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Important Characteristics of Tesla Transformation

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Abstract
Although a large number of publications dealing with Tesla mills have appeared, numerous of these are confined to furnishing an analysis of the motor performance grounded on a lumped original circuit model. The present paper is concerned with further practical issues and begins by considering the frequently overlooked significance of the glamorous coupling between the primary and secondary windings for the range of implicit operations of these mills. It continues by agitating the benefits of using a solid- state primary switch and furnishing a sapience into colorful other additions that may be made to the introductory circuit.

INTRODUCTION
High- voltage (HV) palpitation creators, able of producing affair beats exceeding 100 kV in breadth and with a veritably short rise time form a crucial demand of numerous exploration conditioning, particularly in flyspeck and tube drugs. Other operations where similar creators are used in either single or multi shot modes include

- Pollution Control
- High- Power Spotlights
- X-Ray Radiography
- High- Power Microwave Oven Generation
- Electron Ray Accelerators
- Ultra-Wide Band Electromagnetic Radiation Generation

In numerous of these uses, the needed high voltage is produced via either a Marx creator or a Tesla motor, depending on the moxie of the developer and the specific practical requirements of the operation. The present paper is devoted to the current state of development of the Tesla motor, one of the numerous ingenious inventions to crop from the rich mind of Nikola Tesla (Lomas, 1999). At the turn of the 20th Century, he was working in his laboratory in Colorado Springs in the USA, with Figure 1 illustrating the typical spectacular substantiation of the success of the early trials that were performed.

Figure 1 An example of Tesla's experiments at Colorado Springs

Despite numerous variations on the original conception having appeared, the introductory form of the Tesla motor remains at the heart of numerous of the palpitated- power creators used in a wide range of current operations. Multitudinous detailed and elegant analyses grounded on a simple direct circuit model have appeared in the literature (Glascoe and Lebacqz, 1948; Sergeant and Dollinger, 1989) that, under certain limited conditions can, with reasonable delicacy, prognosticate and describe the functional characteristics of the motor, still, many bandy the different constructional forms and other features that a Tesla motor may bear in different practical operations. The present authors have all worked in this area for numerous times, with the present paper being grounded on their numerous concerted times of experience and seeking to give an sapience into colorful practical features that are now wide. For convenience, the common operation is followed of the term Tesla motor applying to a motor in which the primary and secondary circuits have the same natural frequency. It should still be flashed back that for maximum energy transfer the coupling measure must be one of the well- known series of specific values(1, 0.6, 0.39, 0.23,………..).

Circuit Details

As shown in Figure 2, a Tesla motor is typically a two- winding air- cored arrangement, in which two reverberate circuits, the low voltage primary and the high- voltage secondary, are tuned to the same reverberate frequency of several hundred kilohertz when severed. Generally, a primary winding will be made from a many turns able of opposing peak currents of several hundred amperes while the secondary winding is multi turn single subcase solenoid rated to carry a current of a many amperes. The lower end of this winding is typically earthed.

