SCALE AND WEIGHT CONSIDERATION OF EMI FILTERS

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ABSTRACT:

Amongst the main constraints faced by the designer of EMI filters is the performance sensitivity to system weight. The design of the common mode filter is an important aspect of the weight and space management of an aerospace system. Designable parameters of this filter and its material properties are detailed. The design of a filter with nanocrystalline material and the use of a fourth leg inverter are alternative designs adapted to an optimized space management.

I. INTRODUCTION

Systems with smaller size and lighter weight are in increasing demand on spacecraft power system with high constraints of efficiency and reliability. Amongst the main constraints faced by the designer are the performance sensitivity to system weight and sensitivity to overall cost [1], [2].

In aerospace architecture the potential causes of EMI are varied: ESD related to space environment, intra-system common mode current, power system and transients. In aircrafts huge pulsed currents can flown through the system as a consequences of lightning or generated by high power actuators which replaced more and more hydraulics systems. The electrical system of aerospace structures determines, amongst others aspects, the space craft size. In the electrical drives, the passive components dedicated to EMI filtering can easily represent twice the space occupied by the active part. The EMI filter design appears then as an important design constraint [3].

Designable parameters of a common mode filter and the material property of its choke will be first presented. The second and the third section will focus respectively on the design of a filter with nanocrystalline material and the use of the fourth leg inverter.

II. TRADITIONAL EMI FILTER DESIGN AND DESIGNABLE PARAMETERS

Traditional EMI filter are generally constituted of:

- capacitors between lines and of a series of inductors (differential mode components)
- capacitors to ground and common mode chokes (common mode components)

The common mode current is a key aspect in the control of the radiated emission within the aerospace and the common mode components, especially its bulky choke will be the focus of this section.

The table 1 presents the designable parameter of the common mode chokes and their relation with the characteristic impedance of the device [4]: common mode impedance (Z_{cm}), differential mode impedance (Z_{dm}) and the parasitic capacitances (turn to turn and intra winding). The change of material appears as the only significant way to gain space in the design of the filter.

Impedances of the CMC	Designable parameters
Z_{cm}	Material (complex permeability) Dimension of the choke Number of turns Effective length
Z_{dm}	Number of turns Dimensions of the choke Angle of leakage inductance
Intra Winding Capacitance And Turn to Turn Capacitance	Number of turns Dimensions of the choke Wire dimensions and materials Length of turns

Table 1. Designable parameters of the common mode choke

The value of the CM impedance is strongly related to the value of the permeability of the core. The choke core introduces frequency variable impedance in the circuit. The core will not affect the lower frequency operating signals but does block the conduction of EMI. The permeability of a choke is a complex parameter consisting of a real part and an imaginary part. The real component represents the reactive component and the imaginary part represents the losses. The CM impedance of a CMC can be represented by the series equivalent circuit of a suppression core: the loss free inductor (L_s) is in series with the equivalent loss resistor (R_s). The flowing equation relates the series impedance and the complex permeability.

$$Z = R_s + j.w.L_s = j.w.L_o(\mu_s' - j.\mu_s'')$$

where

$$L_o = \mu_0.\frac{A_e}{l_e}.N^2$$

N: Number of turns

A_e and l_e: Respectively the effective area and length of the core under consideration

This impedance is usually measured and an approach by polynomial approximation is made. In [5] a model is proposed of frequency dispersion of complex permeability in ferrites. The permeability spectra of ferrite materials can be described by the superposition of two kinds of resonance phenomena (domain-wall resonances and gyromagnetic spin rotation). The figure 1 presents the complex permeability spectrum of a sintered MnZn ferrite and its common mode impedance.

