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Organizer:
FEN Research Campus

Grain Oriented Electrical Steel for Medium Frequency Power Converter Applications

Motivation of the work

A new generation of transformers is pushed forward by improvement in power electronic components now able to switch high electric power in the kHz range. Those transformers will need a magnetic core if galvanic insulation is required. Two main classes of magnetic materials can be considered for such applications involving a single direction of magnetization :

- The well established mass product Grain Oriented ELectrical Steel offers high permeability and high magnetic polarization in the few kHz range for thinnest 180 µm grades. GOES is either cut into laminations and stacked or wound to form a magnetic core. The embedded mineral insulation enables operation up to 400°C with low influence on magnetization.
- New magnetic materials as nanocrystalline ribbons of 20 µm thickness offer operation up to hundreds of kHz and low magnetic polarization level. It is mainly shaped as wound cores. Magnetization is very sensitive to temperature.

The two materials are expected for respectively enabling compact design of a core for serving the same energy transfer but involving then a different optimization route. GOES will favour a high induction level when nanocrystalline will most likely operate at higher frequency.

GOES efficiency has been placed under assessment in comparison to nanocrystalline soft magnetic material and Non Grain Oriented Electrical Steel in order to state about its relevance for building Solid State Transformer cores. Interest of NGO stands in its lower permeability and higher resistivity (up to 6.5%) compared to GOES which reduce skin effect at high frequency. Technique and economics are both to be considered in this analysis.