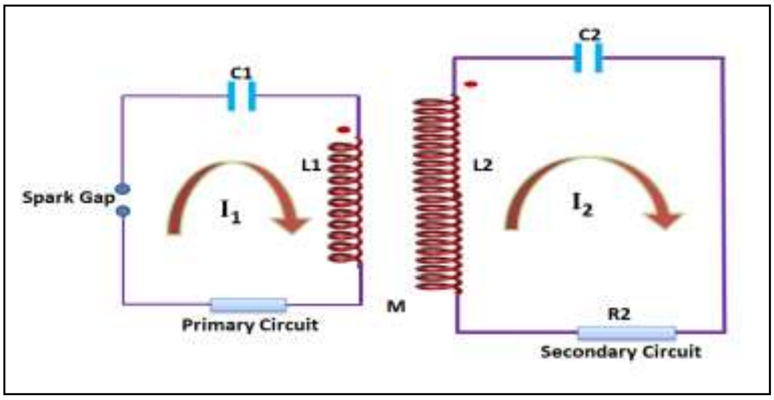

Figure 2. Equivalent lumped circuit of a Tesla transformer

The winding inductances L1 and L2 are tuned to resonance independently by the lumped capacitance C1 and the distributed capacitance C2, comprising the tone- capacitance of the secondary winding plus its surroundings and a high- voltage termination electrode, frequently feeding a palpitation- forming line (PFL) conceivably via a stropping gap. In some systems, the cargo capacitance may be sufficiently high to reduce the reverberate frequency to well below that of the isolated circuit alone. Under these conditions, a lumped element supposition grounded on the original circuit of Figure 2 is acceptable for prognosticating the motor performance, and detailed analyses can be set up away (Glascoe and Lebacqz, 1948; Sergeant and Dollinger, 1989). In single- shot operation, the capacitor C1 is generally charged to about 20 kV and also discharged into the motor circuit by check of a primary switch, frequently in the form of a spark gap.

Coupling in Tesla Transformers

Different designs of motor are needed for different operations, and during an expansive disquisition at Loughborough University(Craven, 2014) a number of important aspects surfaced. When the end of the motor is to induce an extremely high secondary voltage, the sequestration conditions, together with the high primary current and the sharpness of the affair palpitation needed, frequently avert the use of a ferromagnetic core, and it's delicate to achieve a high glamorous coupling measure k between the two windings Alternately, when k is low(generally< 0.3), the energy transfer effectiveness is also low, which impinges on the total power effectiveness and the overall losses. Arising from the different values of k, there are ineluctable differences between the winding and geometric arrangements of Tesla mills for different operations. These have led to a accessible bracket being espoused grounded on the glamorous coupling between the two windings either being ‘ tight’(k> 0.6) or ‘ loose’(k< 0.3). Considerations of this and colorful other significant features of practical mills are given below. Although the value of k has a major impact on the motor characteristics, it has entered little treatment in the literature, other than to explain why a value of 0.6 may frequently be salutary.

Practical tightly-coupled designs

The winding geometries of tightly-coupled transformers are usually cylindrical, heliconical or less frequently flat spiral in form, with Figure 3(a) showing a typical cylindrical transformer wound on a cylindrical former. The single-layer solenoidal secondary winding is surrounded by a coarsely wound helical primary, with layers of high electrical strength plastic material or a fluid with similar properties providing the necessary inter-winding insulation. Coupling coefficients k>0.7 can be achieved by using ferrite loading of the solenoidal core or even k>0.9 by an experienced designer using a metallic core. In this case however, voltage grading and insulation strength problems sometimes then arise.

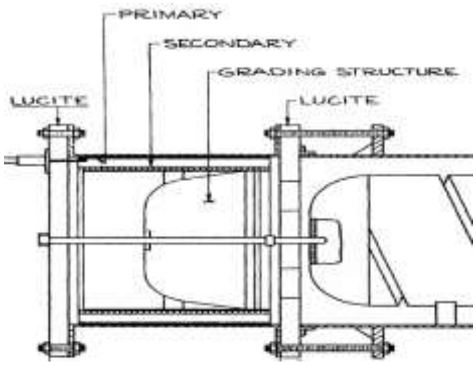

Figure 3. Tightly coupled transformers (a)

In the typical heliconical design of Figure 3(b) (Sarkar et al., 2006), the secondary winding is again a single-layer solenoid. However, the surrounding primary winding is of conical cross section, with the radius broadening towards the high-voltage end. Although easing the voltage gradient and insulation difficulties of the cylindrical design, this is at the expense of the maximum coupling coefficient that is achievable. In an alternative design (Abramyan, 1971), the primary winding has a few turns of copper sheet that couple into the lower end of the internal secondary. This again is in the form of a circular cross- section cone, with a base diameter similar to that of the primary winding and the final diameter some 10% of the starting diameter.

