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The issues with noisy magnetic cores and how to solve them

Everybody who uses soft magnetic cores has experienced noise. The most common is the hum of transformers in the 50Hz net, and a power transformer with a laminated steel core can easily achieve 70dB. Where does this noise come from? Why is it sometimes negligible? And, why does it sometimes reach an unacceptable level?

To understand the cause of this noise, we have to discriminate between two different sources – the noise created by the action of magnetic flux within soft magnetic core and the noise created by magnetic flux when it is present between or outside of the core, especially between core parts or within the windings.

Magnetic flux within the core

When a material has high permeability and there is no gap in the magnetic path, and no significant stray flux due to saturation or flux bypasses, then the only source of noise in a component is magnetostriction. This is a material property that describes a change to the material's shape or dimensions during the process of magnetisation. This is normally defined as the fractional change in length (in ppm) as the magnetisation increases from zero to its saturation value.

$$\lambda_S = \frac{\Delta l}{l}(M = 0 \rightarrow M_S)$$

Magnetostriction can be positive and negative – the value for typical soft magnetic core material can reach 50ppm. For example, in a magnetic core with a magnetic path length of 10cm it reaches a change in length of 0.5µm. This appears to be a negligible size difference, but actually creates a remarkable noise – even for 1ppm. Since the volume of a core remains constant upon magnetisation, the core 'breathes', not only in the direction of the field, but in all directions (Fig. 1). This effect cannot be avoided by design or mechanical measures.

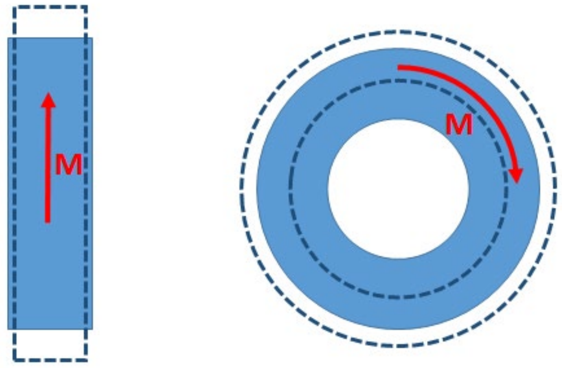

Fig.1: Schematic shape change of a rod and a toroid upon magnetisation due to positive magnetostriction (solid line – no magnetisation, dashed line – with indicated magnetisation)

The only ways to reduce noise caused by the magnetostriction of the core material is either to envelop it with any noise-damping shell, which requires a large volume of material added to the component, increasing its size and weight, or by using a material with zero magnetostriction (zero actually means <1ppm), such as Permalloy (when the Ni-content is 80-82wt% in the austenite Ni-Fe system) or most commercial Co-amorphous materials. These materials have low saturation induction and are expensive; however, there are more cost-effective options, such as the FT-3 type Fe-based nanocrystalline material (for example Acal BFi's kOr 120).

It is worth noting that zero magnetostriction of Fe-based nanocrystalline material can be tuned exactly by material composition and heat treatment. However, more than a 0.2% difference in composition, or few degrees deviation in process temperature, can shift magnetostriction to significant values of >1ppm, so it is a matter of process stability to ensure real 'near-zero' magnetostriction.

Magnetic flux outside the core material

The other major noise source in a component is from magnetostatic forces between different parts of a core, and/or force between the core and the winding.

When different parts (assembled cores such as U/I or E/E cores) are magnetised and external flux is created in the gaps, then each part acts as an electromagnet (Fig. 2) and creates a force towards the other parts. Since the flux density is usually high and the distance between parts is small, the force is enormous. Movement in the sub-micrometre range cannot be avoided completely, even when the parts are pressed together with high force (by straps, for instance), are potted or agglutinated.

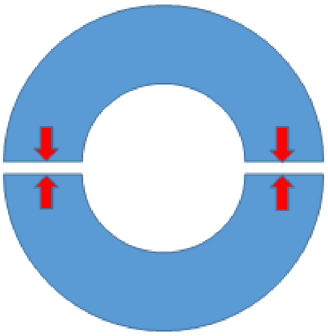

Fig. 2: Schematic displacement of core parts upon magnetisation, additional to the before shown (fig. 1) shape change.

For laminated cores, there are forces between the sheets / ribbons when the flux leaves them. Unfortunately, it is impossible to guide the flux along the lamination sheets, especially at the end of the sheets. Actual core properties such as filling factor, lamination thickness and material between laminations determine the noise level here.

Component assembly can have a huge influence on the noise. For example, when stray flux penetrates the wire winding, Lorentz force moves the winding in relation to the core, causing noise. When assembling a component, the designer should avoid placing windings in areas with significant stray flux where possible, because this increases the noise caused and is also a source of power loss. The mechanical properties of glue or potting mass can also influence the noise level and tone. Testing different substances and processes during the prototyping phase will help you gain the best results for a given design.

How to measure noise in your magnetic component

Testing noise levels is complex and the actual noise created depends on many parameters, each influencing the others. This is probably the reason why no testing standard exists today, but designers, and especially users, still need to be able to understand and quantify the noise level of a magnetic component, to compare different designs, materials or manufacturers.

Although a consistent method has yet to be agreed, there are techniques component designers can use to characterise noise in an objective manner. Designers can measure the noise level at a defined distance in each direction away from the component, for one excitation frequency and level. Then, using different excitation frequencies and levels through the complete operational range, a comprehensive measurement of the noise produced can be obtained.

If there is no interaction between the noise created by different excitation frequencies and sources, you could calculate the resulting noise for any direction using these contributions. However, normally there are a superposition of frequencies / signals which interact, so to gain precise results it is useful to measure the noise level in a selection of different directions under the component's final operational conditions. Usually microphone arrays in special test chambers are used, giving a comparable value as long as the operational conditions are constant and the noise is stable against small changes of conditions.

An additional useful, although complex, measurement technique which can be used to assess the origin of the noise (the displacement of surfaces) is laser interferometry. With 3D interferometry you can visualise these displacements (for simple low frequency movement modes), enabling a designer to detect the main sources of movement and change the exact element of the component creating noise.