Power Loss Calculation of High Frequency Transformers

Geun-Soo Choi*, Shin-Yong Yoon*, Soo-Hyun Baek and Kim Yong****

Abstract – This paper analyzed the power loss of transformers considering the magnetic component. For this, each winding strategy and the effect of air gap between the ferrite core have been an important variable for optimal parameter calculation. Inductors are very well known design rules to devise, but the performance of the flyback converter as a function of transformer winding strategy has not been fully developed. The transformer analysis tool used was PExpert. The influence of the insulator thickness, effect of the air gap, how the window height and variation of the capacitive value effects the coil and insulator materials are some of parameters that have been analyzed in this work. The parameter analysis is calculated to a high frequency of 48[kHz]. Therefore, the final goal of this paper was to calculate and adjust the parameters according to the method of winding array and air gap minimizing the power loss.

Keywords: Flyback, High Frequency Transformer, PExpert, Power loss, Winding strategy

1. Introduction

SMPS (switch mode power supply) is used in the application of industrial control systems, namely OA, FA, robotics, Information machines, and LCD backlights. How it is designed is very important, particularly in the case of transformer design considering power loss at magnetic components. The transformer in this case is the flyback transformer that is able to store energy using a turn off switch. The purpose of this is to transfer power efficiently and instantaneously from an external electrical source to an external load [1-3].

Magnetic components are one of the important components in power electric circuits. The design stage of these components should be carried out not only taking into account the electrical specification of the circuit, but also the influence of the geometrical parameters as well as the material properties of all the parts that form the magnetic components.

The usual procedure to design magnetic components allows us to obtain some of their parameters. However there are other very important parameters that are not included in that procedure due to the difficulty to quantify their influence on the magnetic components. The design method proposed in this paper is based on the use of a model that accounts for geometry and frequency effects using the FEA tool. The performance of the final component can be clearly improved by using the right winding strategy and materials for a given electrical specification [4-6].

This paper analyzes the effect of winding strategy and air-gap variation of the flyback transformer. Therefore, from those power losses, parameters for resistance, leakage inductance and temperature can be acquired.

2. Flybak Transformer

Fig. 1 indicates the flyback transformer converter driving the CCFL (Cold Cathode Fluorescent Lamp) by amplification of the piezoelectric transformer.

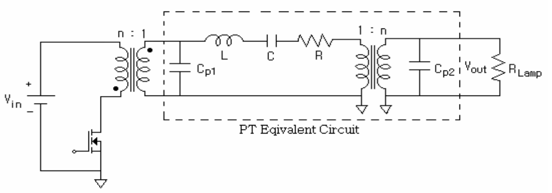
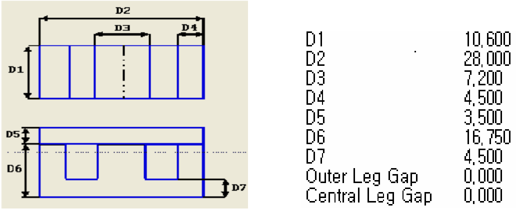


Fig. 1. Inverter of flyback transformer for CCFL

Fig. 2 shows the dimension of the flyback transformer for Fig. 1.

Here, this construction is applied to the core transformer of EI 28 type of the TDK corp.



D1	10,600
D2	28,000
D3	7,200
D4	4,500
D5	3,500
D6	16,750
D7	4,500
Outer Leg Gap	0,000
Central Leg Gap	0,000

(a) EI28 type (b) Dimension values

Fig. 2. Transformer construction and dimension

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Received: May 17, 2005 ; Accepted: January 27, 2006

2.1 Power Loss

Transformer losses can be put into three major categories: core hysteresis losses, core eddy current losses, and winding losses. Transformer loss is sometimes limited directly by the need to achieve the required overall power supply efficiency. More often, transformer losses are limited by a maximum “hot spot” temperature rise at the core surface within the center of the windings. The winding loss worst case is always at low V_{in}, full load.

