Selection and annealing of magnetic materials for transformer cores

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BI Day

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Summary

- Introduction
- Objectives
- Materials
- Testing & Production
- Results
- Outlook & Conclusions

Introduction

- Current transformers

Measure the intensity of the beam using magnetic toroids

Types :

- DC Current Transformers (DCCTs) → 10 kHz
- Fast Beam Current Transformers (FBCTs) → 100 Hz - 1 GHz

In development!

- Integrating Current Transformer (ICT) → 100 Hz - 100 MHz

Introduction

Big procurement problem

Problems

Challenges

Spare magnetic cores

Building new transformers

Cores
- Cost
- Specific properties
- Pairing

Raw material
- Minimum Order Quantities
- Base properties
- Potential properties

Introduction

- Solution

Build our own cores!

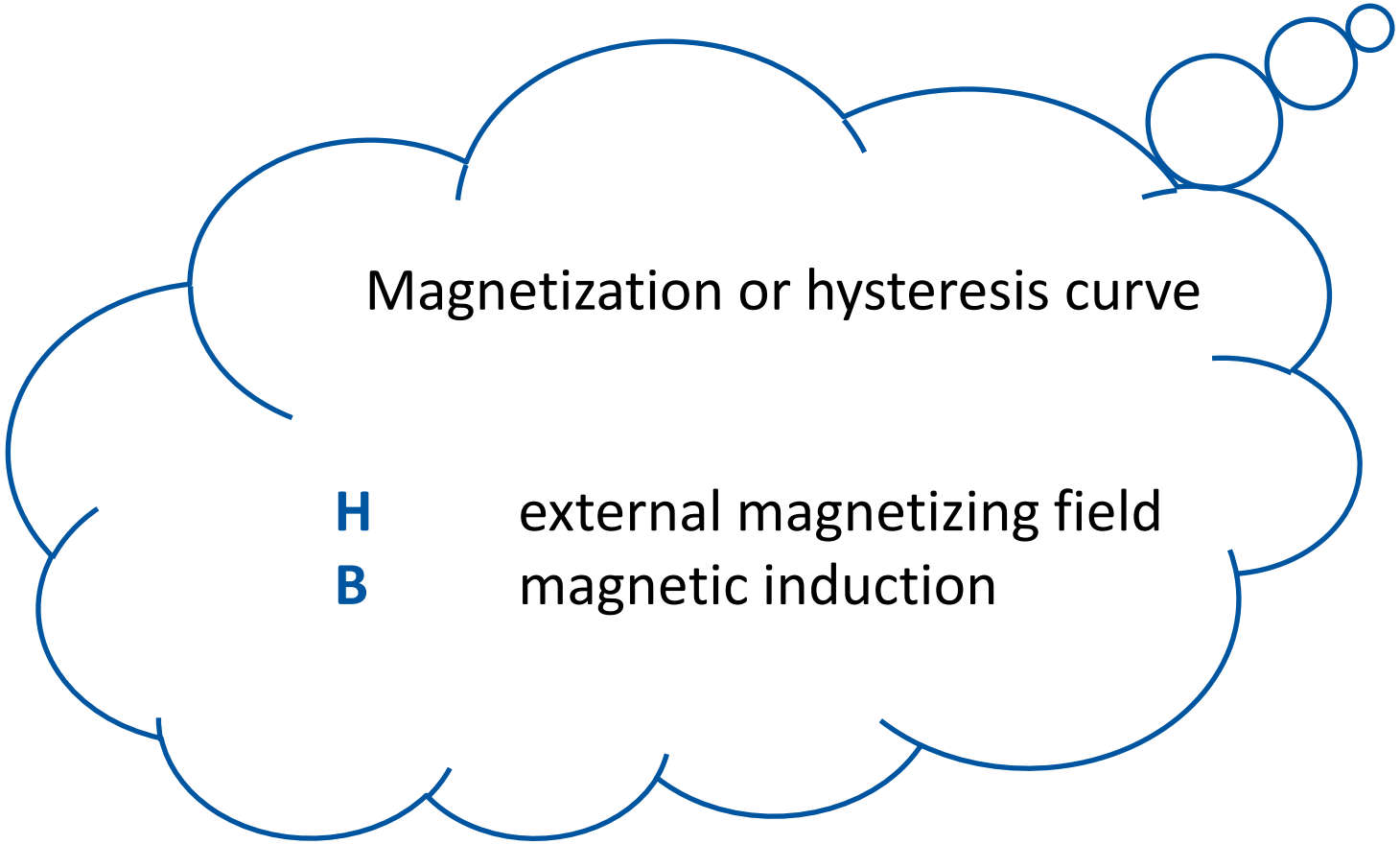
- Things to tackle:

- Choice of material
- Thermal treatment
- Insulation

Introduction

Requisites

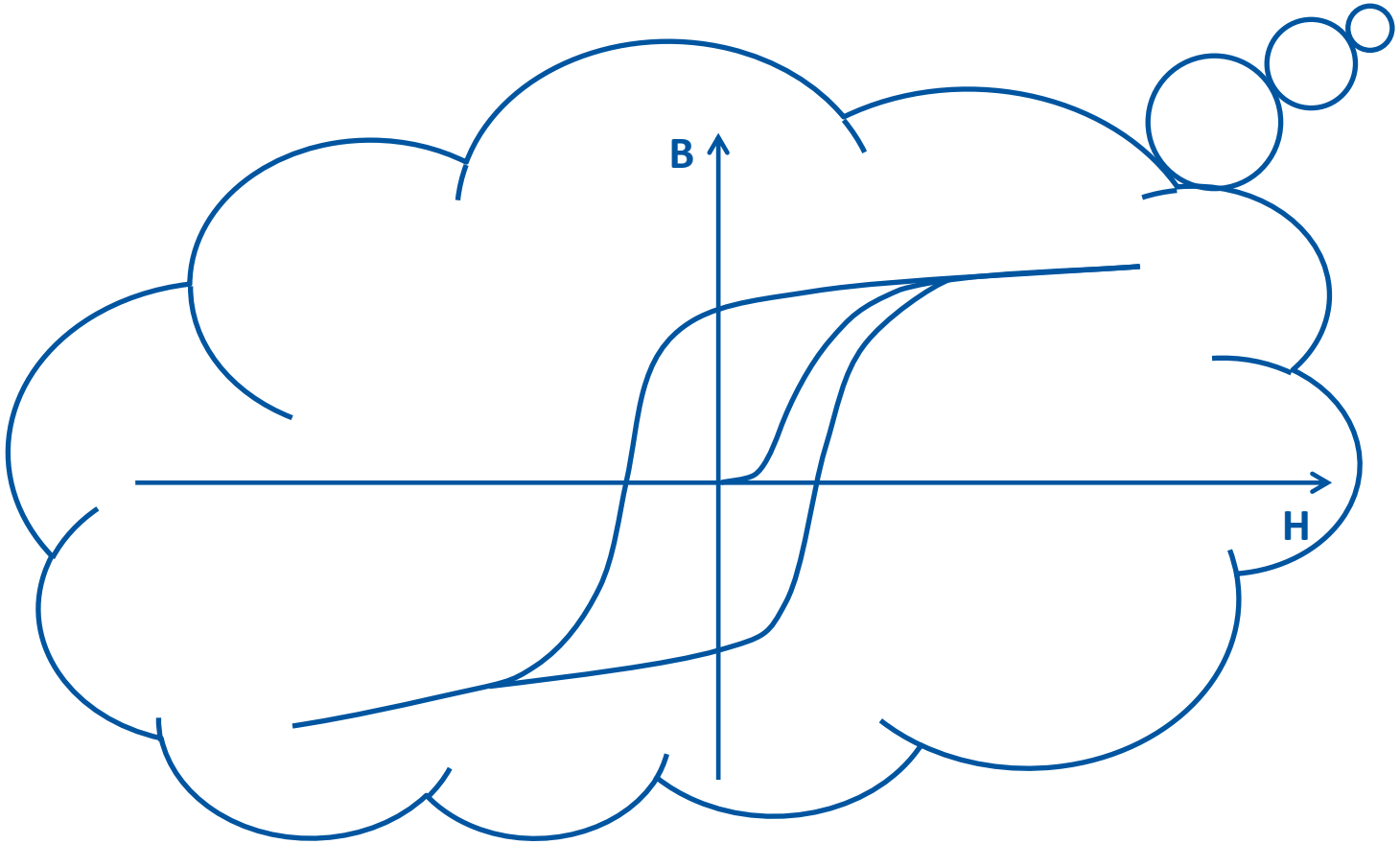
- Different transformers → different B-H curves



Introduction

Requisites

- Different transformers → different B-H curves



Introduction

Requisites

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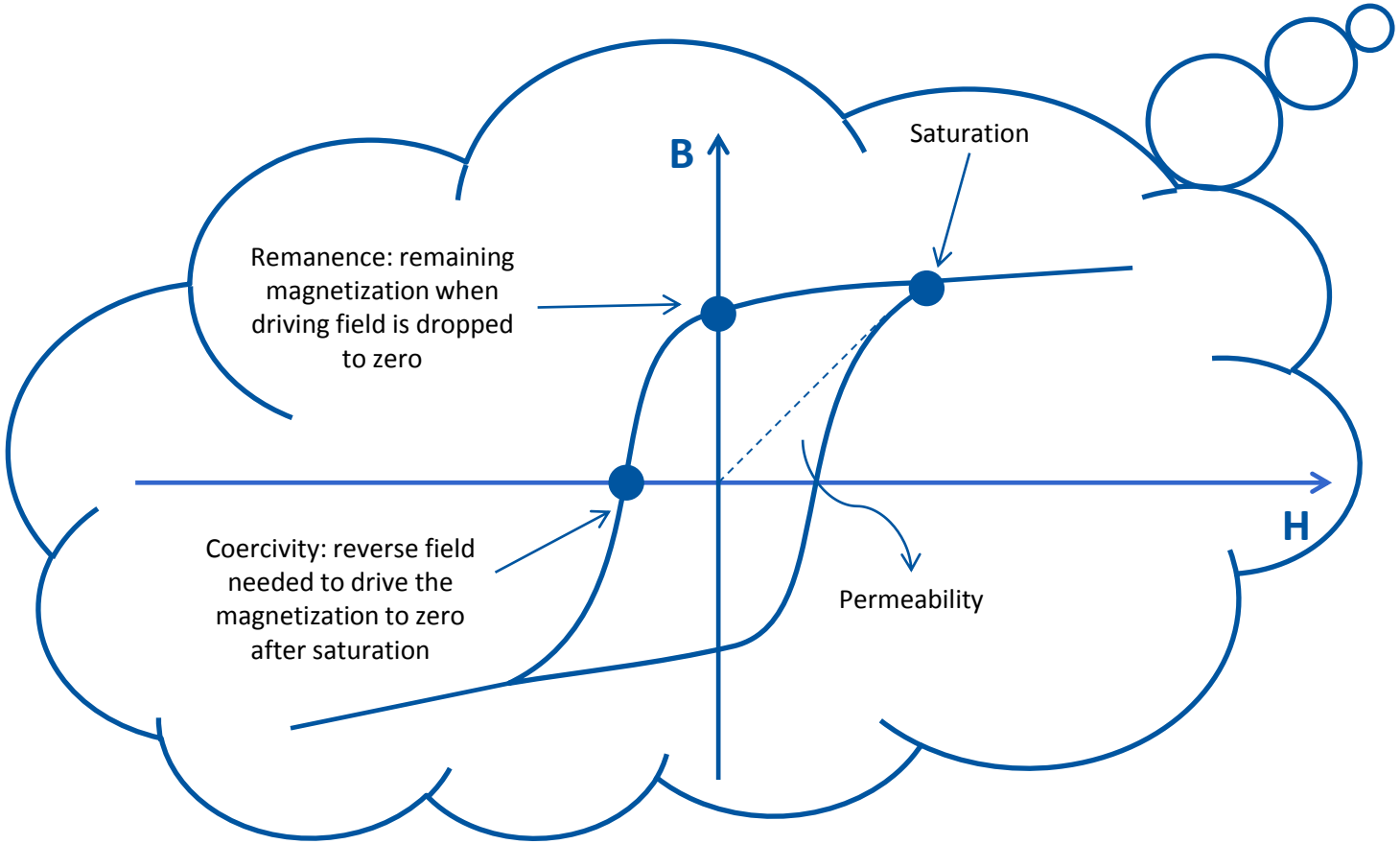
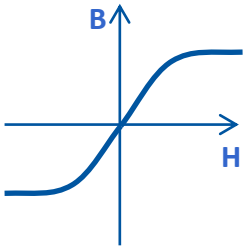