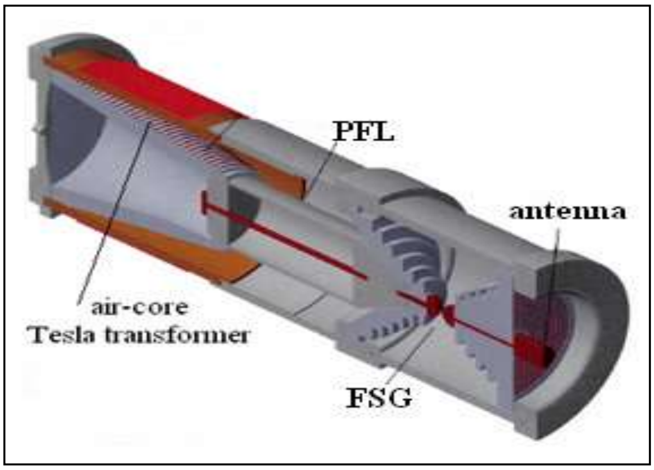

Figure 3. (b) Heliconical

Figure 3. (c) Spiral

The distributed capacitance of such a winding is lower than that of a conventional single-layer winding. In yet a further design (Buttram and Rohwein, 1979) a heliconical primary winding of several turns of copper strip is surrounded by a single-layer solenoidal winding having several hundred turns. In a common spiral design shown behind the seated figure of Tesla in Figure 3(c), the primary and secondary windings are both flat Archimedean spirals of copper strip or wire stacked on a common axis. Although a high coupling coefficient can be obtained without the use of a core material, high electrical stresses are present at the copper edges and the insulation coordination required to sustain the high secondary voltage provides a serious engineering challenge.

Practical loosely-coupled designs

The windings of approximately- coupled designs can again be heliconical, spherical or helical in form, but with the proportions and shapes of the windings changed to enable the lower value of k to be achieved still, in the veritably common form shown in Figure 4, the vertical primary winding is constructed as a flat Archimedean helical with the secondary winding solenoid standing vertically at the center of the helical. The base of the secondary winding may be in the airplane of the primary winding, but it can be either raised or lowered from this position as a means of tuning the value of k. In practice, it's frequently deposited within the lower 25 of the secondary winding height. An indispensable configuration is to use a heliconical primary of indirect cross section, with the periphery tapering outwards and overhead, and the secondary again in the form of a single- subcase solenoid. Although this minimizes both voltage grading and sequestration difficulties, and achieves advanced values of k than the flat helical approach, the mechanical construction is significantly more delicate.

Figure 4. Typical loosely coupled design

Approximately- coupled mills are frequently of an 'open' construction, using simple figure and counting on unpressurised air sequestration. This is in sharp discrepancy to tightly- coupled mills, which constantly employ an ' enclosed' design, utilizing essence pressure vessels within which both windings are housed in a fluid insulator similar as motor oil painting or a pressurized separating gas atmosphere of H_2, N_2 or SF_6.

Important design features

(i) The aspect rate (length- to- periphery) of a typical secondary winding falsehoods between 4 and 6, as a concession between the quality factor (Q), captain periphery for a given design inductance, tone-capacitance and voltage grading. A short, large periphery coil with an aspect rate of 0.5 may give the loftiest Q for a given inductance, but the high- voltage end of the winding may not be separated sufficiently far from the earthed end, and face breakdown along the winding face is a threat. If the aspect rate is 0.4, the winding has minimal inductance (Grover, 2004), therefore minimizing the quantum of bobby needed and the corresponding bobby losses, still the height is again prohibitively short and face breakdown a hazard, although this can be overcome by absorption in an separating fluid or pressurized gas. An indispensable approach is to use a heliconical primary of indirect cross section, with the periphery tapering outwards and overhead, and the secondary again a single- subcase solenoid. The increased winding distance minimizes both voltage grading and sequestration difficulties, but despite advanced coupling portions being attained than with the flat helical approach the mechanical construction is significantly more delicate.

