ELECTRO-MAGNETIC PARAMETERS ON HIGH CURRENT PULSE LINEAR TRANSFORMERS DRIVER

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Abstract

The main objectives of linear transformer driver are how to provide high efficiency of energy from primary storage capacitors into the secondary winding, high peak current and the fast current pulse of submicroseconds.The formulae of the coupling coefficient of primary and secondary windings, the corresponding voltage-seconds of the core, and the allowable transfer energy per unit volume of core are derived. With the expressions and the equivalent circuit, the magnetic saturation properties of the present core of the QIANGGUANG I accelerator are simulated with PSPICE program.

1 INTRODUCTION

The conventional approach for building pulsed power machines with about 100ns rise time current are several pulse forming stages connected to the output of primary energy storage. Such machines are large, complicated and expensive for producing x-ray through plasma radiation source of fast Z-pinch[1]. The analysis of the inductive voltage adders like HERMES III (SNL) and mostly linear transformer drivers (LTD) (HCEI) [2-3] shows that the primary storage based on this scheme can drive the low impedance load with the rise time of about 100 ns without of pulse forming stages. The advantage of linear pulsed transformer driver is that the potential on the capacitor bodies is ground during the charging and discharging periods, excluding the total output voltage insulation of the highest stages, the other advantage is of a coaxial and compact configuration to obtain more less inductance than that of Marx generator. However the coupling coefficient between primary and secondary windings, and the corresponding voltage-seconds of the core of LTD influence the transfer efficiency of energy from primary storage capacitors into the secondary turn, the current pulse width and the peak current. This paper derived the equivalent magnetizing inductance of the linear transformer in one-modular or n-modular discharge, the coupling coefficient of primary and secondary windings, the equivalent circuit in series and the corresponding voltage-seconds of the core, moreover these parameters are applied to simulate the linear transformer driver called the QIANGGUANG I accelerator.

2 ELECTROMAGNETIC PARAMETERS

2.1 The coupling efficiency of primary and secondary winding

One of the LTD stages is shown in figure 1. According to the definition of the coupling efficiency of primary and secondary windings, the coupling factor is derived

$$k=\sqrt{\left(1+\frac{\ln(R_a/R_c)}{\mu_r\ln(R_2/R_1)}\right)^{-1}} \qquad (1)$$

Here R_a/R_c stands for the radius ratio of outer cylinder to inner cylinder of secondary coaxial line, and R_2/R_1 stands for the radius ratio of outer cylinder to inner cylinder of magnetic core, μ_r stands for the relative permeability.

2.2 The equivalent magnetizing inductance of linear transformer

The magnetizing inductance of linear transformer is equal to the inductance of primary winding when secondary winding is open. According to the Ampere's law, the magnetic field of the core when the n-modular primary circuit discharge at synchronization,

$$H_r=\frac{i\cdot n}{2\pi\cdot r} \qquad (2)$$

The magnetic flux through the area of $b \cdot dr$ between the radius R to the radius $R+dr$:

$$d\Phi_r = \mu_r \mu_0 H_r b S_T dr = \frac{\mu_r \mu_0 b S_T i \cdot n}{2\pi} \cdot \frac{dr}{r} \qquad (3)$$

$$\Phi_0 = \int_{R_1}^{R_2} d\Phi_r$$

According to the theory of electric-magnetic field, the inductance is equal to the ratio of the magnetic flux to the current, then the magnetizing inductance,

$$L_n = \frac{n \mu_r \mu_0 S S_t}{l} \qquad (4)$$

Here μ_r is the relative permeability, $\mu_0 = 4\pi \times 10^{-7} H/m$. l, S and S_t are the average perimeter, the cross-section and the filling factor of the core, respectively.

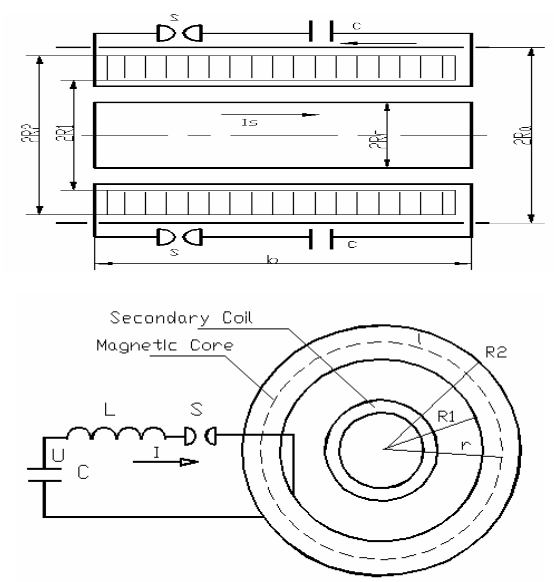


Figure 1. The configuration of one of the stages of linear transformer.

