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XXXVI Cycle

Cryogenic-cooled Induction Motors

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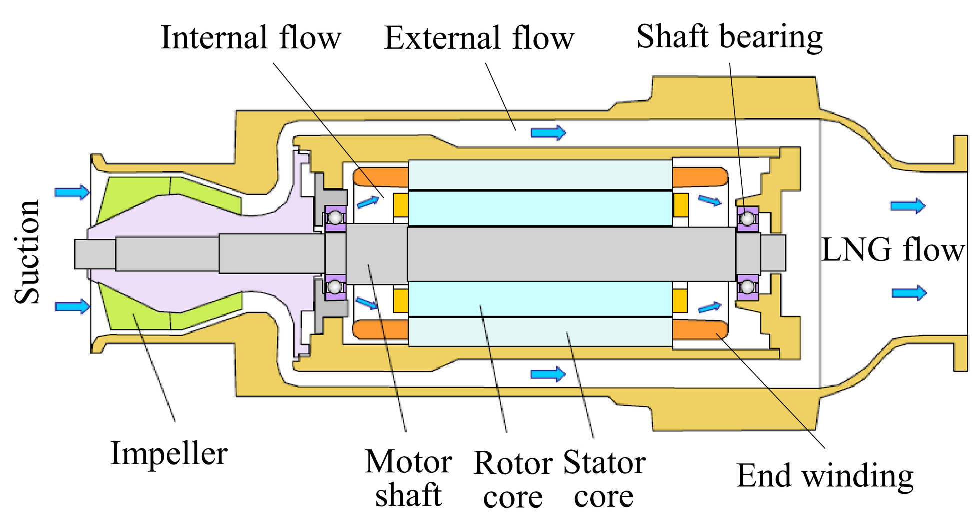
Research context and motivation

- The growth of the global **energy demand**, the need for a **low-carbon energy mix** and the urgency to **reduce harmful greenhouse gas emissions** have opened the doors to the use of **alternative energy resources**;
- The **natural gas** has already proved its potentials as an **alternative fuel** in power plants, i.e., **energy** production, and for vehicle and marine **propulsion**;
- The **natural gas** is normally stored and conveyed in its liquefied state (**LNG**) at **cryogenic temperature**, around -161 °C (110 K);
- **Submerged cryogenic pumps**, driven by a **cryogenic electric motor**, are among the key components of every LNG facility.



♦ **Submerged LNG pump assembly driven by a cryogenic-cooled electric motor.**

The research project has been funded and supported by a leading industrial partner in cryogenic technologies

VANZETTI CRYOGENIC TECHNOLOGY

and carried out in cooperation with the Technical University of Lisbon.

TÉCNICO LISBOA

Addressed research questions/problems

MAIN ADVANTAGES OF CRYOGENIC-COOLED MOTORS:

- The operation of the machine completely submerged in a **cryogenic environment** allows a **superior cooling** of their active parts ⇒ ***alternative materials (electric circuits)?***
- The drastic **decrease** of the **electrical resistivity** of conductors at cryogenic temperature results in **minor winding (Joule) losses**;
- **Cryogenic-cooled machines** feature an **increased torque capability** and **efficiency** compared to conventional industrial machines of the same active volume;

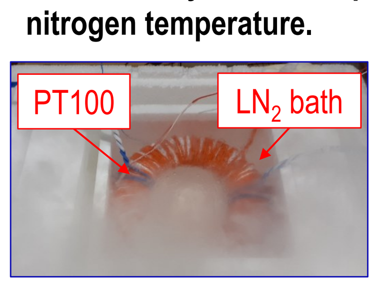
MAIN DISADVANTAGES OF CRYOGENIC-COOLED MOTORS:

- **Increased friction losses**: bearing technology/airgap fluid flow?
- **Increased core losses**: eddy current related phenomena;

ANALYSIS & DESIGN TARGETS:

- Optimal **loss distribution** in the machine;
- Trade-off between **efficiency** and **active volume**.