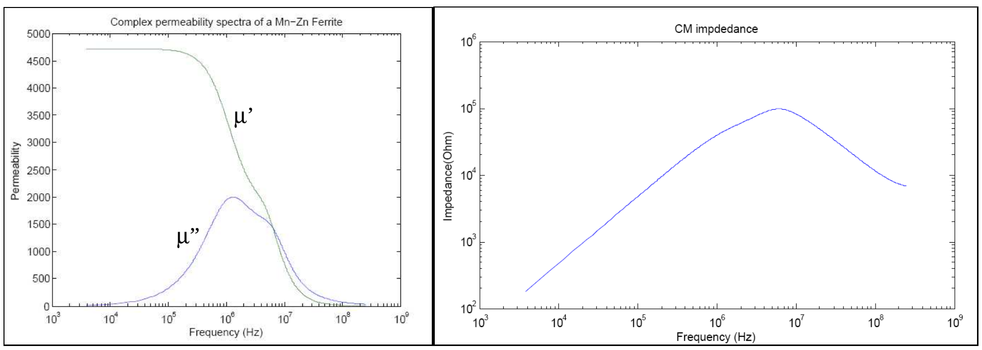

Figure 1: Complex permeability spectrum of a Sintered MnZn ferrite and its common mode impedance (Dimension: 25*10*5 mm, N=20)

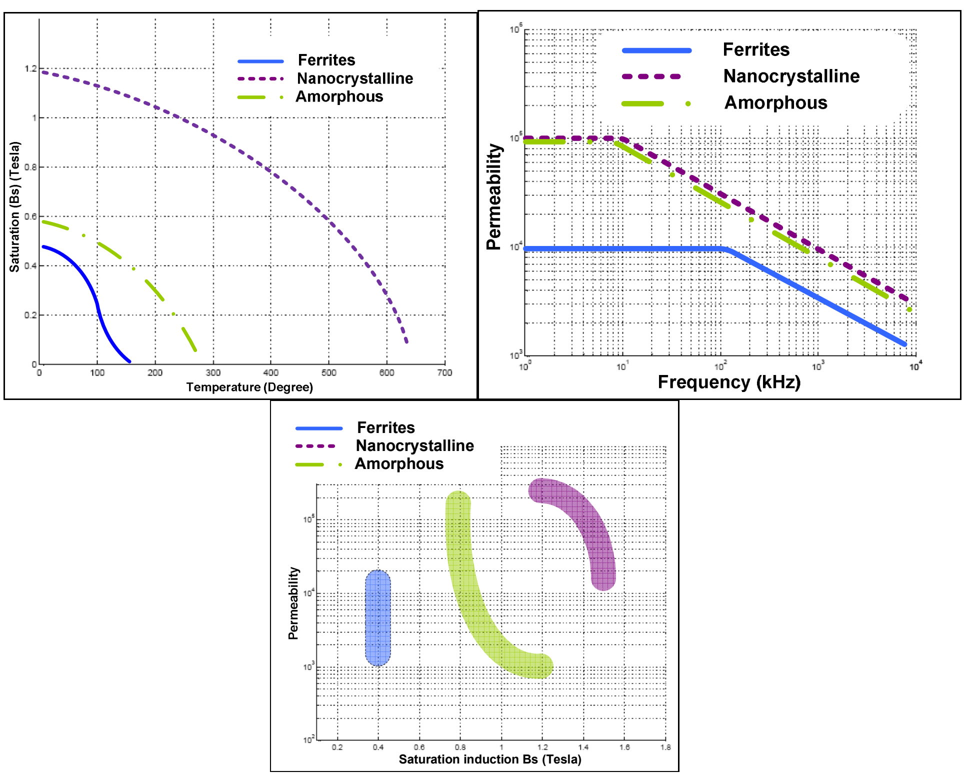

Figure 2: Main magnetic properties for the material ferrites, nanocrystalline and amorphous: Saturation vs. Temperature, Permeability vs. Frequency, and Saturation vs. permeability

The figure 2 presents the main properties of the nanocrystalline, ferrites and amorphous material. It shows fro instance that nanocrystalline material presents a higher saturation level and a higher permeability, and the saturation level remains stable in the working temperature range (up to 100 degree Celsius).

