ANALYSIS AND DESIGN OF FERRITE CORE TRANSFORMER FOR HIGH VOLTAGE, HIGH FREQUENCY WHICH IS USED IN OZONATORS

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Abstract

This paper describes certain analysis ideas stair by stair applied to the ferrite core transformer to accomplish substantial reductions in volume, weight and losses, with improved reliability and better accuracy compared with other transformers. The Ferrite core transformer has been designed and built which is novel in its combination of high voltage (5 kV), high frequency (5 kHz) and power (720 VA) specifications. The design technique utilized a spreadsheet approach which facilitated an iterative design procedure. The transformer used a NiFe for the best choice of frequency about (300 Hz – 20 kHz). Probably, for the analysis of the transformer being carried out by Solid-works, in which magnetic flux density, applied current density, total current density, thermal loss and temperature distribution can be scrutiny. Some of the results such as inductance, flux linkage, leakage inductance and loss can be viewed in the Solid-works. Finally, some of calculations have been derived for intact design of the transformer. It’s used for various real time applications such as Ozone cell, Telecommunications Markets, Power Supply Markets, Fluorescent Lighting Ballast Markets, and Automotive Markets and so on..

Keywords- Solid works, high frequency (PWM), Ferrite materials (NiFe).

1. INTRODUCTION

The Ferrite cores are best suited for high frequency applications and steel laminations are best suited for low frequency applications. Both materials are available in a variety of grades, each best suited for different applications. Ferrites are dense, homogeneous ceramic structures made by mixing iron oxide with oxides or carbonates of one or more metals such as manganese, zinc, nickel, or magnesium.

The specific operating conditions, ordinary laminated core made of steel lamination can be employed only to the working frequency range with in 50k70Hz.[1] For high frequency in the range of kHz, the laminated core cannot be used, for that required such frequency range only the core made of ferrite materials must be used.

The majority ferrite materials used in SMPS relevance, hysteresis losses govern upon 300 kHz. At high frequencies eddy current losses will acquire, because they have a tendency to vary with frequency square. In order to trounce these losses the ferrite core is prepared with laminated metal alloy and powered metal cores are used.

The Common core used for the transformer is E42 type [2].The number of turns in the primary and secondary is limited to the size of the core [3]. The number of turns in the primary and secondary side of the transformer is determined by the standard wire gauge of the conductor to be used. The core is specifically designed for frequency capability. Ferrite is the best choice in high frequency transformer except for mechanical ruggedness.

Frequency has transpired a strategic variable.
Switching power supplies have become so popular because of their knack to maneuver at high frequencies, thus escalating their efficiency. A switching power supply that supplies the same performance requirements of a linear power supply can be many times smaller in size. Since the induced voltage in a transformer is reliant upon the altering magnetic flux, the more we modify the flux (higher frequency), the smaller and more competent the transformer becomes.

With higher frequencies nevertheless, diverse consideration come into take part in. With minor frequencies, core material assortment is driven by core disseminated consideration. Eddy current losses are low soste laminations can be considered.

With higher frequencies, core material assortment is driven by core loss consideration. Eddy currents can be momentous [4]. At this juncture ferrites are usually used because their high electrical resistivity minimizes eddy current losses. On the other hand, there is a outlay to be paid for the compact core losses, and with the intention of this ferrites have lower saturation and permeability values.

The preference of magnetic core will be subjective by numerous factors:

- Circuit topology used, habitually preferred to yield the paramount amalgamation of least power transistor off voltage and peak current stress.
- Operating frequency of the circuit.
- Power necessities.
- Regulation desirable.
- Outlay.
- Competence.
- Input/output voltages.
- Tolerate temperature rise.
- Volume/weight/height requirements.

Some of the drawbacks in other transformer compare with the ferrite core transformers are FlyBack Transformers or Line Output Transformers. Current is limited and the transformer winding may not burn away or blow fuse.

- The typical operating current output of FBTs are extremely low, were as it will be in the range of milliamps.
- The high frequencies essentially make it necessary to construct a supplementary complicated control circuit.
- These reasons render FBTs unsuitable for a Power supply relevance for this task.

Microwave Oven Power Supply

Microwave ovens have a transformer and diode rectifier system. The Microwave Oven Transformer (MOT) is competent of generating about 2 to 3 kW at 1 to 4 kW depending on the oven’s model and power rating.

These transformers are used to impel the magnetron that produces the microwaves, with a sufficient amount power to heat victuals. The MOTs are not current limited by core saturation and are therefore hazardous incase of shorting of the secondary. However, the voltage constraint of this task is upon 15 kV and consequently, cascading of several transformers in series would be necessary. This is also dangerous because the insulation on the MOTs may not grasp up to higher voltages than they are rated.