The analysis procedure is based on the use of the Maxwell Equation, shown below as (1) and (2).

$$\overrightarrow{\nabla} \times \overrightarrow{E} = -\mu \frac{\partial \overrightarrow{H}}{\partial t} \tag{1}$$

$$\overrightarrow{\nabla} \times \overrightarrow{H} = \sigma \overrightarrow{E} + \epsilon \frac{\partial E}{\partial t} \tag{2}$$

Here, $J = \sigma E$, $B = \mu H$

DC resistance and AC resistance are represented as the following Equations (3) and (4).

$$R_{DC} = \rho \frac{l}{A} \tag{3}$$

$$R_{AC} = R_{DC} \times 1.6 \tag{4}$$

DC resistance is constant to frequency, and AC resistance is high variable to frequency.

The power losses of the winding are shown as follows in Eqs. (5), (6), (7).

$$P_{1w} = I_{1DC}^2 R_{1DC} + I_{1AC}^2 R_{1AC} \tag{5}$$

$$P_{2w} = I_{2DC}^2 R_{2DC} + I_{2AC}^2 R_{2AC} \tag{6}$$

$$P_w = P_{1w} + P_{2w} \tag{7}$$

The power loss of the core is indicated as follows in Eq. (8).

$$P_C = K_1 f^{K2} B^{K3} \tag{8}$$

Here, P_C : core loss, P_{ls} : power loss, K_1 : 0.32, K_2 : 1.61, K_3 : 2.68.

Total power losses are shown as follows in Eq. (9).

$$P_{ls} = P_C + P_w \tag{9}$$

Fixed frequency operation, volts-seconds and therefore flux swing are constant. Hysteresis loss is therefore constant, regardless of changes in V_{in} or load current. Core eddy current loss is proportional to $V_{in.}$ Worst case is at high voltage $V_{in.}$ Winding loss is always greatest at low $V_{in.}$ Fig. 3 is for self-capacitance and mutual capacitance of equivalency with analysis models.