III. EXAMPLE OF SPACE MANAGEMENT: NANOCRYSTALLINE MATERIAL

The design of a CM filter was carried out because commercial off-the-shelf filters appeared to be inadequate for this application [5]. The design constraints of mechatronic applications limited the design freedom considerably: only a minimum space could be dedicated to the electromagnetic filter. The constructed filter resulted however in a radiated emission level which is near to the noise floor of the measurement equipment. The final common mode choke with nanocrystalline material and the final radiated emission level of the overall filter are presented in Figure 3.

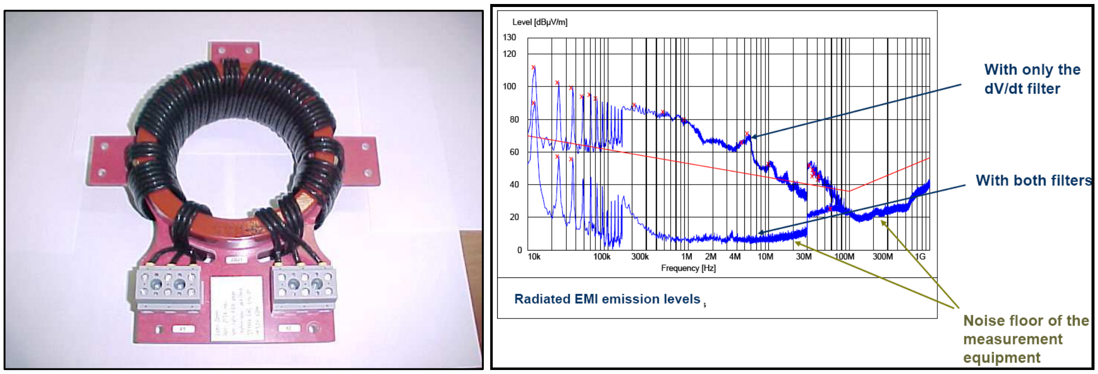

Figure 3: Final common mode choke with nanocrystalline material and final radiated emission level of the overall filter

The functional parameters are:

- direct drive motor, relatively open, in a harsh military environment,
- 440 V mains supply,
- ungrounded and no neutral (3 phases only)
- 15 kVA power consumption.

For the dV/dt filter (series inductors, capacitors between the lines) a commercial of the shelf filter was suitable and applied.
The key parameters for a high performance common mode choke in this application are: a high initial permeability, a high saturation level and a low dependence to the temperature. The common mode choke has to be as small as possible. The nanocrystalline material has been chosen with a high saturation level (above 1 T) and a high permeability (at least 25000 up to 100 kHz). The basic equation for toroidal cores is:

$$B_{sat} = \frac{\mu I_{CM} N}{2\pi R} = \frac{\mu_e \mu_o I_{CM} N}{l_e} \quad [\mathrm{T}]$$

With B_{sat} magnetic field strength, saturation
μ_e effective permeability
I_{CM} common mode current
N number of turns
l_e effective path length

The induction of this toroid inductance is

$$L = \frac{\mu_e \mu_o N^2 A_e}{l_e} \quad [\mathrm{H}]$$

With A_e effective area

We need a minimal flux density and a maximal induction. This can be achieved with a maximal effective path length l_e and maximal effective area A_e. Thus the maximal inductance per given core for a given common mode current can be found via

$$L = \frac{l_e A_e B_{sat}^2}{\mu_e \mu_o I_{CM}^2} \quad \text{[H]}$$

The CMC as depicted in Figure 2 has the required inductance of 40mH, can conduct at least 35 A and has spreading of less than 1 %. That means that 1% of 35 A, i.e. 0.35 A will be added to the 'unwanted' common mode current. The total common mode current should still be less than 1 A to avoid saturation. It is important to note that during saturation the inductance is decreased drastically, and then resonances and voltage overshoots occur which can damage the motor. For the feedthrough capacitors 4.7 nF was used, because 10 nF appeared to be too high and the frequency converter would go in overload. The radiated emission has been measured inside a (full-) anechoic chamber. In Figure 2 the measured levels is given for the set-up with only the dV/dt filter (top) and for both the filters together (bottom).