♦ **Magnetic characterization of SiFe alloys at the liquid nitrogen temperature.**



The research activities during the Ph.D. aim at defining a suitable procedure for the fault-tolerant and efficient design of cryogenic-cooled induction motors (IMs).

♦ **A small fractional-kilowatt IM used in preliminary tests in a liquid nitrogen atmosphere at 77 K (-196 °C).**

External training activities

- European PhD School on Power Electronics, Electrical Machines, Energy Control and Power Systems - online - (7/12/2021, 30 hours).

Novel contributions

MACHINE ANALYSIS & DESIGN:

- detailed loss segregation and performance analysis of fractional-kilowatt cryogenic-cooled IMs by means of experiments and analytical calculations; ✓
- dedicated methodology for the prediction of the steady-state performance of cage IMs featuring superconducting rotor windings (1G-BSCCO HTS); ✓
- investigations on suitable design strategies for cryogenic-cooled IMs. ⚠

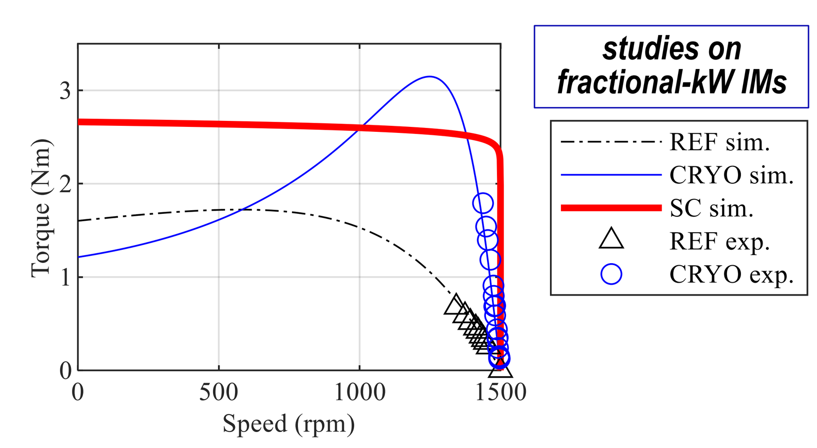
MATERIALS CHARACTERIZATION & MODELING:

- prediction of the power losses in silicon-iron laminated cores, at room and cryogenic temperature, employing an improved method for the separation of the losses into components; ✓
- studies on the best methodology to extrapolate the magnetization curve of silicon-iron alloys up to saturation, starting from measurements at low field levels. ✓

