Design and Modeling of a Tesla Transformer for HPM Sources

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***Abstract*—**This paper details the design and modeling of a 500 kV pulse generator based on a Tesla transformer for driving a matched low-impedance high-power microwave (HPM) source for a duration of 50 ns. An analytical design approach based on the off-resonance mode of operation of the Tesla transformer is made, and simulations are performed to validate the design process.

Keywords-component; Tesla transformer; pulse generator; numerical analysis.

I. INTRODUCTION

Tesla transformers (TTs) have been used as a primer for particle accelerators and high-power microwave (HPM) sources due to their compactness and high pulse repetition rate capabilities. TTs operating in the off-resonance mode due to a ferromagnetic core exhibit improved coupling coefficient, lower primary circuit voltages, and can be designed with high voltage transformation ratios (~ 1500) [1]. This work aims at presenting an analytical approach and simulation to validate the design of a TT.

II. DESIGN OF THE TT

Fig. 1 shows a schematic diagram of a pulse generator based on a TT, and Fig 2 is a 3D model of the TT. Two inductively coupled circuits oscillate at a resonance frequency, ω to elevate a low voltage into the kV and MV range within a nano or microsecond period.

L_1 and L_2 are the primary and secondary inductances; C_1 and C_2 are the capacitance of the primary and secondary circuits, respectively. The maximum secondary voltage, U_{2max} when the circuits oscillate at their resonant frequency is given as;

$$U_{2max} = U_o\sqrt{\frac{L_2}{L_1}} = U_o\sqrt{\frac{C_1}{C_2}} \qquad (1)$$

Korovin showed that the coupling coefficient k due to the presence of a magnetic core can be written as [2];

$$k \approx \sqrt{1 - \frac{8}{3}\cdot F(\beta)\cdot\left(\frac{R_{ex}}{L_{pfl}}\right)^2} \qquad (2)$$

where $F(\beta)$ is a structural function defined in [2], R_{ex} is the radius of the external core, and L_{pfl} is the length of the magnetic core. From (2), it shows that for TTs with magnetic cores, k depends only on the geometric properties of the core.

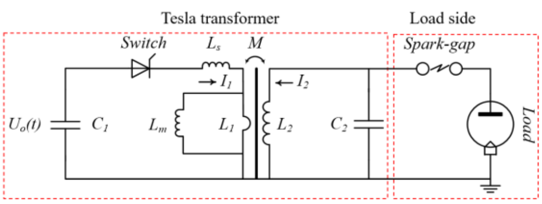

Figure 1. Circuit diagram of open-ferromagnetic cored TT.

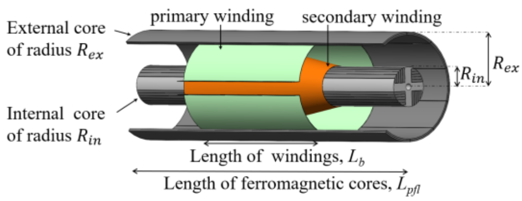

Figure 2. Magnetic core structural diagram of the TT.

III. SIMULATION RESULTS

The input parameters of the TT are shown in Table I. Based on an analytical design approach explained in [2], the calculated parameters of the TT are shown in Table 2. PSICE simulation waveform in Fig. 3. shows that an output voltage and current of 250 kV and 37 kA, respectively, with a 51 ns duration, can be achieved.

TABLE 1. INPUT PARAMETERS OF THE TT

Parameters	U_o	U_{2max}	T_{dur}	Z	ϵ_r
Values	580 V	500 kV	50 ns	6.7 Ω	81

TABLE 2. CALCULATED PARAMETERS OF THE TT

Parameters	L_{pfl}	L_b	R_{in}	R_{ex}	L_s
Values	833 mm	375 mm	41 mm	110 mm	80 nH
Parameters	L_m	L_1	L_2	k	
Values	0.90 μH	0.98 μH	1.24 H	0.96	

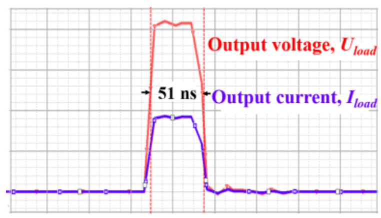

Figure 3. Tesla transformer waveform at rated operations. (U_{load}: 60 kV/div., I_{load}: 20 kA/div., 50 ns/div).

Future work will include electromagnetic simulations to determine areas of electric field enhancements in the PFL and the maximum flux density. The authors look forward to presenting the electromagnetic simulation results during the conference.

REFERENCES

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