Introduction

Requisites

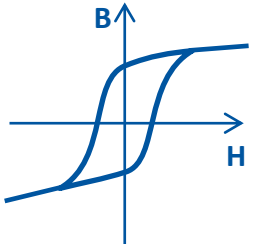
- Different transformers → different B-H curves
- FBCTs:



flat curve

not very high permeability

- DCCTs:

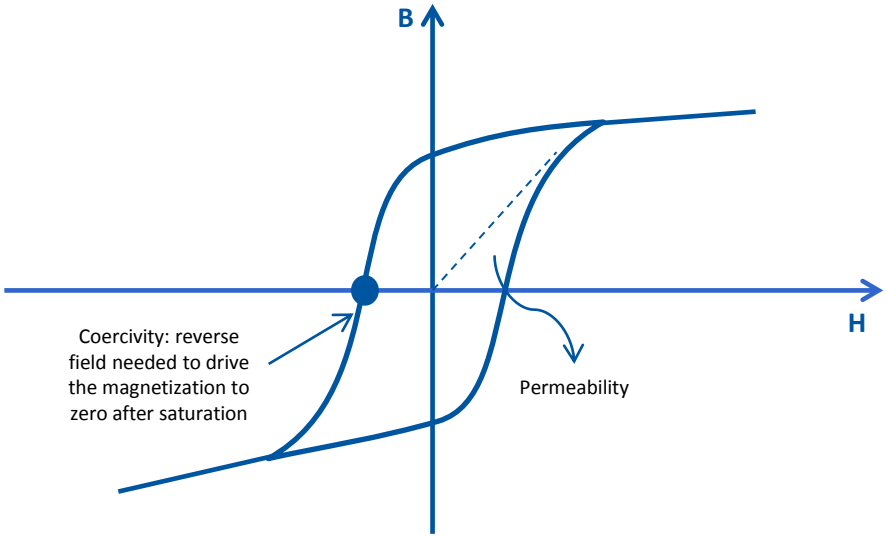


rounded curve

high permeability

Introduction

What are we looking for?



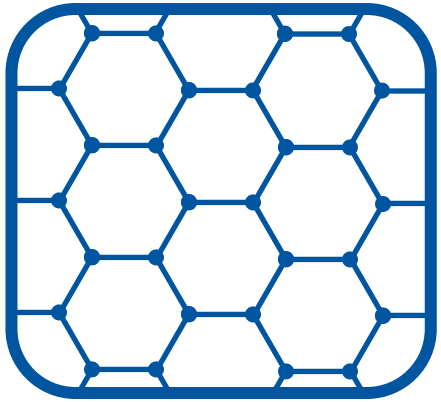
	FBCT	DCCT	ICT
Permeability (@ 10 kHz)	50 000 - 100 000	100 000	50 000
Coercivity [A/m]	As low as possible	~ 3	~ 3

Introduction

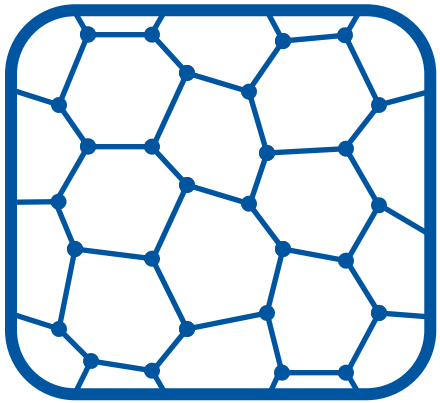
What are we looking for?

Special Co-based or Fe-based alloys…

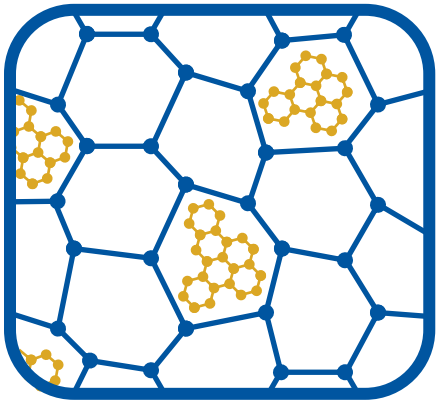
Normal alloy



Amorphous



Nanocrystalline



Objectives

- Find alloys to suit the desired magnetic properties for transformer cores
- Find the parameters for the heat treatment to tailor these properties

Materials

- Ribbons

Metallic Alloys:

- Amorphous Cobalt-based x 2
- Amorphous Iron-based
- Nanocrystalline Iron-based

Thickness ~ 25 μm

Width = 10 mm

Materials

- Price comparison

Origin	Material	Price [CHF/kg]
China	Fe-based amorphous	9
	Fe-based nanocrystalline	9
	Nanocrystalline “high quality”	22
USA	Co-based amorphous	214
Germany	Co-based amorphous (VAC 6025)	392
Germany	Co-based amorphous (2714A)	479

Testing

- Materials - manufacturing cores

- Creation of cores to test the material
- Characteristics:
  - $\varnothing_{outside}$ ~ 45 mm
  - ☐ Section 10 mm x 10 mm