2. DESIGN CONSIDERATION

A. Basic Design Equation

![Transformer Diagram](image)

The relation of the transformer with the turns ratio to the voltage and current given by

\[
\frac{V_1}{V_2} = \frac{I_2}{I_1} = \frac{n_1}{n_2} \quad ---- \text{1}
\]

The ensuing equation illustrates how an assortment of design variables can be manipulated to achieve the preferred outputs. It should be renowned that varying one parameter can and will change the other parameters as well:

\[
E = 4.44 \text{ BNAc } f \times 10^{-8} \quad ---- \text{2}
\]

E is Induced voltage in volts, B is maximum induction in gauss, N is Number of turns in winding, Ac is cross section of the magnetic material in cm², and f is frequency in Hz. From the equation, we can see how the
parameters interact with each other. In the majority transformer design situations, E is already set. The subsequent cases illustrate what happens when one variable is changed and how it affect the other variables again holding E constant for the sine wave condition.[5]

Increase B

The turns would reduce, sinking copper losses. Nevertheless, escalating B increases core losses ensuing in higher core temperatures.

Increase N

B would reduce, sinking core losses. Escalating N leads to higher copper losses and require extra space for extra windings. Advanced copper losses means elevated winding temperatures and reduced efficiencies.

Increase Ac

B would be decrease acquiescent lower core loss per unit mass however, the weight would augment off setting some of that gain. An increased area means longer length of wire escalating copper losses. This would effect in a larger capacity transformer. Extreme core heating may shrink your B value thus sinking the efficiency.

Increase f

B would shrink, possibly ensuing in lower core losses. Conversely, as you shift to higher frequencies, core losses could befall more significantly. A switch to ferrite will diminish these losses but charges of B decrease. However, the efficiency gains from a higher frequency will more than counterbalance the lower B. The elevated frequency would also allow for a smaller transformer, N or else Ac would decrease.

B. selection of ferrite core material

The ferrite core is selected and is composed of 50-80% of NiFe, and at room temperature it has a saturation magnetization of 1.56T. The corelosscanbe70%-80%less than silicon steel material. Ferrite core has a wide range of high frequenciesandhot-spottemperaturesupto 120 degree Celsius. Its thermal bound is close to that of winding conductor’s thermal limit (120 degree Celsius), so the thermal design of the transformer can be most excellently optimized. Its elevated saturation flux density assortment can add flexibility when designing the number of turns sandwiched between the primary and secondary windings[6].The core cross-sectional area can also reduce to bare minimum by increasing the flux density while within the thermal limits. Since its high performance characteristics, this core material is chosen for the 300Hz and 20 kHz transformer design.

These are the majority widespread cores use d in power application. They are cost effectual, allow for simple bobbin winding, and are effortless to amass. But an E core does not, on the other hand, offer self-shielding.

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Table 1: Effective core parameters

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>∑(VA)</td>
<td>Core factor(C1)</td>
<td>0.894</td>
<td>m</td>
</tr>
<tr>
<td>H</td>
<td>Height of yoke</td>
<td>5/1</td>
<td>m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>m</td>
</tr>
<tr>
<td>D</td>
<td>Diameter of yoke</td>
<td>5/1</td>
<td>m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>m</td>
</tr>
<tr>
<td>W</td>
<td>Length of yoke</td>
<td>5</td>
<td>m</td>
</tr>
<tr>
<td>H</td>
<td>Height of frame</td>
<td>2(1/4)</td>
<td>m</td>
</tr>
<tr>
<td>A</td>
<td>Area of window</td>
<td>0.7</td>
<td>Sq. Inch</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>g</td>
</tr>
</tbody>
</table>

m Mass of core        1 g
Stamping size are
A=31/32, B=2(17/32), C=2(1/4), D=E5/16,

1. Winding Area Calculation

Core Area is given by,

\[ A_c = \frac{nI_{1\text{rms}}2}{JK} \]

\( n \) is number of primary turns, \( J \) is function of primary current, \( K \) is filling factor (0.4-0.7).

<table>
<thead>
<tr>
<th>Width of the window= (B-A-2D)/2</th>
<th>Height of the window= C-2E</th>
<th>Area of the window (A_{w})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4685 inch</td>
<td>1.625 inch</td>
<td>0.76 sq.inch</td>
</tr>
</tbody>
</table>

Table.2 window winding Area

Area of the product is given by,

\[ A_p = A_c \times A_{w} \]

\[ A_p = \frac{(V_{1}t_{on})2I_{1\text{rms}}}{f_s\Delta B JK} \]

\( V_{1} \) & \( t_{on} \)

C. Core losses

In which magnetic losses being calculated based on flux density & magnetic field strength, this expressed by prototype

3F3 is the specific core material selected in which flux density in mT with the amplitude for e.g.: If for 100 kHz the amplitude of which 200 Mt with core loss of about 100 MW/cm³ or 100 KW/m³ at temperature of about 100°C.

