Structure and applications of tesla coil engineering essay

A Tesla coil is a type of resonant transformer circuit invented by Nikola Tesla around 1891. It is used to produce high voltage, relatively high current, high frequency alternating current electricity. Tesla used the coils to conduct innovative experiments in electrical lighting, phosphorescence, x-ray generation, high frequency alternating current phenomena

Tesla coil circuits were used commercially in sparkHYPERLINK " http://en. wikipedia. org/wiki/Sparkgap_transmitter" gap radio transmitters for wireless telegraphy until the 1920, and in electrotherapy and medical devices such as violet ray. Today their main use is entertainment and educational displays. Tesla coils are built by many high-voltage enthusiasts, research institutions, science museums and independent experimenters. Modified Tesla coils are widely used as igniters for high power gas discharge lamps, common examples being the mercury vapor and sodium types used for street lighting.

Tesla Coil principle

A Tesla coil transformer operates in a different manner than a conventional (i. e., iron core) transformer. In a conventional transformer, the windings are very tightly coupled, and voltage gain is limited to the ratio of the numbers of turns in the windings.

However, unlike a conventional transformer, which may couple 97%+ of the magnetic fields between windings, a Tesla coil's windings are " loosely" coupled, with the primary and secondary typically sharing only 10-20% of their respective magnetic fields and instead the coil transfers energy (via loose coupling) from one oscillating resonant circuit (the primary) to the other (the secondary) over a number of RF cycles.

As the primary energy transfers to the secondary, the secondary's output voltage increases until all of the available primary energy has been transferred to the secondary (less losses). Even with significant spark gap losses, a well designed Tesla coil can transfer over 85% of the energy initially stored in the primary capacitor to the secondary circuit. Thus the voltage gain of a disruptive Tesla coil can be significantly greater than a conventional transformer, since it is instead proportional to the square root of the ratio of secondary and primary inductances.

In addition, because of the large gap between the primary and secondary that loose coupling makes possible, the insulation between the two is far less likely to break down, and this permits coils to run extremely high voltages without damage.

Alternate Tesla Coil Configuration

This circuit also driven by alternating currents. However, here the AC supply transformer must be capable of withstanding high voltages at high frequencies.

Electrical transmission

A large Tesla coil of more modern design often operates at very high peak power levels, up to many megawatts (millions of watts). It should therefore be adjusted and operated carefully, not only for efficiency and economy, but also for safety. If, due to improper tuning, the maximum voltage point occurs below the terminal, along the secondary coil, a discharge (spark) may break out and damage or destroy the coil wire, supports, or nearby objects.

Tesla experimented with these, and many others, circuit configurations. The Tesla coil primary winding, spark gap and tank capacitor are connected in series. In each circuit, the AC supply transformer charges the tank capacitor until its voltage is sufficient to break down the spark gap. The gap suddenly fires, allowing the charged tank capacitor to discharge into the primary winding. Once the gap fires, the electrical behavior of either circuit is identical

Tuning precautions

The primary coil's resonant frequency should be tuned to that of the secondary, using low-power oscillations, then increasing the power until the apparatus has been brought under control. While tuning, a small projection (called a " breakout bump") is often added to the top terminal in order to stimulate corona and spark discharges (sometimes called streamers) into the surrounding air. Tuning can then be adjusted so as to achieve the longest streamers at a given power level, corresponding to a frequency match between the primary and secondary coil. Capacitive ' loading' by the streamers tends to lower the resonant frequency of a Tesla coil operating under full power. For a variety of technical reasons, toroids provide one of the most effective shapes for the top terminals of Tesla coils.

Air discharges

A small, later-type " Tesla coil" in operation. The output is giving 17-inch sparks. The diameter of the secondary is three inches. The power source is a 10000 V, 60 Hz current limited supply.

While generating discharges, electrical energy from the secondary and toroid is transferred to the surrounding air as electrical charge, heat, light, and sound. The electric currents that flow through these discharges are actually due to the rapid shifting of quantities of charge from one place (the top terminal) to other places (nearby regions of air). The process is similar to charging or discharging a capacitor. The current that arises from shifting charges within a capacitor is called a displacement current. Tesla coil discharges are formed as a result of displacement currents as pulses of electrical charge are rapidly transferred between the high voltage toroid and nearby regions within the air (called space charge regions). Although the space charge regions around the toroid are invisible, they play a profound role in the appearance and location of Tesla coil discharges.

When the spark gap fires, the charged capacitor discharges into the primary winding, causing the primary circuit to oscillate. The oscillating primary current creates a magnetic field that couples to the secondary winding, transferring energy into the secondary side of the transformer and causing it to oscillate with the toroid capacitance. The energy transfer occurs over a number of cycles, and most of the energy that was originally in the primary side is transferred into the secondary side. The greater the magnetic coupling between windings, the shorter the time required to complete the energy transfer. As energy builds within the oscillating secondary circuit, the amplitude of the toroid’s RF voltage rapidly increases, and the air surrounding the toroid begins to undergo dielectric breakdown, forming a corona discharge.

As the secondary coil’s energy (and output voltage) continues to increase, larger pulses of displacement current further ionize and heat the air at the point of initial breakdown. This forms a very conductive “ root” of hotter plasma, called a leader that projects outward from the toroid. The plasma within the leader is considerably hotter than a corona discharge, and is considerably more conductive. In fact, it has properties that are similar to an electric arc. The leader tapers and branches into thousands of thinner, cooler, hair like discharges (called streamers). The streamers look like a bluish ‘ haze’ at the ends of the more luminous leaders, and it is the streamers that actually transfer charge between the leaders and toroid to nearby space charge regions. The displacement currents from countless streamers all feed into the leader, helping to keep it hot and electrically conductive.