Testing

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- **Testing**
- Production
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- Outlook
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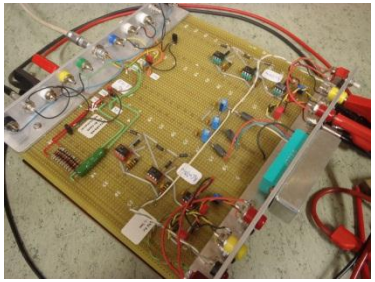
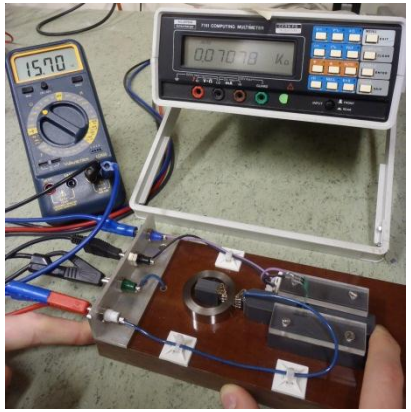
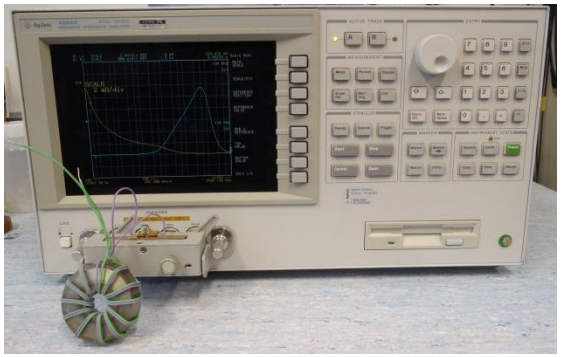
- Measurements





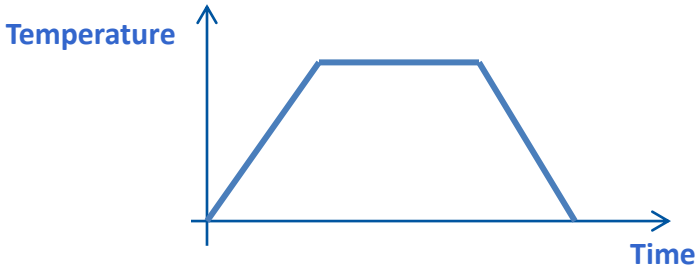
- B-H curve
- Resistance of section
- Impedance



- Ferrofluid: magnetic nanostructure

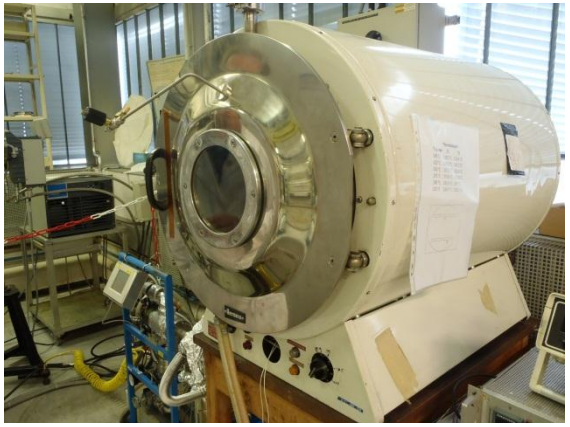
Production

- Annealing



What for?

- Relieve internal stresses
- Change B-H curve



Magnetic annealing → change B-H even more

Production

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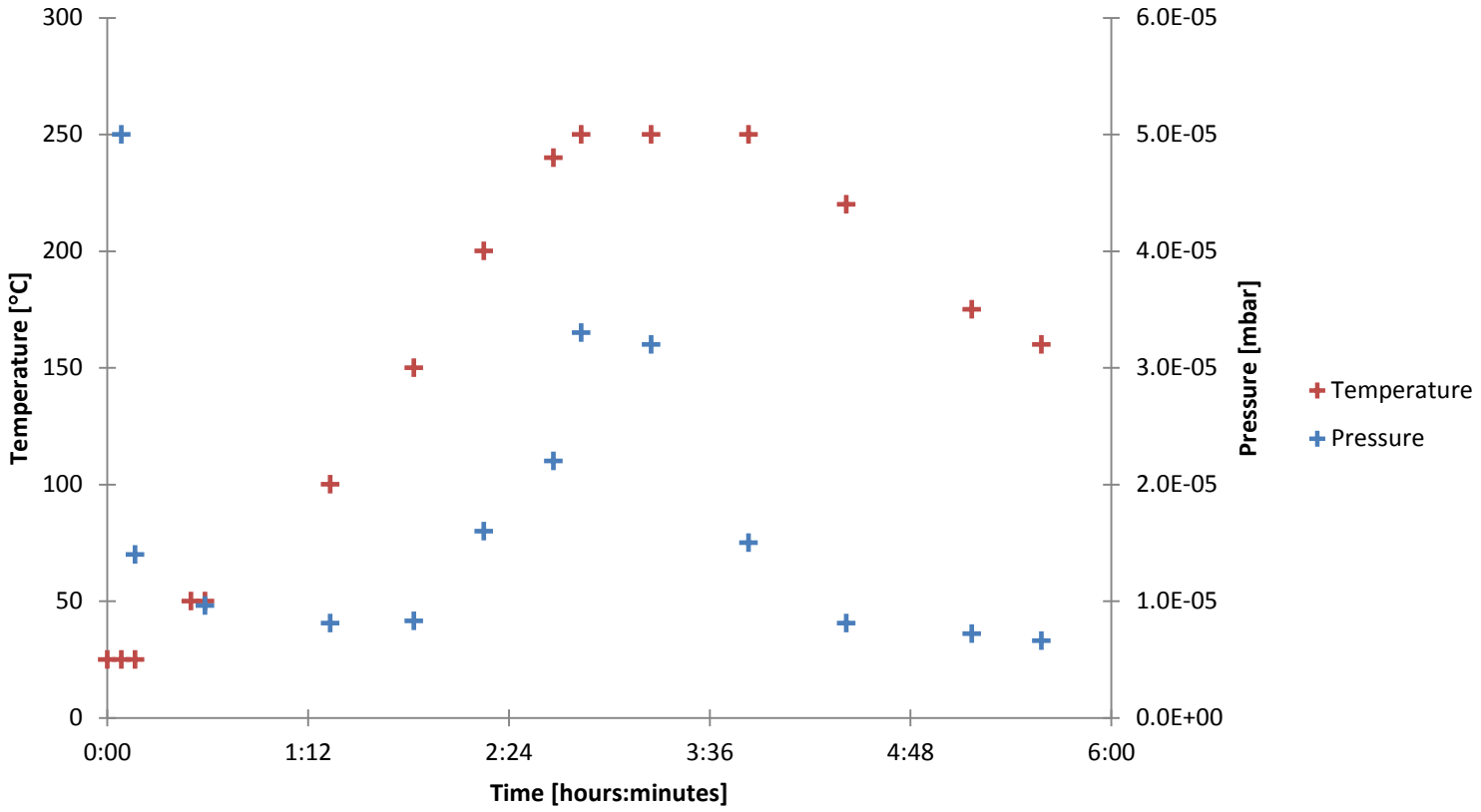
- Annealing - Temperature, pressure



