MAGNETIC MATERIALS FOR CURRENT TRANSFORMERS

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ABSTRACT

At CERN, the circulating beam current measurement is provided by two types of transformers, the Direct Current Current Transformers (DCCT) and the Fast Beam Current Transformers (FBCT). Each type of transformer requires different magnetic characteristics regarding parameters such as permeability, coercivity and shape of the magnetization curve. Each transformer is built based on toroidal cores of a magnetic material which gives these characteristics. For example, DCCTs consist of three cores, two for the measurement of the DC component and one for the AC component. In order to study the effect of changes in these parameters on the current transformers, several interesting raw materials based on their as-cast properties were selected with the annealing process used to tune their properties for the individual needs of each transformer. First annealing tests show that the magnetization curve, and therefore the permeability, of the material can be modified, opening the possibility for building and studying a variety of transformer cores.

CURRENT TRANSFORMERS AT CERN

96 Current Transformers

22 DCCTs 74 FBCTs

And spares:
6 for DCCTs, 22 for FBCTs

What is inside?

Magnetic cores made out of wound soft magnetic material

DCCTs: three magnetic cores
FBCTs: one magnetic core

What do we need?

- ✓ B-H curve adapted for each transformer
- ✓ DCCT: coercivity around 3 $A \cdot m^{-1}$
- ✓ High permeability
- ✓ Controlled power losses
- ✓ Low Barkhausen Noise [1]

OBJECTIVES

Fabrication of different sized cores

Obtain the ability to tune the magnetic properties

Study the influence of these parameters on the transformer's performance and resolution

PARAMETERS UNDER STUDY

Parameter	Why?
Ribbon thickness	Affects Eddy currents [2]
Power losses	Heats up the core [3]
Shape of B-H curve	Influences response
Barkhausen Effect	Influences resolution [4]

MATERIALS

Materials that comply with the required characteristics are soft ferromagnetic alloys [3]:

- ✓ Permalloys (80 % Ni + 20 % Fe)
- ✓ Alloys of 80 % Fe and/or Co + 20 % B, Si, C
  - Amorphous
  - Nanocrystalline

Tuning of B-H curve : thermal treatment with or without magnetic field

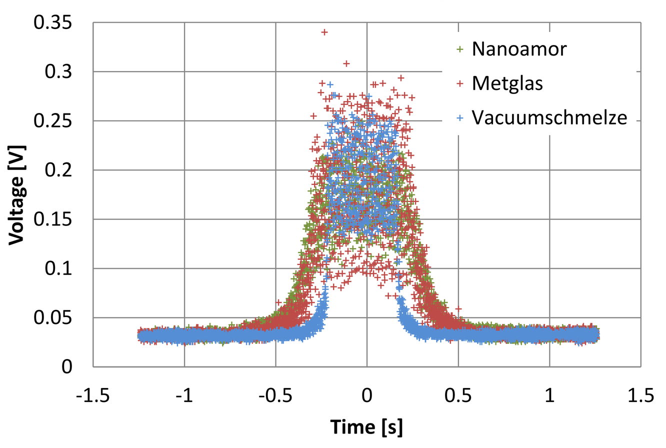
Thermal treatment under crystallization temperature to maintain structure

Origin	Type
China - Yanqin	Iron-based amorphous
	Iron-based nanocrystalline
USA - Nanoamor	Cobalt-based amorphous
Germany - Vacuumschmelze	Cobalt-based amorphous (VAC 6025)
Germany - Metglas	Cobalt-based amorphous (Metglas 2705 M)

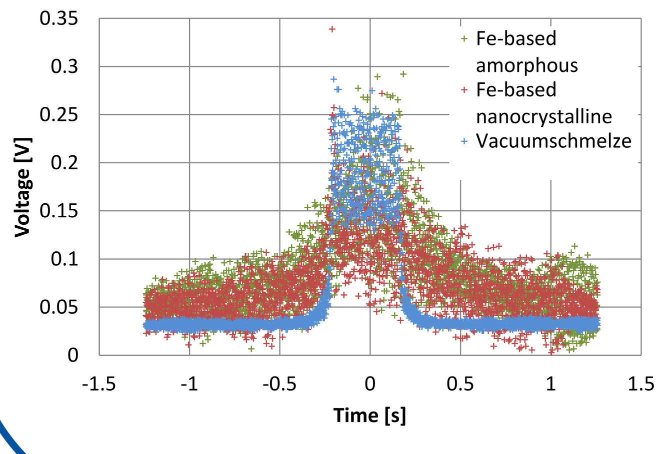
TESTS

Barkhausen Noise (BN)