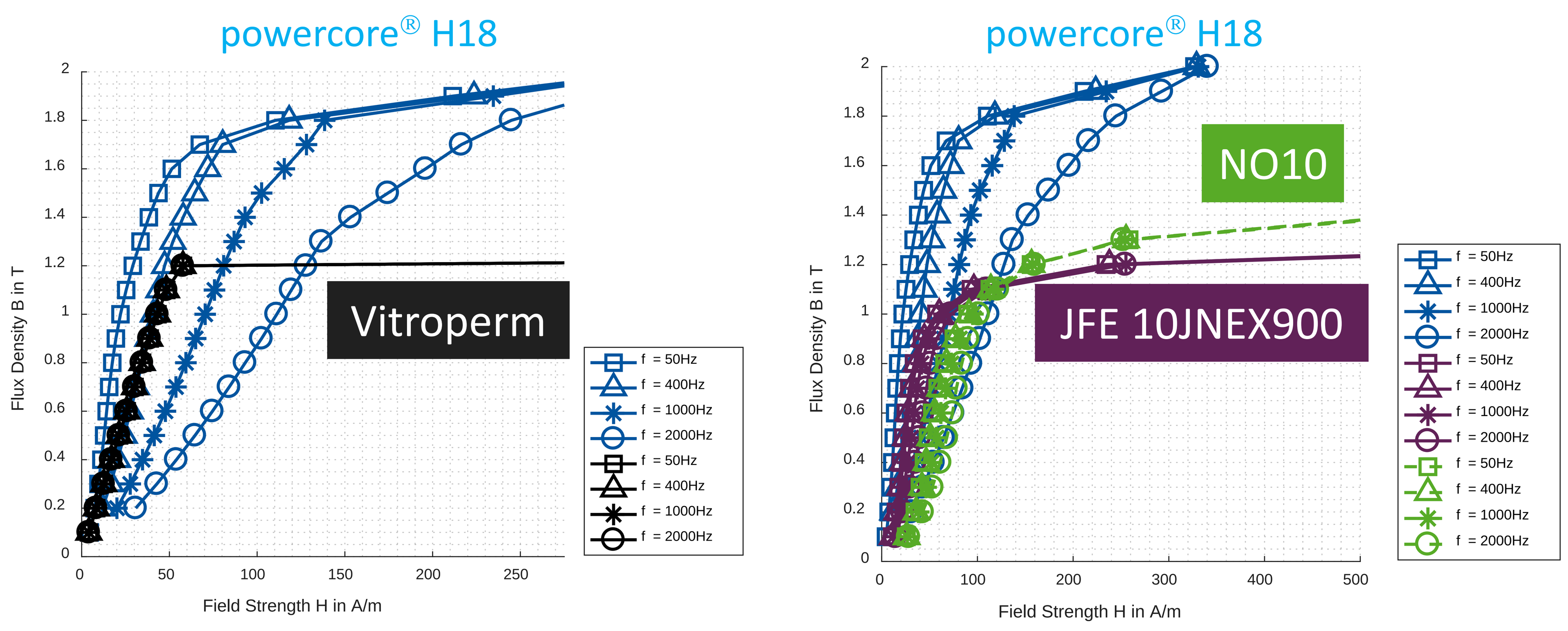

Fig. 1: Magnetizing behaviour of various materials and frequencies under sinusoidal magnetization.

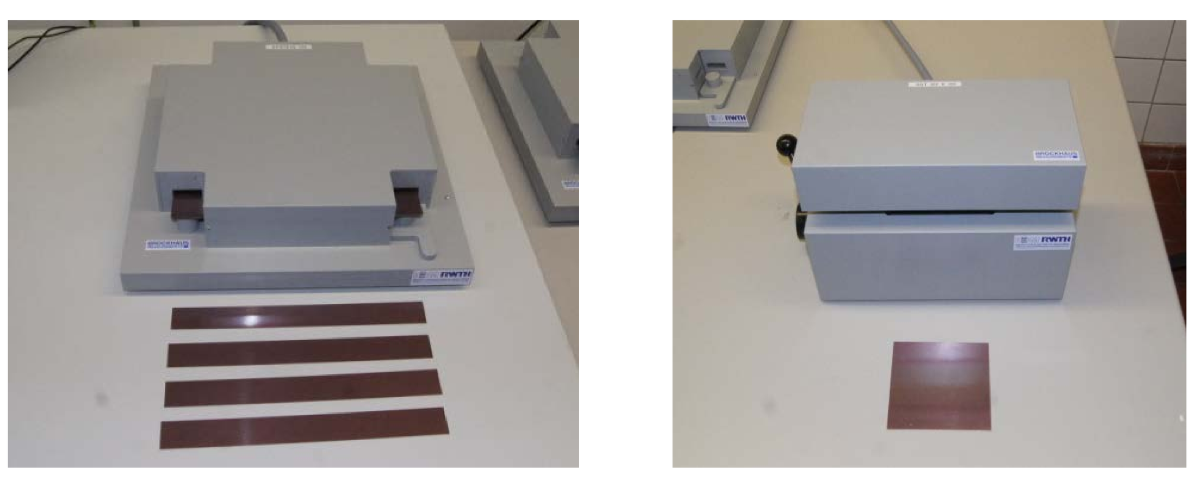

Fig. 2: Epstein frame and Single Sheet Tester (SST)

First trends

Many information has to be taken into account for tailoring a core, the primary ones being magnetising characteristics, losses and a performance factor $\mathcal{F}$. The latter is related to the compactness of the core and is obtained by multiplying the maximum reachable peak flux density *B* with the frequency *f*.

$$\mathcal{F} = B \times f \quad (1)$$

The IEM performed measurements with standardized Epstein frames or a ring coil testing module according to DIN EN 60404-2 and DIN EN 60404-6 (Fig. 2).

Arbitrary flux density wave forms can also be applied for emulating converter applications. This will be specifically needed for core dimensioning when coming to the effective applied voltage regime to be used by the converter (e.g., DAB3).

The magnetising characteristics plotted for various materials and frequencies at Fig. 1 show that GOES offers a high permeability (slope of B-H curve) up to 1.5 T for a frequency of 1 kHz and that at 4 KHz the permeability dropped down compared to the other measured materials but high polarisation levels are still reachable compared to others.

The performance factor helps at refining the choice in comparing GOES to one of the best candidate in magnetising current, e.g. nanocrystalline.

In this regard, the performance factor plotted at Fig. 3 indicates an advantage for GOES up to 1.5 kHz considering a maximum power loss density of 40 W/kg.

