Ordinary transformers are designed to be "tightly coupled". Due to the iron core and close proximity of the windings, they have a high mutual inductance (M), the coupling coefficient is close to unity 0.95 - 1.0, which means almost all the magnetic field of the primary winding passes through the secondary. The Tesla transformer in contrast is "loosely coupled", the primary winding is larger in diameter and spaced apart from the secondary, so the mutual inductance is lower and the coupling coefficient is only 0.05 to 0.2; meaning only 5% to 20% of the magnetic field of each coil passes through the other. This slows the exchange of energy between the primary and secondary coils, which allows the oscillating energy to stay in the secondary circuit longer before it returns to the primary and begins dissipating in the spark.

- Each winding is also limited to a single layer of wire, which reduces proximity effect losses. The primary carries very high currents. Since high frequency current mostly flows on the surface of conductors due to skin effect, it is often made of copper tubing or strip with a large surface area to reduce resistance, and its turns are spaced apart, which reduces proximity effect losses and arcing between turns.

The output circuit can have two forms:

- Unipolar - One end of the secondary winding is connected to a single high voltage terminal, the other end is grounded. This type is used in modern coils designed for entertainment. The primary winding is located near the bottom, low potential end of the secondary, to minimize arcs between the windings. Since the ground (Earth) serves as the return path for the high voltage, streamer arcs from the terminal tend to jump to any nearby grounded object.
- Bipolar - Neither end of the secondary winding is grounded, and both are brought out to high voltage terminals. The primary winding is located at the center of the secondary coil, equidistant between the two high potential terminals, to discourage arcing.

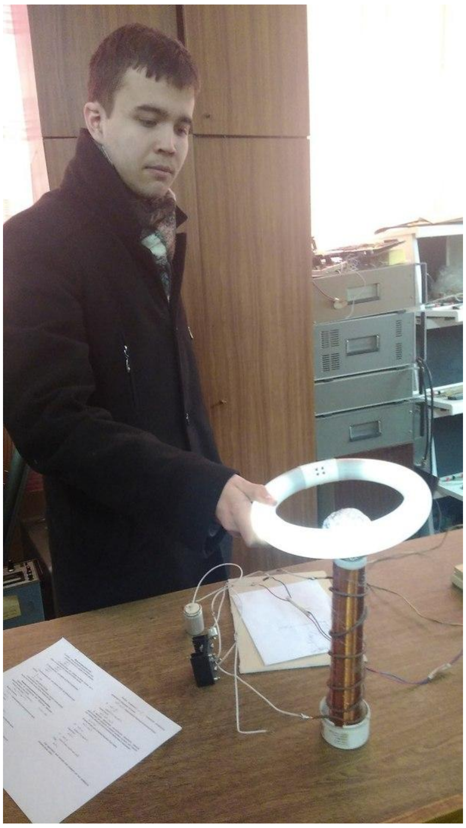
VII. Modern-day Tesla coils

Modern high-voltage enthusiasts usually build Tesla coils similar to some of Tesla's "later" 2-coil air-core designs. These typically consist of a primary tank circuit, a series LC (inductance-capacitance) circuit composed of a high-voltage capacitor, spark gap and primary coil, and the secondary LC circuit, a series-resonant circuit consisting of the secondary coil plus a terminal capacitance or "top load". In Tesla's more advanced (magnifier) design, a third coil is added. The secondary LC circuit is composed of a tightly coupled air-core transformer secondary coil driving the bottom of a separate third coil helical resonator. Modern 2-coil systems use a single secondary coil. The top of the secondary is then connected to a topload terminal, which forms one 'plate' of a capacitor, the other 'plate' being the earth (or "ground"). The primary LC circuit is tuned so that it resonates at the same frequency as the secondary LC circuit. The primary and secondary coils are magnetically coupled, creating a dual-tuned resonant air-core transformer. Earlier oil-insulated Tesla coils needed large and long insulators at their high-voltage terminals to prevent discharge in air. Later Tesla coils spread their electric fields over larger distances to prevent high electrical stresses in the first place, thereby allowing operation in free air. Most modern Tesla coils also use toroid-shaped output terminals. These are often fabricated from spun metal or flexible aluminum ducting. The toroidal shape helps to control the high electrical field near the top of the secondary by directing sparks outward and away from the primary and secondary windings.

A more complex version of a Tesla coil, termed a "magnifier" by Tesla, uses a more tightly coupled air-core resonance "driver" transformer (or "master oscillator") and a smaller, remotely located output coil (called the "extra coil" or simply the resonator) that has a large number of turns on a relatively small coil form. The bottom of the driver's secondary winding is connected to ground. The opposite end is connected to the bottom of the extra coil through an insulated conductor that is sometimes called the transmission line. Since the transmission line operates at relatively high RF voltages, it is typically made of 1" diameter metal tubing to reduce corona losses. Since the third coil is located some distance away from the driver, it is not magnetically coupled to it. RF energy is instead directly coupled from the output of the driver into the bottom of the third coil, causing it to "ring up" to very high voltages. The combination of the two-coil driver and third coil resonator adds another degree of freedom to the system, making tuning considerably more complex than that of a 2-coil system. The transient response for multiple resonance networks (of which the Tesla magnifier is a sub-set) has only recently been solved. It is now known that a variety of useful tuning "modes" are available, and in most operating modes the extra coil will ring at a different frequency than the master oscillator.

VIII. Conclusions and own experiments

After all the reading, the question is raised. And why do we need this coil, and is there any practical application in it? I decided to solder it myself and see what will happen. The results you can see in the photo.



We have a good device for testing the performance of fluorescent lamps. Alternatively, after adjustment, an electric arc can be used to light the candles. As a result, it's still more of a toy for my opinion, but it provides an elementary knowledge about radio design, which is what I need in my professor's work.

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