- BN was measured and compared with a triangular pulse wave



Co-based amorphous alloys

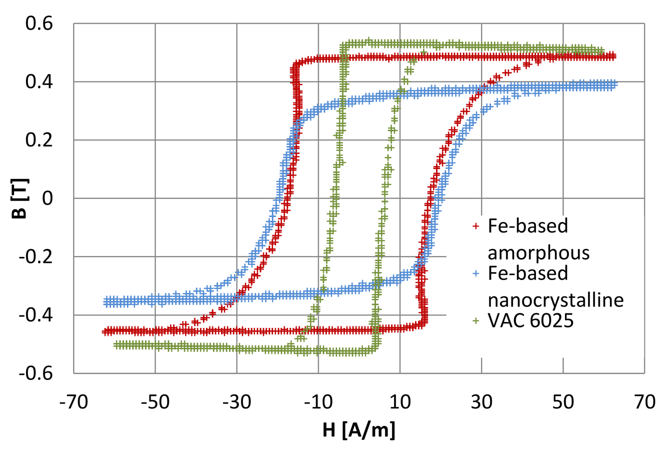


Fe-based amorphous alloys vs VAC 6025

- Iron-based alloys present higher BN than the cobalt-based alloys
- Cobalt-based alloys: less BN

B-H curve and permeability

- B-H curves were measured at 200 Hz
- Permeability was calculated from the inductance value measured with an impedance analyser

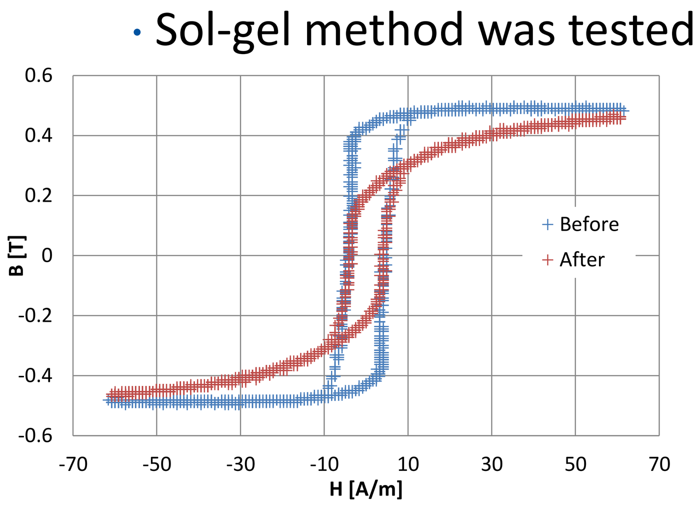


Type	Max. relative complex permeability
Iron-based amorphous	2650
Iron-based nanocrystalline	4200
Nanoamor	134 000
VAC 6025	64 000
Metglas 2705 M	173 000

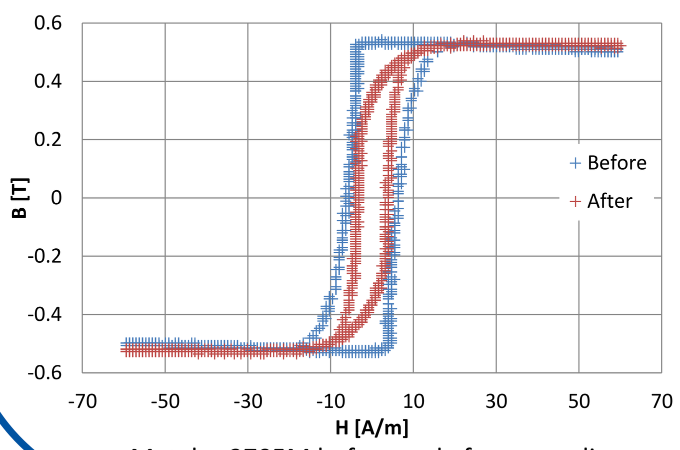
- Iron-based alloys present too low permeability to be used for transformer cores
- Cobalt-based alloys: good candidates

Annealing and insulation

- Annealing: under vacuum at 250 °C during one hour
- Sol-gel method was tested as insulation



VAC 6025 before and after annealing



Metglas 2705M before and after annealing

- No differences in B-H curves between non-insulated and insulated cores → need to study insulation further
- Rounding effect after annealing

CONCLUSIONS & OUTLOOK

- ✓ Iron-based alloys: low permeability, high coercivity → Not the best option
- ✓ Cobalt-based alloys: good characteristics
- ✓ Further study on insulation required
- ✓ Study annealing process: with/without magnetic field, time, temperature, etc.

REFERENCES

[1] P. Odier, DCCT Technology Review, Workshop on DC Current Transformers and Beam-Lifetime Evaluations, Lyon, p. 3, December 2004, http://inspirehep.net/record/672655
[2] K.Unser, Beam Current Transformer with DC to 200 MHz Range, Particle Accelerator Conference, Washington D.C., (1969)
[3] G. Bertotti, *Hysteresis In Magnetism*. (San Diego: Academic Press 2008)
[4] P. Kottman, Theoretical and Experimental Investigation of Magnetic Materials for DC Beam Current Transformers. PS/BC/Note 97-06