Production

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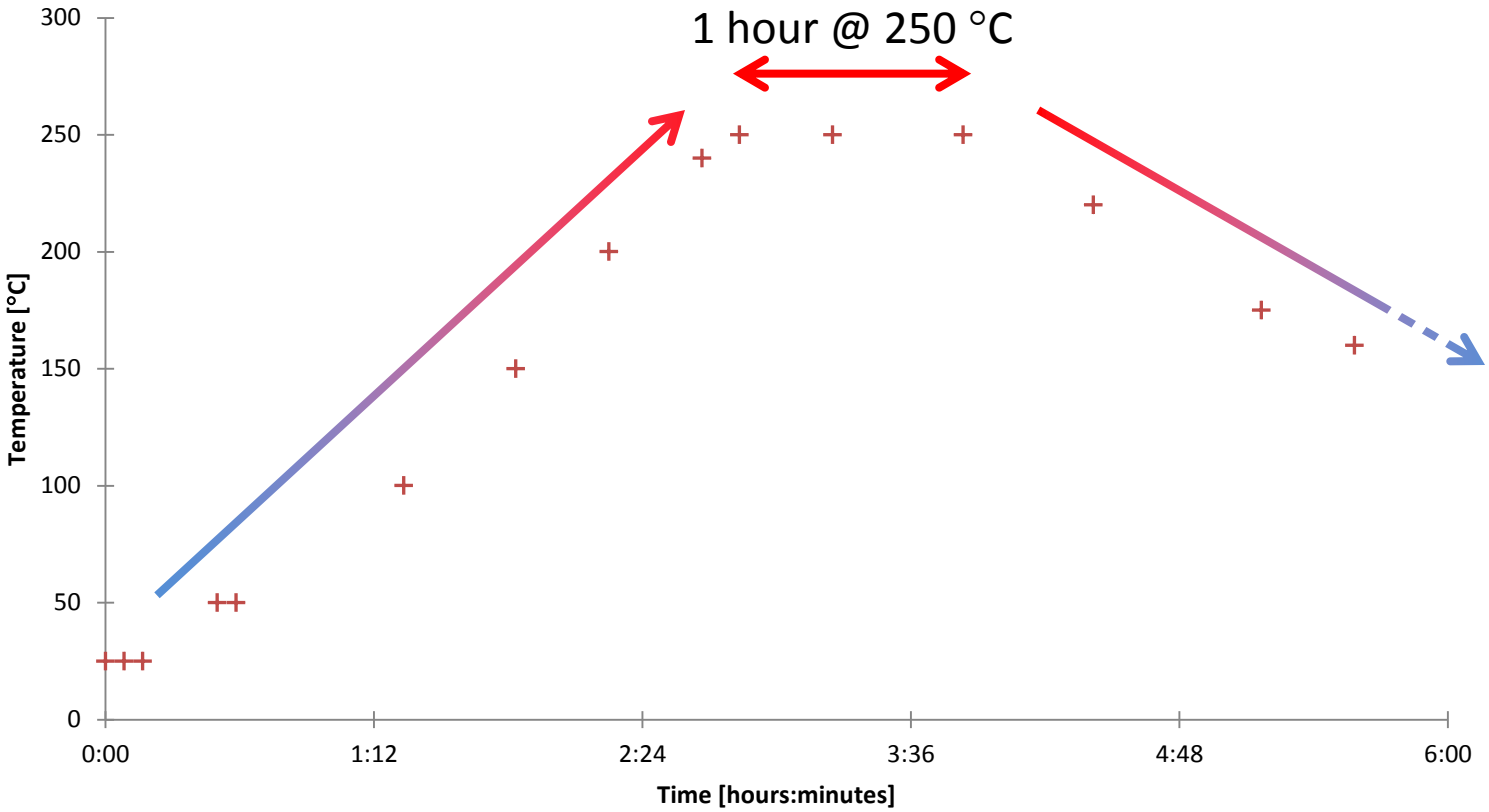
- Annealing - Temperature



Production

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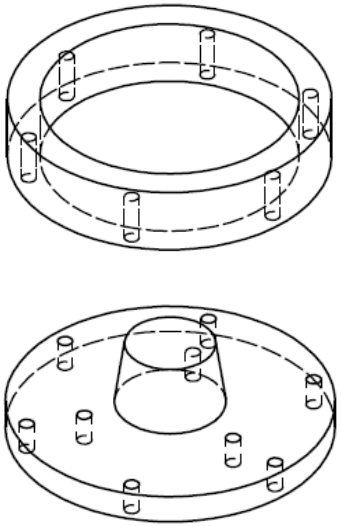
- Annealing - Insulation

