Investigating High Frequency Power Loss in Litz Wire

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Abstract
There are many contributing factors to the power loss that occurs in litz wire. Through the summation of these losses, interesting loss characteristics can be seen if the wires are tested over a large range of frequencies. This investigation is designed to demonstrate the behavior of several designs of litz wire. The investigation has 3 main aims. To provide calculations of proximity and skin losses of ideal litz wire. Computerized simulations of the coil behavior under conduction. Thirdly, physical model has been developed to provide a real-time demonstration of how the different litz wire coils behave at a predetermined range of frequencies.

1. Introduction

Litz wire are commonly used for windings in transformers and inductors of switch mode power supplies. These are used in this application as if constructed properly they can provide low power loss at high frequencies. At high frequencies, the current will only conduct in the center of a solid conductor. By using strands it reduces this effect and therefore reduces losses. This advantage over using a solid wire only occurs up to a certain frequency. Therefore, construction of the litz wire used for a certain task needs to be set up specifically for that task. If the frequency goes above a certain threshold that the wire can handle the wire will provide higher losses than a solid wire [1].

In the calculations section, the skin effect losses will be calculated as well as the proximity losses. The mutual inductance of each of the coils will also be calculated for each of the coil that will be used in the physical experiment.

In the simulations section, two different software will be used to help further the investigation. Ansoft Maxwell is used to give the inductance of the coils and the magnetic field created during conduction. PSIM is also used to simulate the circuitry that will be set up to run the physical experiment.

Finally, the physical experiment section will outline the circuit that has been set up to demonstrate the losses that occurs in litz wire at a range of frequencies.

2. Calculations

Mutual inductance calculations were carried out to determine the theoretical mutual inductance of the coils. These calculations were carried out using Matlab. The theory of the calculations were based on calculations for mutual inductance for coils in air set out by W.G.Hurley et al. [2].

There are many papers and books for calculating skin and proximity effects. There are many pieces of literature that were used for investigating skin and proximity effects as well and the best method for constructing the litz wire coils [3] [4].

3. Simulations

3.1. Finite Element Analysis

Ansoft Maxwell was used to create and model the coils of wire being investigated. Ansoft Maxwell provides inductance calculations as well and displaying magnetic field effects.

The software was used to calculate the self-inductance of a single coil and of the full coil with opposing currents and as shown in Figure 1 and Figure 2 the software has also displayed where on the coils the magnetic field is the strongest.

![Figure 1 Ansoft Maxwell geometry of full coil (left) and single coil (right)](image-1.png)

3.2. PSIM

This PSIM model is designed to simulate the voltage and current characteristics that will be flowing through the coils.

This was used to develop the correct circuitry and components for the physical model. The inputs to the MOSFET on the circuit in Figure 3 has been set up to mimic the output of the driver to allow accurate analysis of the power in the coils.

![Figure 2 PSIM circuit](image-2.png)
4. Physical Experiment

The model will demonstrate the increasing losses by displaying the thermal energy being emitted by the coils as the frequency increases. The circuit has the ability to test for frequencies up to 1 MHz by simply controlling the resistance and capacitance on pins 5 and 6 respectively.

The components that had to be sourced for the project are PWM controller - UC2852, Half bridge driver - IRS2183 and, 2 x Power MOSFET - IRF4104.

Coils used for the investigation are 1 x 1.32mm, 7 x 0.5mm, 10 x 0.355mm and 180 x 0.1mm. All coils were kept to similar cross-sectional areas.

![Figure 3 Circuit diagram for physical experiment (left) and actual device (right)](image)

The losses for each coil can be compared as the frequency is increased. The temperature of each coil is monitored by a LM35DZ temperature sensor that is connected back to an Arduino UNO to display the value to and LCD screen for analysis by the user.

5. Results

5.1. Calculations

Through the calculations of mutual inductance, the mutual inductance based on the coils used was 1.06 µH.

Figure 5 shows the skin and proximity effects for each of the coils. The skin effect is displayed for each wire size over a 50 to 500 kHz range. Proximity is shown for the cross-sectional area used. The heavy line show the 50 to 500 kHz range.

![Figure 4 Rac/Rdc due to skin effect (left) and proximity effect (right)](image)

5.2. Finite Element Analysis

From the analysis, the program determined that the inductance of the single coil was 1.82 µH and the full coil had an inductance of 0.9 µH. This corresponds with the calculated mutual inductance of the coils.

![Figure 5 Ansoft Maxwell magnetic field intensity on full coil (left) and single coil (right)](image)

5.3. PSIM

The RMS current flowing through the coils at a 15 Vdc supply is 2.6 A. This is common across all coils. The voltage across the output capacitor was 4.9 Vdc.

6. Conclusion

The work that has been carried out provides in-depth analysis of the losses that occur in litz wires at high frequency. This information gives a good understanding as to what is the contributing factors to the losses.

To compliment this the experiment that has been designs enables further investigation into losses at a range of different frequencies.

There is much more investigation to be done in this field. However, these methods may outline some simplified method of analysis.

6. References