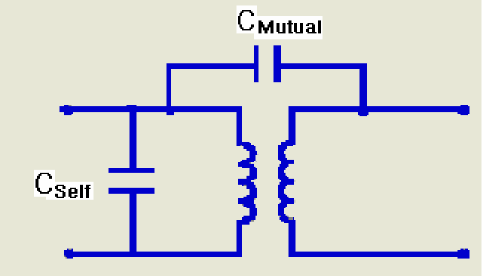

Fig. 3. Self-capacitance and mutual capacitance of EI28 models

3. Simulation Result

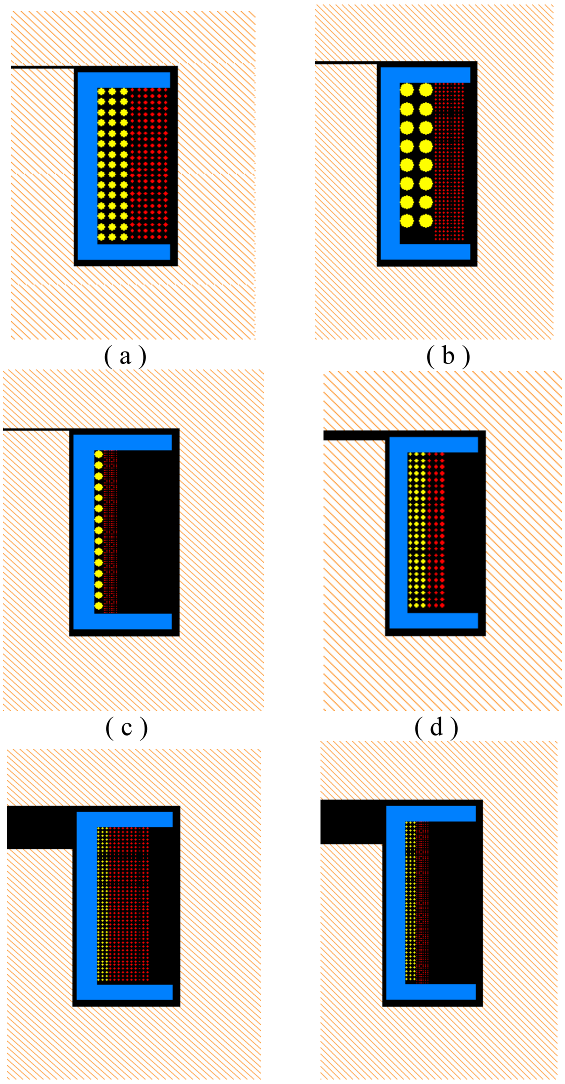

Fig. 4. Winding strategy of EI type core

Fig. 4 shows the represented analysis result of the EI28 type transformer by FEA Export. Here, constructions of analysis objects are the same as the following conditions: core size EI28, bobbin EI28, core material PC40, manufacture corp. TDK, window width 5,90[mm], window height 12,25[mm], volume 4145.20[mm].

The common condition for analysis of Fig. 4, circuit simulation conditions of the flyback transformer are as follows: duty cycle 0.5%, switching frequency 48kHz, operation condition: continuous mode, magnetizing inductance: 130.23[μ H], V_{in} : 5[V], I_{rms} : 1.417[A], permeability : 0.23[T], at Fig.3(a) winding1 structure: AWG 25, gap: 0.1637[mm], number of turns 15, parallel Turns 3.

Fig. 4(b) winding1 structure: AWG 20, gap: 0.1931[mm], number of turns 16, parallel turns 1. Fig. 4(c) winding1 structure: AWG 25, gap: 0.1637[mm], number of turns 15, parallel turns 1. Fig. 4(d) winding1 structure: AWG 30, gap: 0.6151[mm], number of turns 25, parallel Turns 3. Fig. 4(e) winding1 structure: AWG 35, gap: 2.6416[mm], number of turns 42, parallel Turns 3. Fig. 4(f) winding1 structure: AWG 35, gap: 2.6416[mm], number of turns 42, parallel Turns 3. Here yellow rounding coils signify 1 order winding, blue rounding coils signify 2 order winding.

Table 1 reveals the AC resistances, DC resistances, and capacitance analysis by PExprt.

Table 1. AC/DC Resistance and Capacitance

Items		1	2	3	4	5	6
AC Res.	Wind.1 [mΩ]	35.5	37.8	98.8	184.5	966.3	966.3
	Wind.2 [Ω]	3.8	7.07	11.5	19.17	31.52	10.04
DC Res.	Wind.1 [mΩ]	35.6	36.1	98	184	966.3	966.3
	Wind.2 [mΩ]	35.6	36.1	98	184	966.3	966.3
Cap.	Self Cap [pF]	6.86	4.61	6.8	10.55	10.55	10.55
	Mutual. Cap. [pF]	31.7	25.8	31.7	48.8	48.96	48.96