(ii) If the design ideal is for the Tesla motor to produce at the affair a spark of maximum length, a 'top load' in the form of a conducting toroid is connected to the high- voltage end of the secondary winding. In addition to controlling nimbus conformation on the secondary winding, by controlling the electric field, the increased charge storehouse area allows rapid-fire conversion of the accumulated charge into the spark as it forms. The motor design easily has to regard for the effect of the toroid on the tone-capacitance of the secondary winding, to insure that the secondary resonance is still achieved at the asked frequency. The toroid is frequently made by spinning a essence distance on a lathe and forming against a mandrel to shape the distance into a half toroid. Two of these are perfection welded together, with the welded confluence ground flush and the combined unit, of "anchor ring" or "donut" form is polished to give a veritably invariant face as shown in Figure 5.

Figure 5. Examples of conducting toroid top loads

Primary switching

The type of primary switch, whether a spark gap, a solid- state device or a thermionic device is governed primarily by the degree of coupling that's sought and the peak and average powers to be switched, and eventually decides the performance of the motor. In tightly- coupled mills (k> 0.6), the time for the energy transfer to do is inescapably shorter than that of a approximately- coupled device and the power fed to the cargo is comparatively high. Effective design of the primary switch also governs the ultimate secondary voltage that's developed, since during the time that the secondary is free to deliver an affair (ringing down) the primary is effectively an open circuit, as the primary switch ceases conduction incontinently the primary current has fallen to zero and all the energy has been transferred to the secondary circuit. However, the eschewal- of- phase currents that are generated in the secondary winding help the willed affair voltage from being achieved, If this fails to be. In extremely approximately- coupled mills,(k< 0.2) the degree of damping that the secondary suffers due to the presence of the primary winding is extremely low. Nonetheless, since the effective Q of the secondary winding is likely to be advanced than if the windings were tightly coupled, it's doubtful to suffer from this problem and may achieve a advanced voltage. In summary, a tightly- coupled Tesla motor produces a advanced average power affair, but at a lower ultimate voltage, whereas a approximately- coupled motor provides a advanced affair voltage at the expenditure of a lower power transfer effectiveness. The effectiveness can still be restored by operating the motor in the palpitated reverberate mode, when the maximum energy transfer is achieved after a certain number of reverberate half- cycles of the primary oscillations have been completed.

Solid-state switching

Solid- state Tesla mills use semiconductor bias as the primary switch, configured as “half” or “full” H-ground circuits formed from commercially available MOSFET or IGBT packages. Each of the bias needs to be suitable to repel the full voltage applied to the ground. Their performance approaches that of an ideal device, with an on- state resistance generally below a many hundreds of milliohms and an out-state resistance that's extremely high. Their capability to switch fleetly between the two countries enables them to be used in tightly- coupled circuits, although a fairly high cost compared with that of a simple spark gap, the complexity of their associated electronics, the vulnerability to damage from electromagnetic hindrance and their limited power running and dV/ dt limitations are less desirable features. Solid- state switching can be used “ out- line ”, with domestic electrical mains power furnishing the force to the primary winding via an H- ground motor, which is driven at the reverberate frequency of the secondary circuit and capacitive tuning becomes gratuitous. It can also be run in a nonstop- surge mode, when there's little difference between the peak power delivered to the primary winding and the r.m.s. power at the same point. The primary circuit is again unturned and, since the mode delivers a medium average power, the stresses endured by the switch are fairly low. In palpitated operation, the force to the primary winding during a proportion of the number of the force cycles is significantly advanced than that during the remainder of the cycles. Although a slightly lower average power is delivered the peak power is advanced, and a advanced peak voltage is delivered by the motor.

Conclusion

The practical details presented in this paper constitute an essential addition to the numerous readily available theoretical analyses of the Tesla motor, and give an important background to anyone meaning designing or using such a motor for the first time. It's hoped that the paper will intrigue and profit those concerned with the education of prospective masterminds in this fascinating field of technology. fresh benefactions regarding further advances to the solid- state switch topology and control of the electric field are planned for a unborn paper.

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