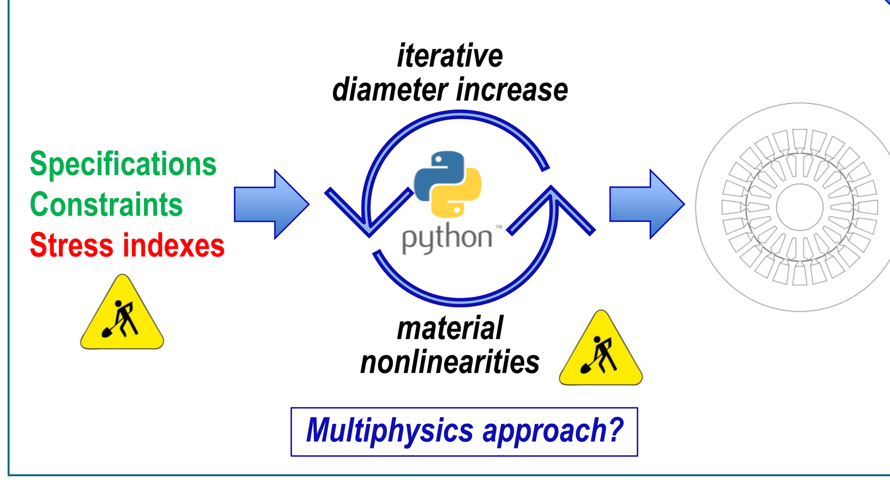
Adopted methodologies

MACHINE ANALYSIS & DESIGN

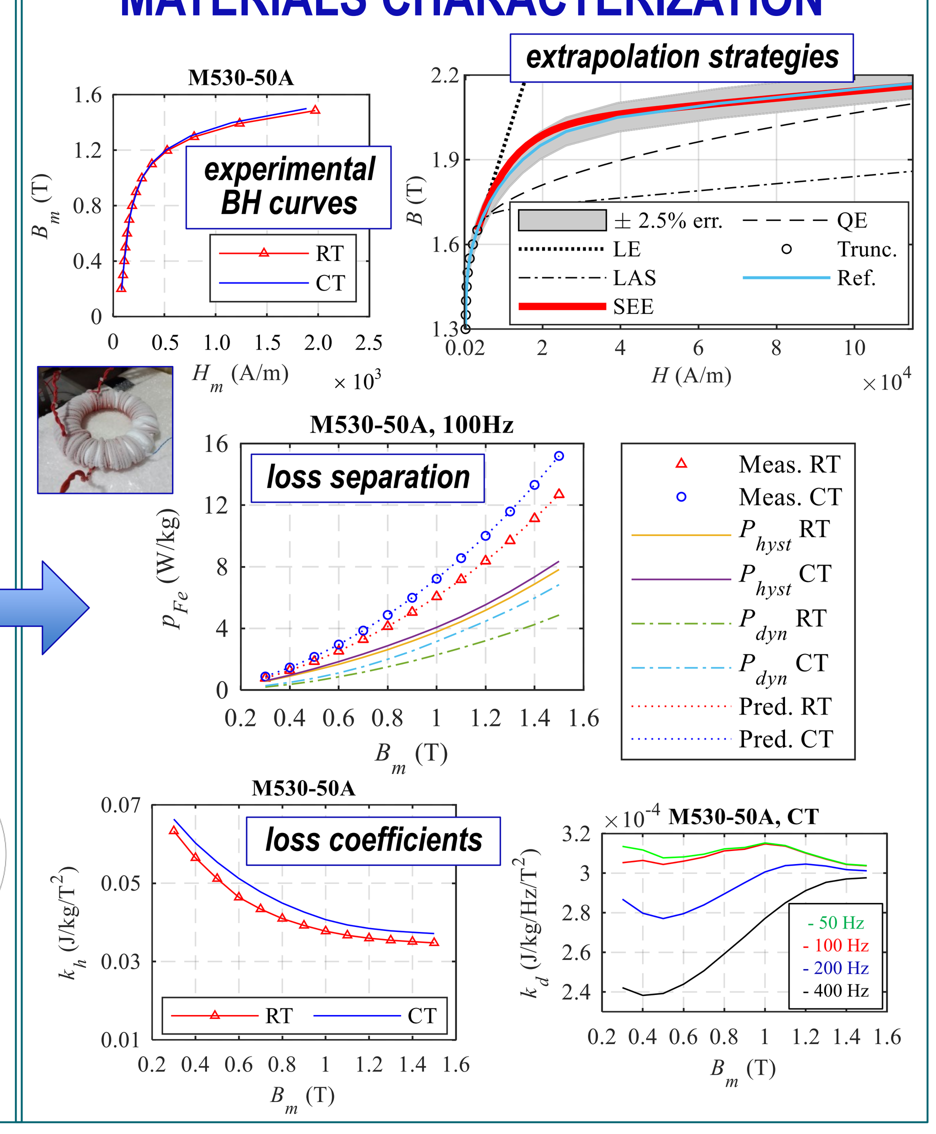
- steady-state performance analysis:



- design of cryogenic-cooled IMs:



MATERIALS CHARACTERIZATION



Future work

The future research activities will mainly focus on:

- improved **calculation methods** for estimating the **iron losses** in cryogenic-cooled induction machines supplied by **inverters**;
- experimental investigations on the **thermal behavior** of cryogenic-cooled induction machines to define suitable **design guidelines** in terms of allowed **electric loading**;
- experimental and theoretical studies on how to minimize the **impact of the friction losses** on the **efficiency** of cryogenic-cooled induction machines;

- **Design** and **testing** of a **15 kW, 15 krpm cryogenic-cooled induction machine** for submerged cryogenic pump applications. ⚠

Submitted and published works

- **M. Biasion**, J. F. P. Fernandes, S. Vaschetto, A. Cavagnino and A. Tenconi, "Superconductivity and its Application in the Field of Electrical Machines," 2021 IEEE International Electric Machines & Drives Conference (IEMDC), 2021, pp. 1-7.
- **M. Biasion**, J. F. P. Fernandes, P. J. d. C. Branco, S. Vaschetto, A. Cavagnino and A. Tenconi, "A Comparison of Cryogenic-Cooled and Superconducting Electrical Machines," 2021 IEEE Energy Conversion Congress and Exposition (ECCE), 2021.
- L. F. D. Bucho, J. F. P. Fernandes, **M. Biasion**, S. Vaschetto and A. Cavagnino, "Experimental Assessment of Cryogenic Cooling Impact on Induction Motors," in *IEEE Trans. Energy Convers.*, 2022.
- O. Stiscia, **M. Biasion**, S. Rubino, S. Vaschetto, A. Tenconi and A. Cavagnino, "Iron Losses and Parameters Investigation of Multi-Three-Phase Induction Motors in Normal and Open-Phase Fault Conditions," in 2022 International Conference on Electrical Machines (ICEM), 2022.
- **M. Biasion**, I. S. P. Peixoto, J. F. P. Fernandes, S. Vaschetto, G. Bramerdorfer and A. Cavagnino, "Iron Loss Characterization in Laminated Cores at Room and Liquid Nitrogen Temperature," in 2022 IEEE Energy Conversion Congress and Exposition (ECCE), 2022. *(submitted)*
- **M. Biasion**, D. Kowal, R. R. Moghaddam and M. Pastorelli, "Influence of the Lamination Material and Rotor Pole Geometry on the Performance of Wound Field Synchronous Machines," in 2022 IEEE Energy Conversion Congress and Exposition (ECCE), 2022. *(submitted)*
- L. F. D. Bucho, J. F. P. Fernandes, **M. Biasion**, P. J. d. C Branco, S. Vaschetto and A. Cavagnino, "Losses Analysis of Induction Motors under Ambient and Cryogenic Conditions," 2022 IEEE Energy Conversion Congress and Exposition (ECCE), 2022. *(submitted)*

List of attended classes

- 02QRNRV – Electromagnetic dosimetry in MRI: comp. and exp. methods (5/5/2021, 5 CFU).
- 02ITTRV – Generatori e impianti fotovoltaici (4/12/2021, 5 CFU).
- 01VFNRV – High Temperature Superconductors for electrical appl. (1/25/2021, 2 CFU).
- 03OYCIV – Hybrid propulsion systems (6/25/2021, 3 CFU).
- 01LDVRU – Magnetismo nei materiali e misure magnetiche (6/8/2021, 4 CFU).
- 01DOBRV – Mathematical-physical theory of electromagnetism (6/6/2022, 3 CFU).
- 02SFURV – Programmazione scientifica avanzata in MATLAB (5/25/2021, 6 CFU).
- 01QEZRV – Sviluppo e gestione di sistemi di acquisizione dati (4/4/2022, 5 CFU).
- 01PJMRV – Etica informatica (5/3/2021, 4 CFU).
- 01RISRV – Public speaking (8/11/2021, 1 CFU).
- 01UNXRV – Thinking out of the box (4/14/2021, 1 CFU).
- 01SWPRV – Time management (4/15/2021, 1 CFU).
- 01QORRV – Writing scientific papers in English (3/25/2021, 3 CFU).

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PhD program in
Electrical, Electronics and Communications Engineering