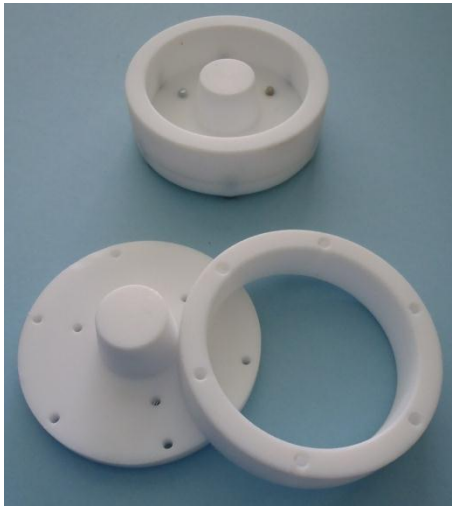
- Sol-gel method → ceramic insulation

Production

- Encapsulation

- Moulds: design, fabrication

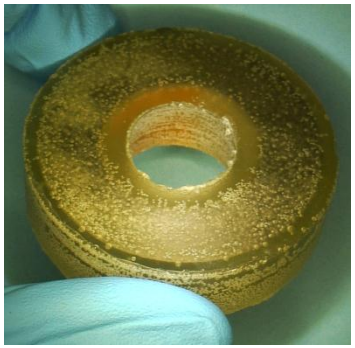
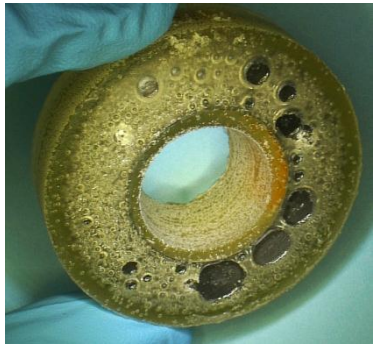




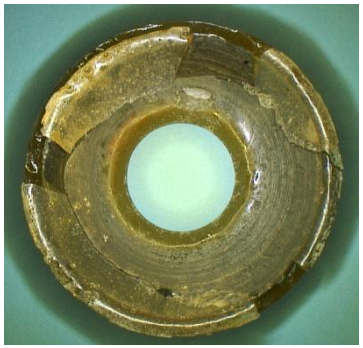
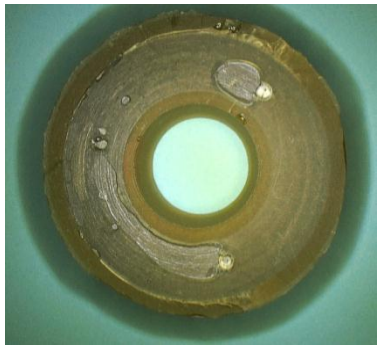
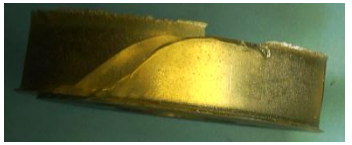
Production

- First tests - not very encouraging

Polyurethane (PU)

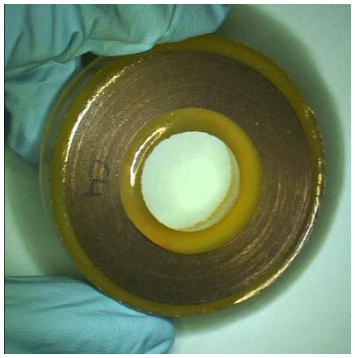

Epoxy

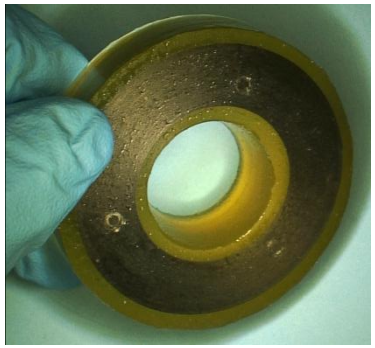




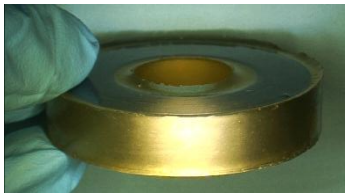
Production

- Vacuum is our friend!

+







Results

- Permeability

Origin	Material	Max. permeability
China	Fe-based amorphous	2650
China	Fe-based nanocrystalline	2610
China	Nanocrystalline “high quality”	4200
USA	Co-based amorphous	134 000
Germany	Co-based amorphous (VAC 6025)	64 000

Results

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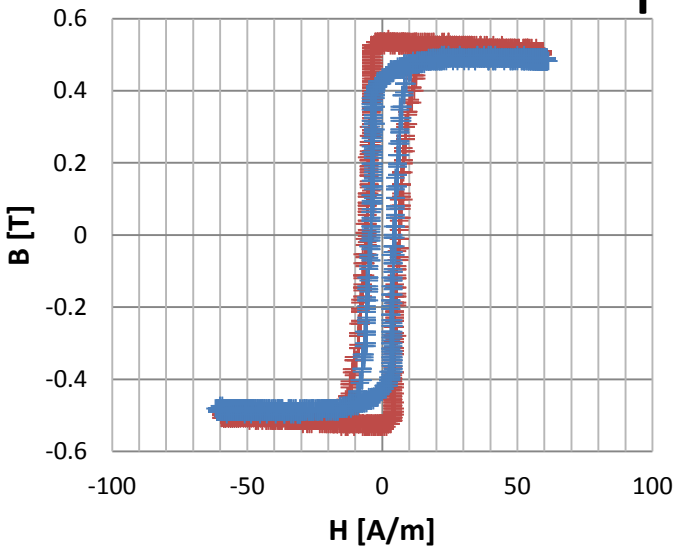
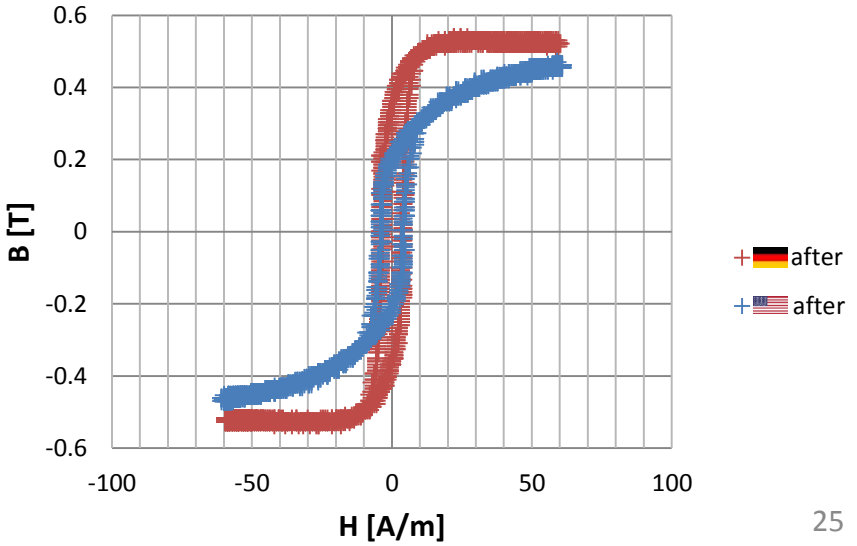
- Co-based amorphous - comparison