The volume of the core can be reduced by 50 to 80% when an appropriated ferrite is replaced by a well-chosen nanocrystalline core, as a result of its superimposed advantages of high permeability, high saturation and inductive behavior near CMC resonance.

IV. ALTERNATIVE DESIGN OF THE COMMON MODE CHOKES

To improve performance and efficiency in VSD (Variable Speed Drive) applications, the PWM (Pulse Width Modulation) is now a standard configuration for motor drive. The IGBTs inside the motor drive are switching with very fast transient to make the power dissipation as low as possible. At least these problems are emerging with the incorporation of these IGBT-based drives,

- The bearing of induction motor fails at a much higher rate than before;
- The life time of the bearing of induction motors is much shorter than before.
- The EMI measured is much severe than before.

These problems are caused by the fast-switching switches working asymmetrically. First, the fast transients brought by high dv/dt and di/dt are much stronger noise source. Secondly, the asymmetrical operation makes the bearing fail due to the high amplitude CM (Common mode) voltage.
Passive solutions are widely accepted by industry due to its simplicity. The disadvantages are that the values of by-pass capacitors are limited by the safety requirements. Therefore, the suppression relies on the CMC (Common Mode Choke).

To create blocking impedance Z at certain interesting frequency f, the inductance L needs

$$L \geq \frac{Z}{2\pi f}$$

For high CM current, the volume requirement of CMC is quite large to avoid saturation. [6]

$$l_e A_e \geq \frac{L \mu_e \mu_o I_{CM}^2}{B_{sat}^2} \quad [\mathrm{m}^3]$$

The winding window has this limitation

$$A_w \geq \frac{I_{rms}}{J_{\max}} \quad [\mathrm{m}^2]$$

The volume requirement satisfies

$$Vol \approx k(A_e A_w)^{3/4}$$
$$k \approx 10.776 \cdot 10^{-2} (\mathrm{dm}^3)$$

Ideally, to completely cancel the CM voltage and CM current, the CMC needs to provide infinite impedance which is not feasible. Therefore, cancelling by passive approach is inadequate.
An active approach is proposed in [7] to suppress the CM voltage generated in VSD system. The strategy is trying to suppress both the transient slope and amplitude of CM voltage using only one additional inverter leg. The diagram of this approach is shown in Figure 4.

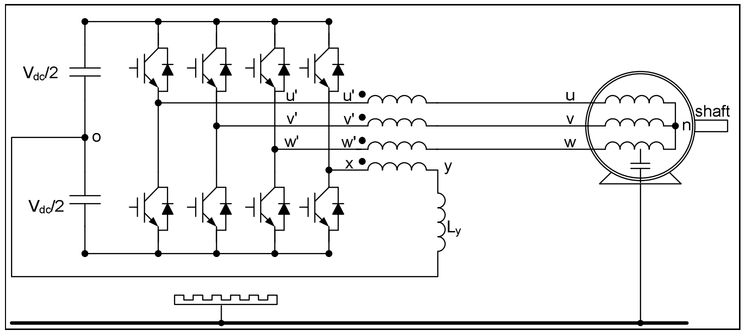

Figure 4. The diagram of the fourth leg approach

Compare to the passive solution, to generate V_{CM} in L_1, the dimension of the transformer is determined by the amplitude of integration of V_{CM}. For the minimum PWM switching frequency f_{sw} of the IM drive, this equation follows [8]:

$$L_{\min} = \frac{V_{DC}}{8 f_{sw} * I_{\mathrm{m}ax}},$$

The benefit using active method is that the noise can be eliminated completely if the compensation is perfect. The minimum inductance is set to avoid the saturation but not to create infinite impedance. Therefore, the volume requirement of the CMC can be much smaller.

V. CONCLUSION

The design of the common mode filter is an important aspect of the weight and space management of an aerospace system. Designable parameters and material properties have been detailed. Two examples of applications allowing a significant reduction of space have been presented.

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