This figure is only taking into account the core performance. Costs of raw materials and energy consumed by power electronic should be taken into consideration for higher frequency and induction cases.

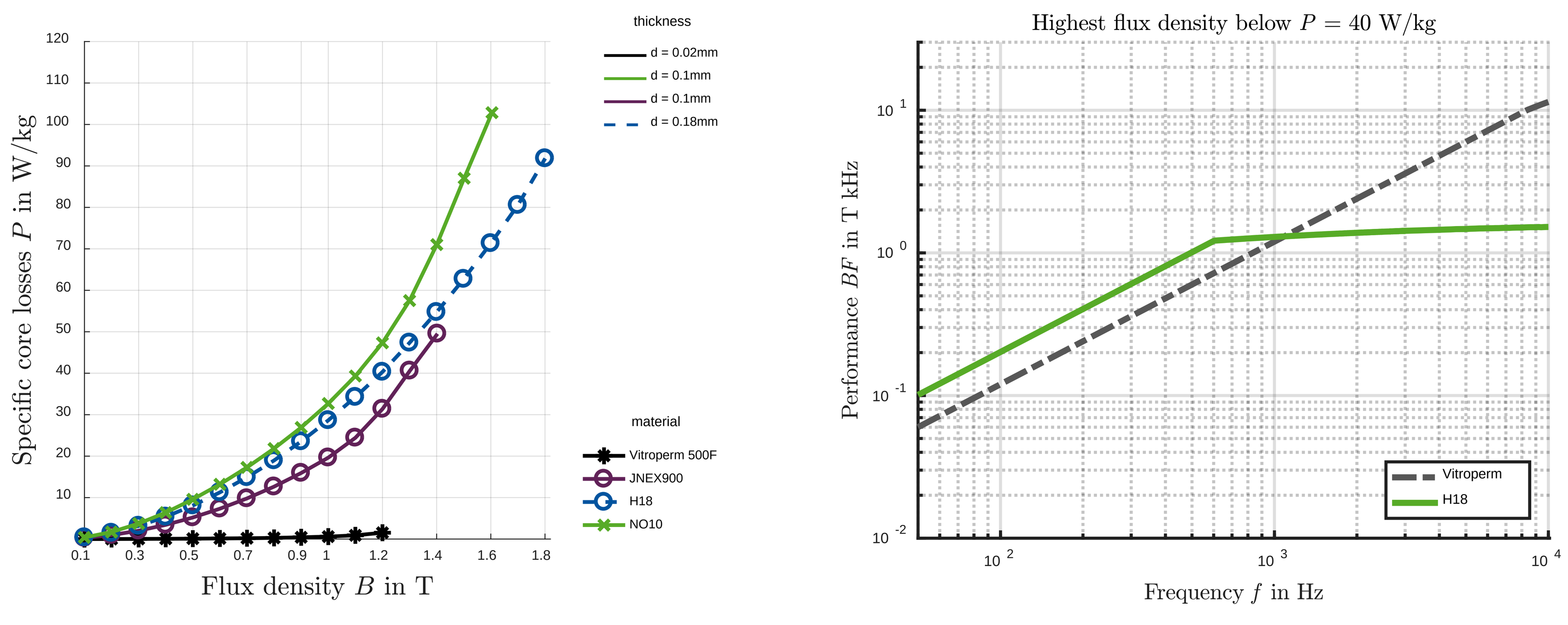

Fig. 3: Specific losses at f = 1 kHz (a) and maximum flux density as function of *f* for limited losses (b).

Conclusions

- Transformers and inductors for high power applications can be made compact by increasing frequency or/and flux density.
- The choice of grain oriented electrical iron combines high flux densities for a realistic switching frequency range of power electronic components. The low magnetizing current at high flux density allows a compact design.
- The grain oriented material powercore® H18 has a useful range up to *f* = 1.5 kHz and up to saturation flux density.
- The higher price of nanocrystalline material may prevent economic designs in high power applications.
- Reduced efficiency at higher frequencies due to increased switching losses of power electronic shall be considered.

Acknowledgement

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