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Design& Development of Common ModeChoke (CMC)

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***Abstract*- This paper presents a design procedure of common mode choke (CMC)/RF choke.A common mode choke is used to reduce electrical noise known as common mode noise. The procedure describes properties of ferrite core CEL T-45 HP3 C like size etc., and finally design of choke. The proposed design procedure and methods are verified by experiments.**

***Keywords*- Common mode choke (CMC), Alternating Current (AC), Direct Current (DC), Inner circumference (I.C.), Electromagnetic interference (EMI), Radio frequency interference (RFI) etc.**

I. INTRODUCTION

In electronics, a choke is an inductor used to block higher-frequency alternating current in an electrical circuit, while passing lower-frequency or direct current (DC). It consists of coil of insulated wire wounded on a magnetic core; some consist of donut-shape ferrite material on a wire. Impedance of choke increases with increase in frequency [1]. Common-mode chokes, has two coils wounded on single core, which is useful toprevent electromagnetic interference (EMI) and/or radio frequency interference (RFI) from power lines andalso to prevent malfunctioning of electronic equipment. It passes differential currents (equal but opposite), but blocking common mode currents. Magnetic field produced by differential mode currents in the windings cancel each other. Thus, the choke presents less inductance or impedance to differential mode currents. Common mode currents see high impedance due to the combined inductance of the windings [2].

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II. MATERIAL SELECTION

Ferrite cores are generally used in development of common mode choke. A torodial ferrite core CEL T-45 HP3 C of average diameter 36mm is used. Toroids shaped cores have following advantages:

(a). Toroids are cheaper than the other shapes because they are in one piece whereas; other shapes are in two halves.

(b). Toroids have highest effective permeability for any type of core shape. Air gap between the piecesis induced, in case of 2 piece construction which lowers

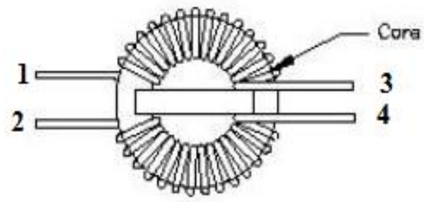

Figure 2.1 Common Mode Choke

effective permeability of set typically by about 30% [3].

This section describes the design steps for CM choke. Common mode inductor consists of two windings each with equal number of turns.

The windings placed on the core such that line returnneutral current creates the fluxes that are equal in magnitude and opposite in phase. These two fluxes cancel out each other, and leave core in an unbiased condition. The common mode currents are attenuated by the choke.

The three important parameters for common mode inductor design are as follows:

(A). Input current- Input current determine the size of conductor needed for windings. Single stranded wire is mostly used because it is least expensive and its main contribution is to attenuate noise within high frequency skin effect losses.

(B). Frequency- A first order filter attenuates noise that is increased by -6 dB per octave beyond corner frequency. Cut off frequency is an important parameter for CM choke design.

III. DESIGN CONSIDERATIONS

Input current, frequency, and impedance are the basic parameters required for common mode inductor design. Input current is used to determine size of conductor needed to place windings. Figure 3.1 describes the flowchart for design steps of CM choke.

Single stranded wire is mostlyused because of its low cost and contributesin noise attenuation towithstand high frequency skin effect losses.The impedance ofinductor is stipulated as min. value at given frequency. This impedance, when connected in series with line impedance provides desired noise attenuation. Impedance of line is rarely known, so designers mostly test their filters with a 50Ω Line Impedance Stabilization Network (LISN). This is a standard method of measuring filter performance but, can lead to results that differ from those in real. A true first order filter provides attenuation that increment by -6 dB per octave above corner frequency. This corner frequency is usually considered low enough so that inductive reactance becomes primary contributor to the impedance, allowing the inductance to be calculated as:

$$L_S = \frac{X_S}{2\pi f}$$

Once inductance (L_S) is known, the remainder of design which involves core, material selections and calculating number of turns. First step in designing of CM choke is to select core size. If the design has some physical requirements, then largest core should be selected andif there is no size restriction, then core size can be selected randomly.

In next step calculate required maximum number of turns that will overlay the core. Common mode inductors require two windings, with single layer, each winding on opposite sides of the core in order to provide isolation. Since, the wire size is determined by the line current, so inner circumference can be calculated by subtraction of inner radius of core by radius of wire. Maximum number of turns is then calculated by dividing wire

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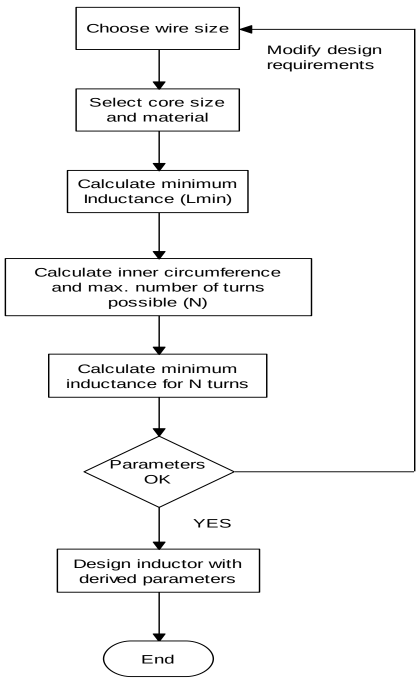

Figure 3.1 Flowchart for CM Choke design

diameter, with insulation, to that of the circumference occupied by each winding.