The total magnetic current in figure 1 for n-modular same primary circuit discharge at synchronization when the secondary winding is open,

$$nI = nU / \sqrt{L/c} = U \cdot \sqrt{\frac{nCl}{\mu_r \mu_0 S S_t}} \qquad (5)$$

Here U and C stand for the charging voltage and capacitance of one-modular primary capacitor bank. With the same procedure, the magnetizing inductance and the magnetizing current for only one-modular primary circuit discharge at synchronization,

$$L_1 = \frac{\mu_r \mu_0 S S_t}{l}$$

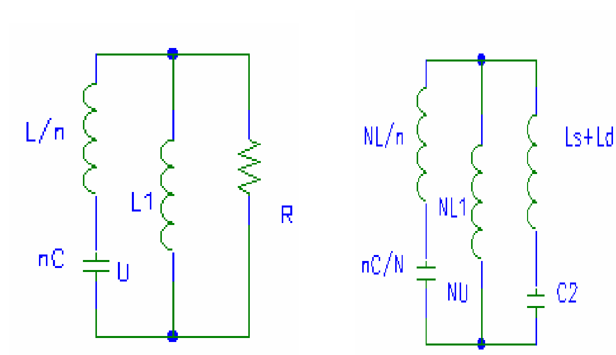
$$I = U / \sqrt{L/C} = U \cdot \sqrt{\frac{Cl}{\mu_r \mu_0 S S_t}} \qquad (6)$$

The magnetic field strength ratio of n-modular primary discharge at synchronization than that of only one-modular primary discharge,

$$H_n / H_1 = \sqrt{n} \qquad (7)$$

2.3 The relationship between the magnetic flux swing of the core and the circuit parameters

The equivalent circuit for one stage and N stages in series where every modular consists of n-sub-modular discharge in parallel at synchronization is shown in figure 2(a,b), respectively.



(a) (b)

Figure 2. The equivalent circuit for one stage and N stages of LTD

The two factors: $\alpha = \frac{(NL/n)}{NL_1} = \frac{L/n}{L_1}$ and $\beta = \frac{L_s + L_d}{NL_1}$ are used to describe the ratio of the inductance of primary and secondary to the magnetizing inductance. When the linear transformer drives the matched capacitive load. For simplifying the analysis, the voltage on the secondary circuit inductance is neglected, according the Falady's magnetic-electric inductive law, the integrate of the voltage applied to the magnetizing inductance,

$$\frac{\pi U}{2} \sqrt{LC_s} = \Delta B \cdot S S_t \qquad (8)$$

The L, C_s and L_1 in formula (13) are replaced by the relative expressions, then

$$\Delta B^2 = \frac{\pi^2}{4}(\alpha+\beta)\mu\left(\frac{1}{2}nCU^2\right)\frac{1}{lSS_t} \qquad (9)$$

Considering that the storage energy $W = \frac{1}{2}nCU^2$ and the volume of the core $V = lSS_t$,

$$\frac{W}{V} = \frac{4}{\pi^2(\alpha+\beta)}\Delta B\cdot\Delta H \qquad (10)$$

With the same procedure, when the linear transformer drives the inductive load, the integrate of the voltage applied to the magnetizing inductance ,

$$U\sqrt{LC_s} = \Delta B\cdot SS_t \qquad (11)$$

The L, C_s and L_1 in formula (17) are replaced by the relative expressions,

$$\frac{W}{V} = \frac{1}{2(\alpha+\beta)}\Delta B\cdot\Delta H \qquad (12)$$

3 THE CALCULATED EXAMPLE OF THE QIANGGUANG I ACCELERATOR

The QIANGGUANG I accelerator located in NINT is a multi-purpose pulsed apparatus based on linear transformer. In order to increase the peak current of the accelerator from 2.3MA at present to 4～5MA in future for fast Z-pinch, the method is that the primary storage energy of linear transformer is increased from nominal value of 450kJ to 900kJ, then the crucial topic is whether the present magnetic core is saturated without changing the configuration of the linear transformer. According to the above expressions and the equivalent circuits, the simulated results are given in Table 1.

The results demonstrate that the magnetic core is not saturated when the primary storage energy of linear transformer is increased from nominal value of 450kJ to 900kJ and the linear transformer drives the matched capacitor or 10μH inductive load.

Table 1. the corresponding voltage-seconds of the core

Parameters U=3MV NL_1=9.144mH	C=90nF L=5μH L=105nH W=450kJ Load： C=55nF or L=10μH	C=180nF L=5μH L=343nH W=900kJ Load：C=180nF or L=10μH
PSPICE simulation	2.517VS or 2.333VS	3.319VS or 3.304VS
saturation time	1.336 μs or 1.846μs	2.202 μs or 2.613μs
$\frac{\pi U}{2}\sqrt{LC_s}$ N	1.904VS	3.266VS
$\Delta B\cdot SS_t$	3.456VS	3.456VS
conclusions	Not saturation	Not saturation

4 SUMMARY

The formulae of the magnetizing inductance of linear transformer are derived when the primary winding are supplied by only one-modular circuit and n-modular same circuit. The equivalent circuit of N-modular in series of linear transformer is obtained. The corresponding voltage-seconds of the core is derived. With the expressions and the equivalent circuits, the magnetic saturation properties of the present core of the QIANGGUANG I accelerator are simulated. The results show that the magnetic core is not saturated when the primary storage energy of linear transformer is increased from nominal value of 450kJ to 900kJ and the linear transformer drives the matched capacitor or the 10 μH load.

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