Results

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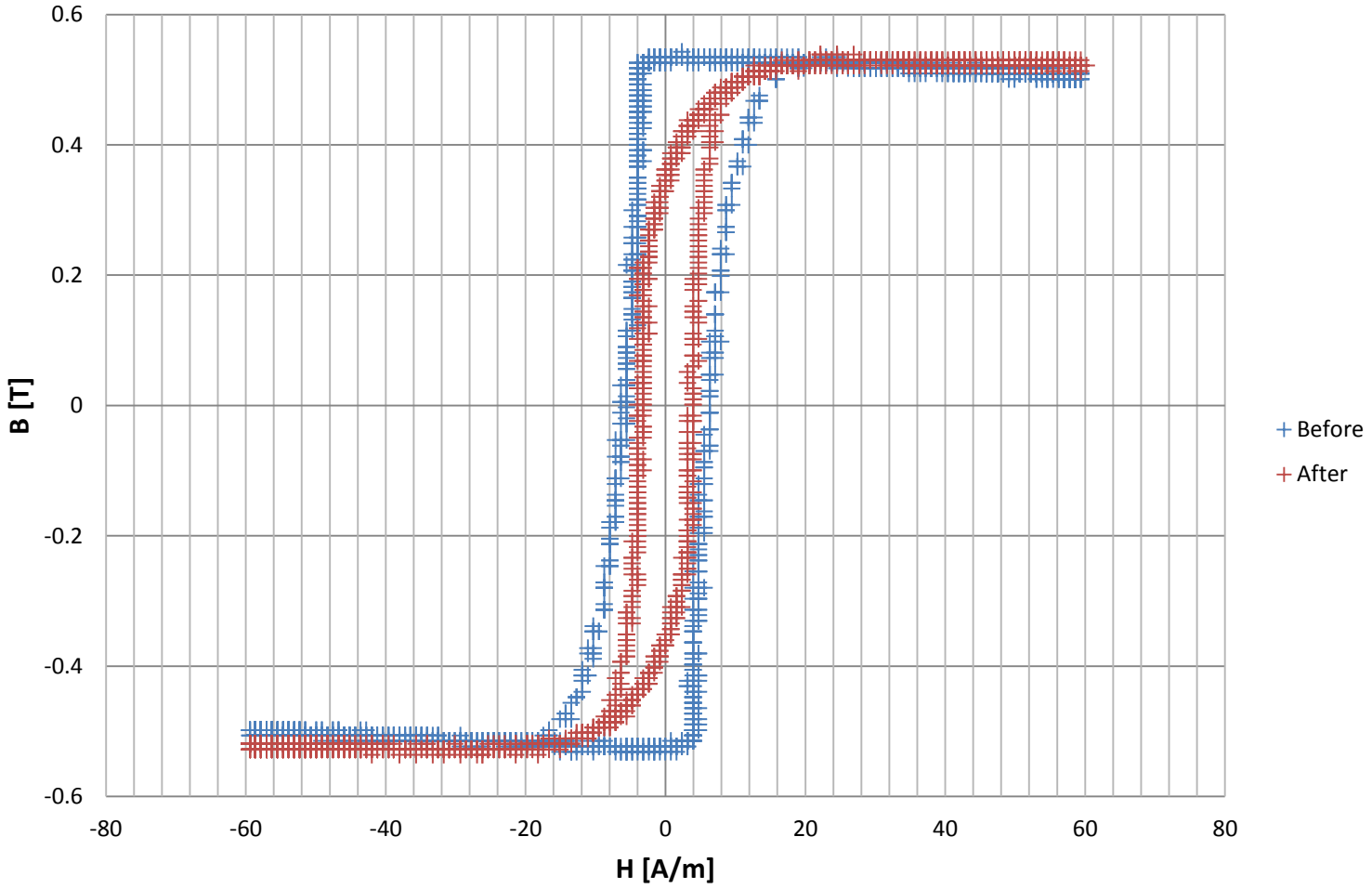
- Co-based amorphous