Once maximum number of turns is calculated, next steps are to choose a core material and determine inductance. Material choice involves many factors; operating temperature, frequency range and cost etc.Many ferrite manufacturers provide inductance factor (A_L) values for various types of cores, which then provide an easy method for calculating inductance. The relation between number of turns and inductance is given by:

$$N = 1000\left(\frac{L}{A_L}\right)^{\frac{1}{2}}$$

Where;

N = Number of turns

L = Inductance (mH)

A_L = Inductance factor in mH/1000 turns

If minimum inductance (L_{min}) is too small for the required design, then high permeability material, larger core can be selected. If the calculated inductance is sufficiently above the design limit, then a small core with less number of turns can be substituted [3].

IV. DESIGN EXAMPLE

The Current Rating chosen for CM Choke is 3A. Based on this parameter, design steps of common mode choke is given. The requirement of input current is of 3 Ampere current density at 400 A/cm^2 [4] yields a wire area of 0.007 cm^2. As input current determines the size of conductor needed for winding therefore, a wire of 1.3 mm diameter (with insulation) and 1 mm diameter (without insulation) is selected which consists of Teflon insulation. Further calculate minimum required inductance (L_{min}) based on X_S which is series inductive reactance. This represents that the calculated value of L_{min} is the lowest and is equated as [3];

$$L_{min} = \frac{X_s}{2\pi f_c} \qquad (4.1)$$

Where X_S is taken as 100Ω, f_C is cut-off frequency and its value is taken as 900 kHz. By substituting values of X_S and f_C, value of L_{min} is;

$$L_{min} = \frac{100}{2\pi \times 900 \times 10^3}$$

$$L_{min} = 0.017\ mH \approx 0.02\ mH$$

Since it is minimum inductance so,

$$L_{CM} \nless 0.02\ mH$$

Next step is to choose core size and material. A ferrite core is used to design common mode choke and its dimensions are as follows: inner diameter (ID) 27.5 mm and outer diameter (OD) 44.6 mm. Suitability of core is determined by finding (A_L, $Inner\ Circumference$). For determining A_L value, an experimental measurement was made where

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L=0.65 mH for 20 turns. From this value A_L was calculated as,

$$0.65 = k \times (20)^2 \qquad (4.2)$$

$$A_L = k \times (1000)^2 \qquad (4.3)$$

k= constant

Now taking ratio of equation (4.3) to (4.2) so we get,

$$\frac{A_L}{0.67} = \frac{1000 \times 1000}{20 \times 20}$$

$$A_L = 500 \times 5 \times 0.67$$

$$A_L = 1675 \frac{mH}{1000\ turns}$$

Where value of L was measured to be 0.65 mH for 20 turns;

Next needed parameter is the inner circumference (I.C.) of the ferrite core. This determines the maximum number of turns that can be wounded. Inner circumference (I.C.) formula is given by the following form [4]:

$$\mathrm{I.C.} = \pi[\text{Average core diameter} - \text{Wire diameterwithout insulation} \qquad (4.4)$$

$$= \pi(36\ mm - 1\ mm)$$

$$= \pi(35\ mm)$$

$$= 109.9\ mm \approx 110\ mm$$

By using inner circumference parameter calculate maximum number of possible turns on ferrite core using formula [4];

$$N = \frac{Angle\ covered\ by\ winding\ on\ a\ core}{360°} \times \frac{(I.C.)}{\left(1.3\frac{mm}{turn}\right)} \qquad (4.5)$$

$$N = \frac{30°}{360°} \times \frac{110\ mm}{1\frac{mm}{turn}}$$

$$N = 0.083 \times 84.61$$

$$N = 7\ turns$$

Further calculating maximum inductance for 7 turns which consists of previously known parameters number of turns (N) and Inductance factor (A_L) in mH/1000 turns. To calculate maximum inductance following equation is used [3];

$$\mathrm{N} = 1000\sqrt{\frac{L_{max}}{A_L}} \qquad (4.6)$$

Where, N=7 turns and,

A_L=1675 mH/1000 turns

Substitute values in eq. (4.6) we get,

$$(7)^2 = (1000)^2 \times \frac{L_{max}}{A_L}$$

$$L_{max} = \frac{(7)^2 \times 1675}{(1000)^2}$$

$$L_{max} = 82.075\ mH$$

Common mode inductance L_{CM} lies between L_{min} and L_{max}. The value of inductance is $L_C = 0.015\ mH$. The required number of turns N_2 is given by;

$$0.67 = k \times (20)^2$$

$$0.15 = k \times N_2^2$$

$$\frac{0.15}{0.67} = \frac{N_2^2}{400}$$

$$N_2^2 = \frac{60}{0.67}$$

$$N_2 = 9.6 \approx 10\ turns$$

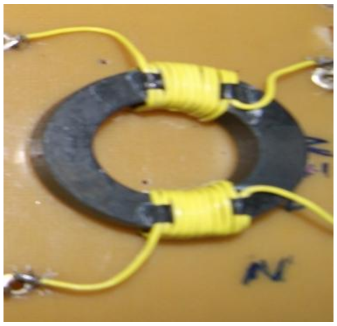

Figure 4.1Hardware design of CMC

V. CONCLUSION

In this paper, we propose an inductor design procedure using low permeability magnetic materials. The procedure and methods proposed in this paper can help to design a magnetic-core inductor with low/high permeability RF core materials.

VI. FUTURE SCOPE

Common Mode Choke according to requirements can be designed. Or modifications in pre designed choke can be made as desired.

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