In a spark gap Tesla coil the primary-to-secondary energy transfer process happens repetitively at typical pulsing rates of 50-500 times per second, and previously formed leader channels don’t get a chance to fully cool down between pulses. So, on successive pulses, newer discharges can build upon the hot pathways left by their predecessors. This causes incremental growth of the leader from one pulse to the next, lengthening the entire discharge on each successive pulse. Repetitive pulsing causes the discharges to grow until the average energy that’s available from the Tesla coil during each pulse balances the average energy being lost in the discharges (mostly as heat). At this point, dynamic equilibrium is reached, and the discharges have reached their maximum length for the Tesla coil’s output power level. The unique combination of a rising high voltage Radio Frequency envelope and repetitive pulsing seem to be ideally suited to creating long, branching discharges that are considerably longer than would be otherwise expected by output voltage considerations alone. High voltage discharges create filamentary multi-branched discharges which are purplish blue in color. High energy discharges create thicker discharges with fewer branches, are pale and luminous, almost white, and are much longer than low energy discharges, because of increased ionization. There will be a strong smell of ozone and nitrogen oxides in the area. The important factors for maximum discharge length appear to be voltage, energy, and still air of low to moderate humidity.

Tesla Coil components

The simplest Tesla Coil consists of only 6 basic parts shown in the photograph on the left:-

The Neon Sign Transformers (shown bottom left) provide the high voltage supply which is required to operate the spark gap.

Power from the transformers charges the bank of high voltage capacitors (shown bottom right.)

Energy from the capacitors is transferred into the primary winding when the spark gap fires. The spark gap (shown bottom centre) is an RQ style static gap with forced air cooling.

Energy in the primary coil is transferred into the secondary coil by magnetic coupling between the two coils.

When the energy is transferred to the secondary coil it results in an extremely high voltage at the top of the secondary.

The toroid is the last stopping place for the electricity before it jumps into the air.

Spark Gap

The spark gap is basically a high power switch. It is the spark gap which is responsible for initiating the discharge of the tank capacitor into the primary winding of the Tesla Coil. It turns-on when sufficient voltage exists across the spark gap. The air in the gap ionizes and begins to conduct electricity like a closed switch. The spark gap turns-off when the current flowing through it drops to a low level, and the air gap regains its insulating properties.

When used in this way as a switch, the spark gap has the following properties:-

High voltage hold-off capability in the off-state,

High current carrying capability in the on-state,

Extremely fast turn-on time,

Physically scalable to almost any power rating,

Good overload margin, (robust)

A typical Tesla Coil circuit diagram

How Tesla Coils Work

A classic Tesla coil consists of two inductive-capacitive (LC) oscillators, loosely coupled to one another. An LC oscillator has two main components, an inductor and a capacitor. An inductor converts an electrical current into a magnetic field or a magnetic field into a current. Inductors are formed from electrical conductors wound into coils. Capacitors consist of two or more conductors separated by an insulator. A capacitor converts current into an electric field or an electric field into current. Both magnetic fields and electric fields are forms of stored energy. When a charged capacitor (U= CV2/2) is connected to an inductor an electric current will flow from the capacitor through the inductor creating a magnetic field (U= LI2/2). When the electric field in the capacitor is exhausted the current stops and the magnetic field collapses. As the magnetic field collapses, it induces a current to flow in the inductor in the opposite direction to the original current. This new current charges the capacitor, creating a new electric field, equal but opposite to the original field. As long as the inductor and capacitor are connected the energy in the system will oscillate between the magnetic field and the electric field as the current constantly reverses. The rate at which the system oscillates is given by (the square root of 1/LC)/2pi. One full cycle of oscillation is shown in the drawing below. In the real world the oscillation will eventually damp out due to resistive losses in the conductors (the energy will be dissipated as heat).

In a Tesla coil, the two inductors share the same axis and are located close to one another. In this manner the magnetic field produced by one inductor can generate a current in the other.. The primary oscillator consists of a flat spiral inductor with only a few turns, a capacitor, a voltage source to charge the capacitor and a switch to connect the capacitor to the inductor. The secondary oscillator contains a large, tightly wound inductor with many turns and a capacitor formed by the earth on one end (the base) and an output terminal (usually a sphere or toroid) on the other.

While the switch is open, a low current flows through the primary inductor, charging the capacitor. When the switch is closed a much higher current flows from the capacitor through the primary inductor, The resulting magnetic field induces a corresponding current in the secondary. Because the secondary contains many more turns than the primary a very high electric field is established in the secondary capacitor. The output of a Tesla coil is maximized when two conditions are met. First, both the primary and secondary must oscillate at the same frequency. And secondly, the total length of conductor in the secondary must be equal to one quarter of the oscillator’s wave length. Wave length is equal to the speed of light divided by the frequency of the oscillator.

Uses of Tesla coil

Two variations of the Tesla coil are found in everyday devices, the CRT display and the internal combustion engine. Every CRT type display (televisions, computer monitors, etc.) uses a small Tesla coil, usually referred to as a fly back transformer in this application, to provide the high voltage necessary to accelerate electrons from the electron gun in the narrow end of the picture tube to the phosphors coating the inside of the screen. An oil filled Tesla coil, known as an ignition coil, is found under the hood of all internal combustion powered automobiles. It provides the high voltage to fire the spark plugs.

Tesla coils have also been used to provide special effects for the entertainment industry.