# MAGNETIC MATERIALS FOR CURRENT TRANSFORMERS

Silvia Aguilera - CERN, Geneva, Switzerland

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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

→ Thermal treatment under crystallization temperature to maintain structure

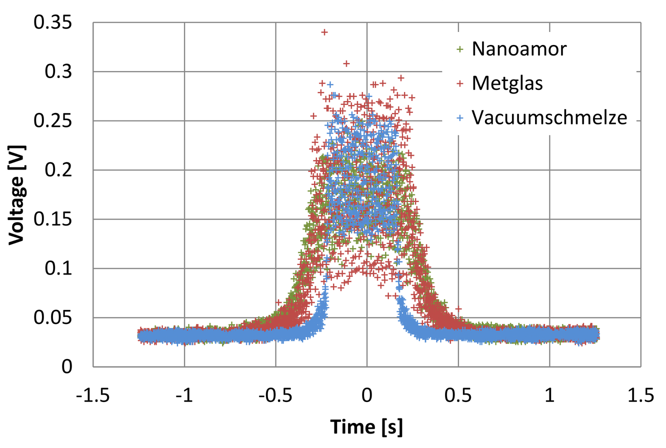
Tuning of B-H curve : thermal treatment with or without magnetic field

| 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) |

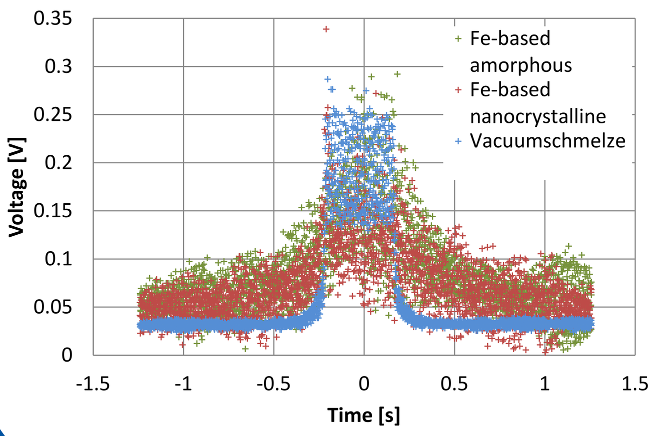
## TESTS

### *Barkhausen Noise (BN)*

- BN was measured and compared with a triangular pulse wave




Co-based amorphous alloys

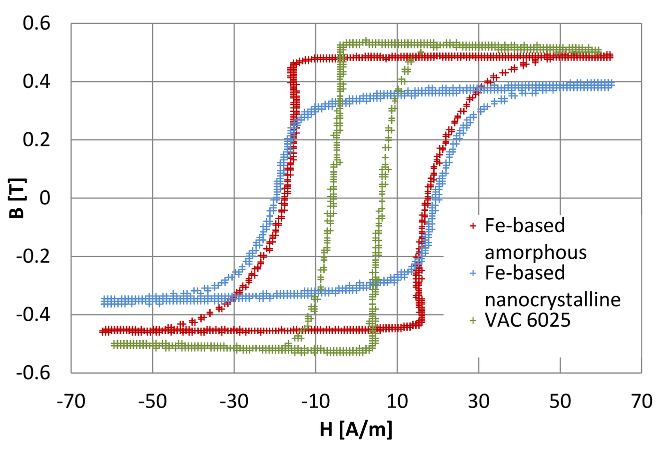



Fe-based amorphous alloys vs VAC 6025

- 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

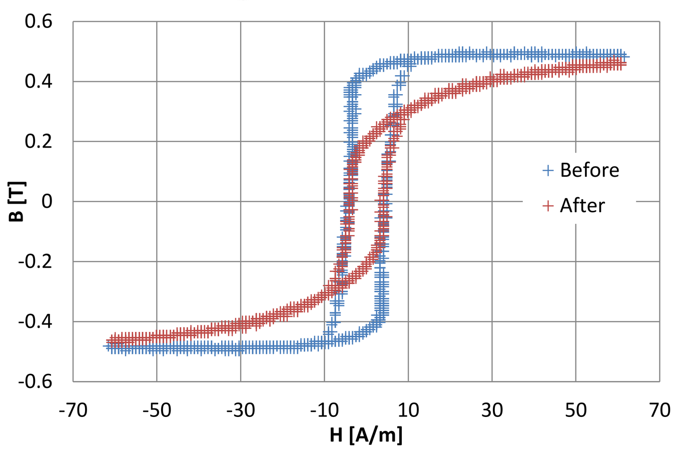



| Type | Max. relative complex permeability |
|---|---|
| Iron-based amorphous | 2650 |
| Iron-based nanocrystalline | 4200 |
| Nanoamor | 134 000 |
| VAC 6025 | 64 000 |
| Metglas 2705 M | 173 000 |

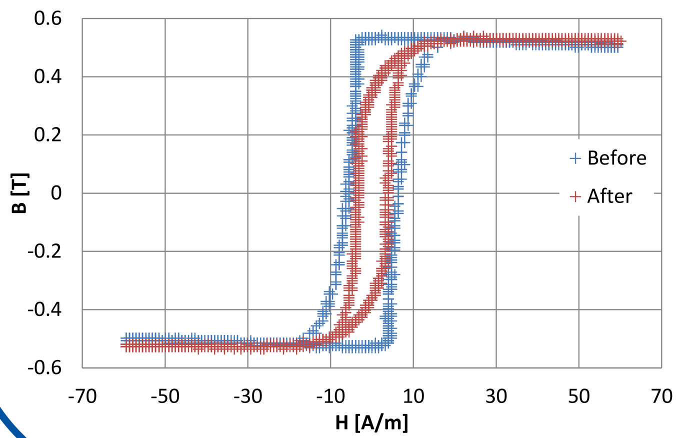
- Iron-based alloys present too low permeability to be used for transformer cores
- Cobalt-based alloys: good candidates

### *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 & ACKNOWLEDGMENTS

Acknowledgments: Patrick Odier and Romain Ruffieux

[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