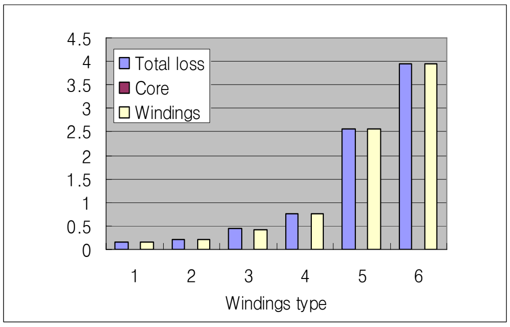

Fig. 5. Winding loss, core loss, and total loss for winding constructors

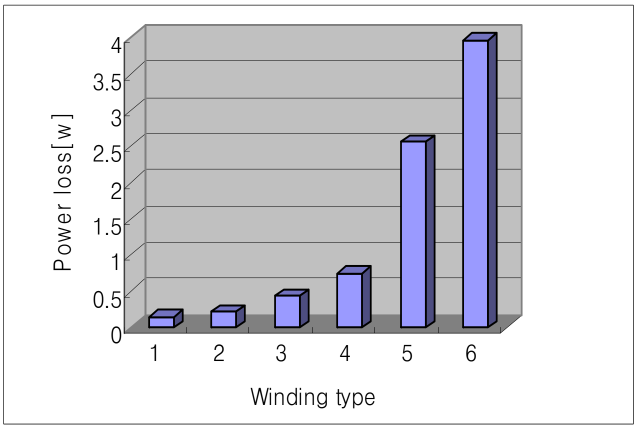

Fig. 6. Power loss to winding types

Fig. 5 shows winding loss, core loss, and total loss for the winding constructor of Fig. 4. Here number 6 is largest at total loss, because the gap and turns are big, and the diameter is small. Number 1 is lowest at total loss, because gap and turns are small, and diameter is large. Fig. 6 represents the power loss of total loss at Fig. 4. It is equal to the explanation of Fig. 5.

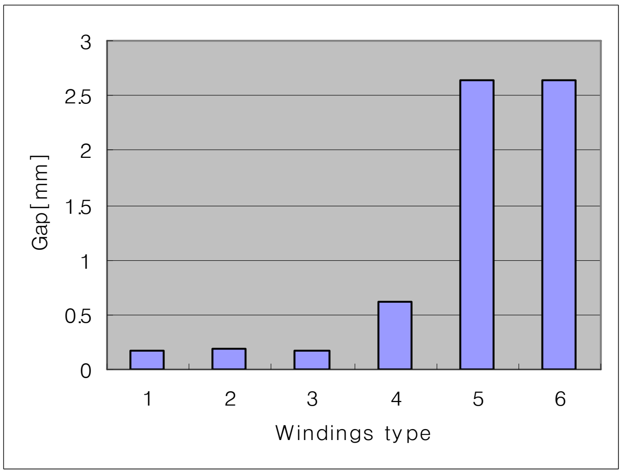

Fig. 7. Gap values to winding types

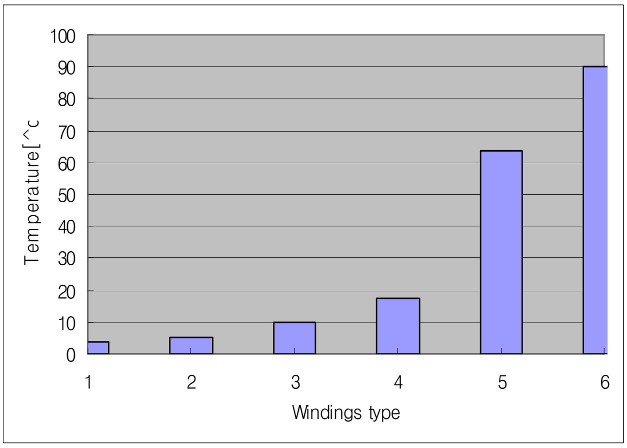

Fig. 8. Temperature for winding arrays

Fig. 7 shows the gap value for winding type. The explanation for this is represented in Fig. 4. Fig. 7 depicts temperature loss, with number 6 indicating the biggest temperature rise.

Fig. 9 indicates DC loss and resistance for winding type. Here Numbers 1 and 2 represent the least amount of loss.

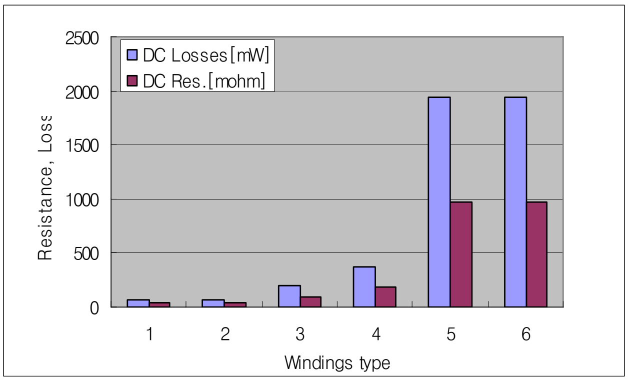

Fig. 9. DC loss and resistance for winding types

Fig. 10 represents AC resistance at 1 and number 2 shows winding. Number 6 indicates the largest ac resistance.