Results

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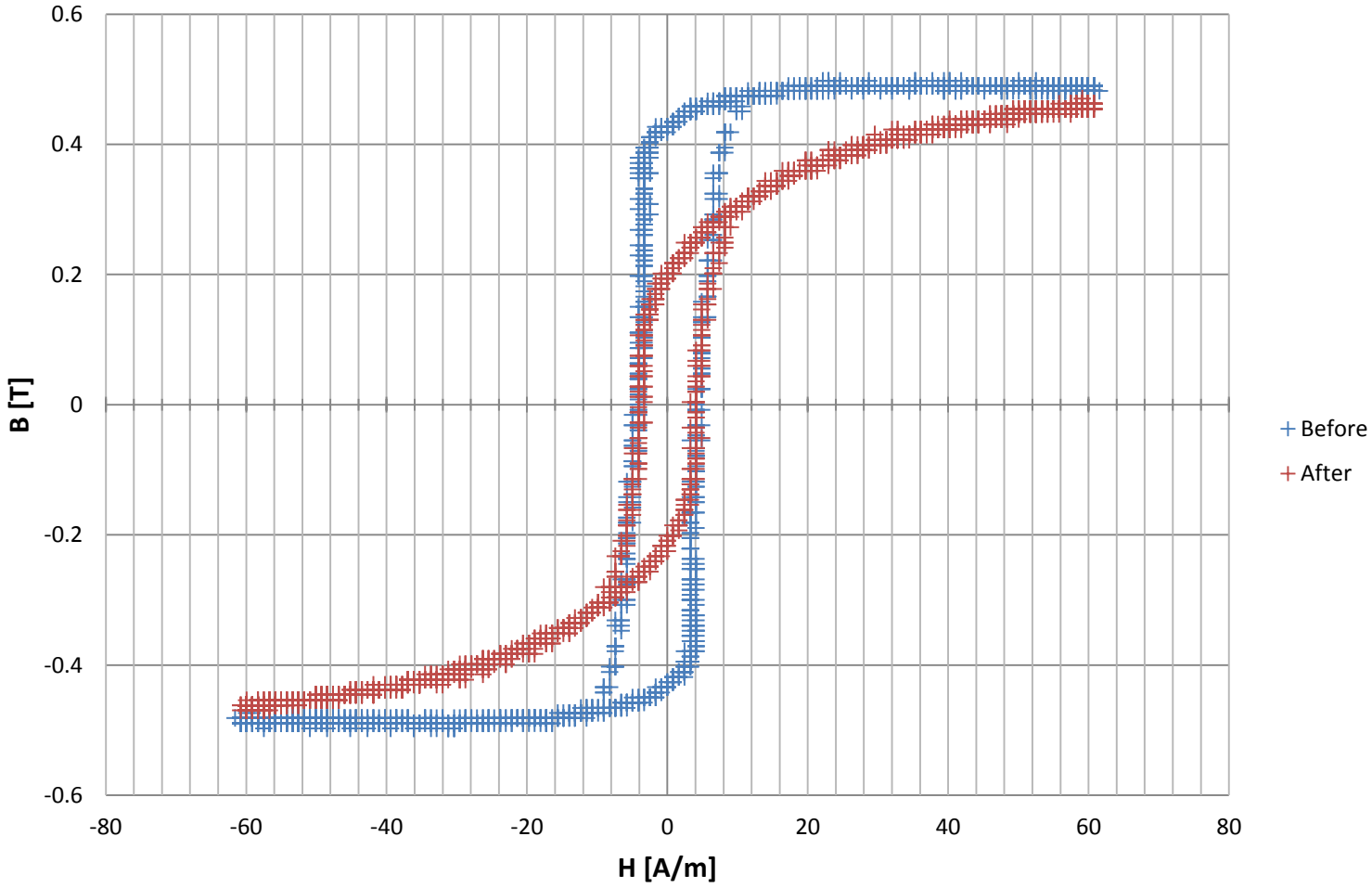
- Co-based amorphous



Results

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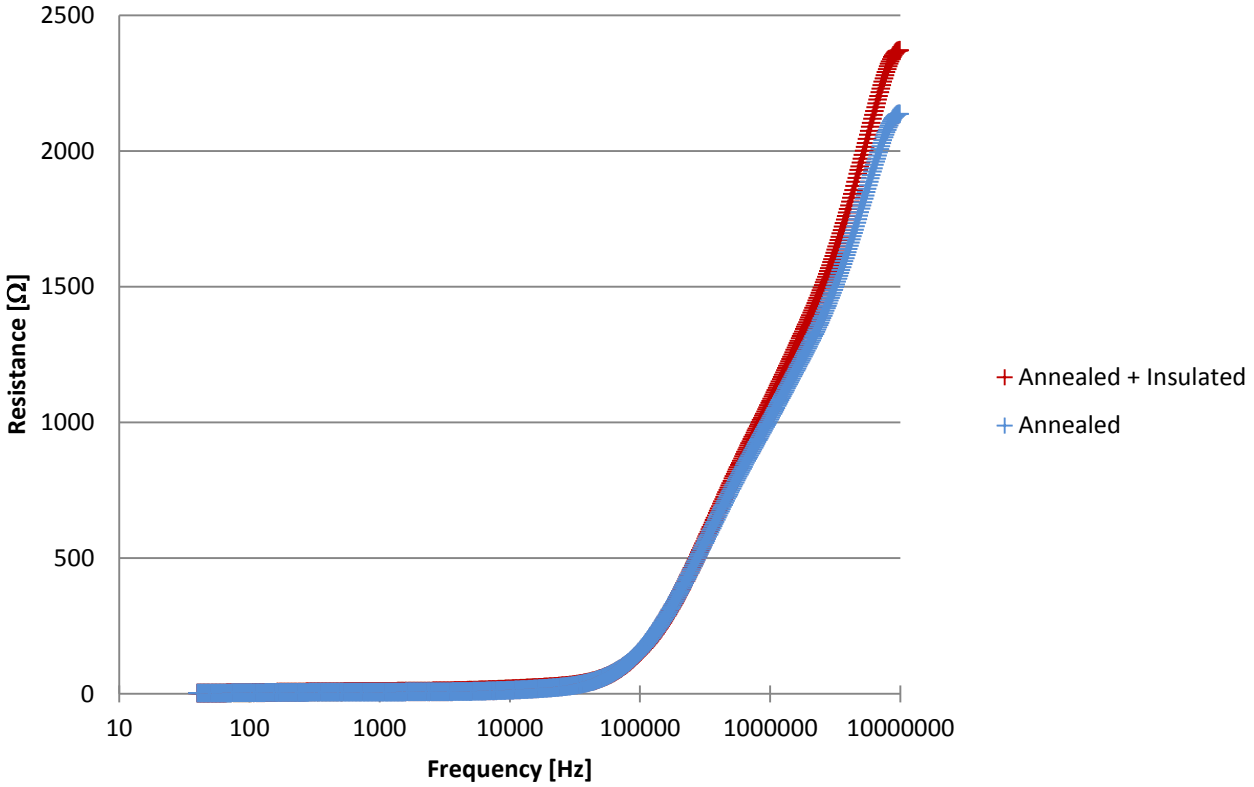
-  Co-based amorphous - insulation



Outlook

Exciting future!

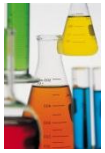
- New material
- New insulation (Kapton)
- New annealing tests (Time, Temperature)
- New measurements (Ferrofluid)

Conclusions

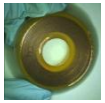
- Best material candidate: Co-based alloys
- Insulation: another approach for sol-gel
- Annealing: rounded B-H curves
- Encapsulation: Polyurethane

Acknowledgements


Material characterization: S. Sgobba, M. Scheubel, M. Czapski, D. J. Marcinek


Sol-Gel: B. Teissandier, C. Charvet, D. Letant-Delrieux


Annealing: W. Vollenberg


Moulds, encapsulation: L'atelier, F. Camba, M. Hamani

Thanks to today's organisers!

Thank you for your attention
Questions!