Fig.4 Core loss (y-axis) in terms of \( B_x \) (x-axis) and y-axis

Fig.5 Flux density & power for frequency at 3f1 material

Fig.6 Magnetic loss vs. temperature
3. Analysis and calculation of transformer using solid works

The magnetic field distribution in the single Phase core is analyzed in this section. The main reason for a core is to provide a return path for harmonic flux. Nevertheless, the crisis commence by this construction is that the authentic flux paths are uncertain. The uncertainty of the flux paths is owing to the reality that the yokes are not huge enough to hold the whole flux from the core. Although the natural tendency is for the flux to follow the pattern, the yokes saturate and force excess flux to spill over into the outer legs. For this reason, it is a good practice to design the flux density in the core in the lower region than the saturation knee, to avoid saturation [7]. Leakage inductance delays the transfer of current between switches and rectifiers during switching transitions. These delays, proportional to load current, are the main cause of regulation and cross regulation problems. The simulation result for each model is shown in Table 5.

The energy losses in a transformer appear as heat in the core and coils. This heat must be dissipated without allowing the windings to reach a temperature which will cause excessive deterioration of the insulation. One of the challenges of high frequency design is the heat dissipation on effective cooling surfaces. The major cooling technique designed for these transformer designs is natural convection method that is the heat generated from core and coils get transfer to air through effectual cooling surface area. Alternately, cooling fans may be needed for elevated loss designs. The temperature restrictions for conductor and core are 120°C respectively. The design temperatures for each component should be around 100°C and allow 20°C for localize hottest spot temperature

A. Transformer Analysis with EMS post-processing

![Fig. 9 coil winding of the transformer for analysis](image)

After the materials has assigned. Then to assign of the thermal in puts at which convection is applied to the
To find the coils, wound coil by setting direction & no. of. Turns for both primary & secondary side.

B. Analysis of loss from result stable

Fig. 11 Analysis results data for inductance

Fig. 12 Analysis results data for Flux Linkage
Fig. 10 Flowchart for analysis of high voltage, high frequency transformer using Solidworks
In the temperature analysis, thermal radial & heat flux in temperature distribution can be analyzed with more gradient of heat flux. Thermal plot can be manipulated from electrical orbits which can be ISO clipping, section clipping & shapes can be viewed in Fig.19 and 20.

Fig. 13 Analysis results data for Leakage inductance

Fig. 14 Analysis results data for Losses

From the result analysis, we can obtained the leakage inductance, flux linkage, inductance and hysteresis loss, eddy loss & core loss

C. Analysis of field plot for coil winding

Magnetic flux density can be viewed enough by ISO clipping of the B field can be animated by varying the phase angle.

In which applied current density can be shown using stress of vectors.

In total current density, inside the transformer can be analyzed using section clipping, multi section in which clipping can be applied.[8]
4. CONCLUSIONS

In this paper, the designs have been proposed, analyzed and calculated. The main objective of this paper was to design a transformer with smallest physical size, least expensive transformer and minimum loss for high frequency design with current technology. The main contribution is to analysis of Ferrite core transformer based on commercial core of EEtype. The main features of the high frequency transformer are:

- High resistivity with low eddy current loss and high usable frequency range.
- High Magnetic permeability with high induction in minimal space.
- Versatility of core shapes which satisfies magnetic requirements in minimal space.
- Lightweight due to winding core of lightweight.
- Low cost relative to alternate materials.

A ferrite core transformer with an output voltage of 5kV, output power of 900W, and switching frequency of 5kHz was built and the design and analysis have been verified using SolidWorks. Total efficiency is approximately about 92%, and the hot spot temperature on the surface at 100°C.

5. FUTURE WORK

The high power and high-frequency transformer is an emerging challenge. Especially, insulation concerns directly related to safety issues. More careful and accurate research at the high voltage and high-frequency operation is required. Probably, high frequency in ferrite core is simplex and low losses yet to try high

Fig. 17 Analysis of Total current density inside the transformer.

Fig. 18 Analysis of Temperature gradient for thermal radial & heat flux.

Fig. 19 Windings of the transformer with Ecore.

Fig. 20 Ferrite core transformer after designing.
voltage in the same field.

Table 3 Specifications of High Voltage high frequency

<table>
<thead>
<tr>
<th>Corematerial</th>
<th>NiF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>EE42</td>
</tr>
<tr>
<td>Power</td>
<td>900</td>
</tr>
<tr>
<td>Frequency</td>
<td>5kHz</td>
</tr>
<tr>
<td>Primary voltage</td>
<td>300</td>
</tr>
<tr>
<td>Secondary voltage</td>
<td>5000</td>
</tr>
<tr>
<td>Turns Ratio</td>
<td>16.7:</td>
</tr>
<tr>
<td>Primary winding</td>
<td>48</td>
</tr>
<tr>
<td>Secondary winding</td>
<td>94</td>
</tr>
<tr>
<td>Efficiency</td>
<td>9</td>
</tr>
<tr>
<td>Fluxofcore</td>
<td>0.563mwb</td>
</tr>
<tr>
<td>Netcore area</td>
<td>0.563mm²</td>
</tr>
<tr>
<td>Widthof window</td>
<td>0.486inch</td>
</tr>
<tr>
<td>Heightof window</td>
<td>1.625sq. Inch</td>
</tr>
<tr>
<td>Area of window</td>
<td>0.76 sq.Inch</td>
</tr>
</tbody>
</table>

References