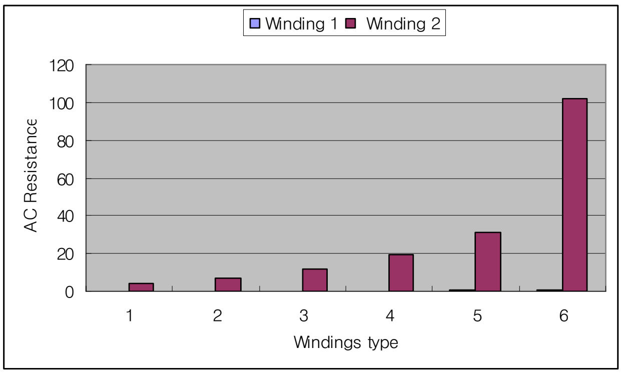

Fig. 10. AC resistance of 1, 2 winding

Fig. 11 illustrates leakage inductance to winding type. Here number 3 indicates lowest leakage inductance, while numbers 5 and 6 represent the biggest leakage inductance.

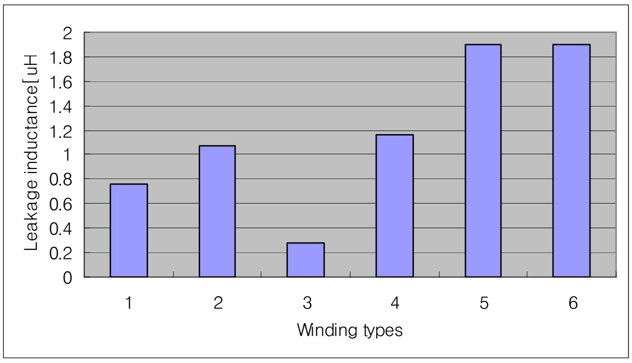

Fig. 11. Leakage inductance to winding types

Fig. 12 represents the flux density distribution of the above analysis model (EI28) by Maxwell-2D.

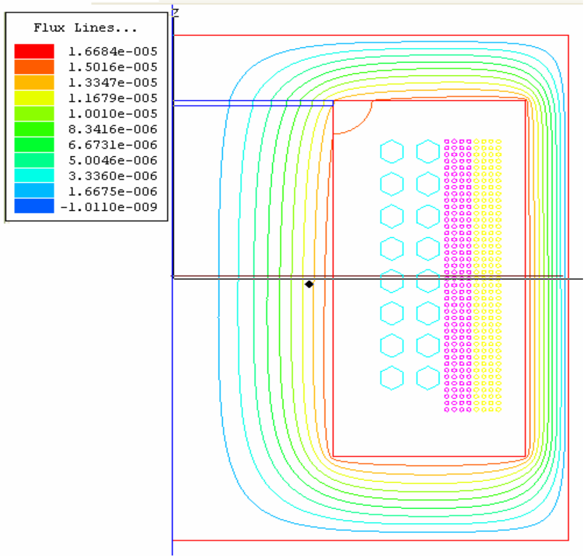

Fig. 12. Flux density distribution of EI28 type core

3. Conclusions

Transformer design at the SMPS is very important to considering loss. For this, it is required to obtain the parameters for loss considering winding strategy. This paper analyzed power loss according to the winding strategy of the flyback transformer. Here, the simulation tool used was PExprt.

From the above analysis result considering parameters, namely winding diameter, gap, turns, resistance, temperature, leakage inductance etc., the EI28 type of number “1” shows the smallest power loss.

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