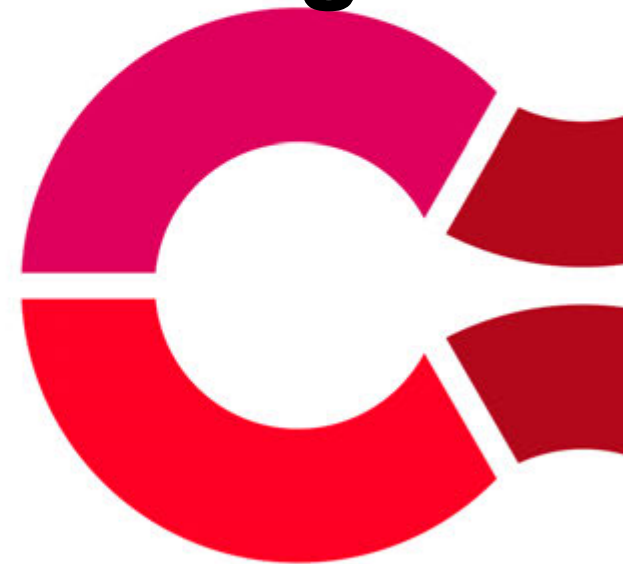# Technological requisites for induction heating with rotating magnets

Aluminium extrusion congress 4th April 2019

Speakers:

Prof. Fabrizio Dughiero

Ing. Marcello Zerbetto

Introduction

University of Padua

- Padua is a city in the north-east of Italy, 30km from Venice (250.000 people – 50.000 students).

- The University foundation year is 1222 (Galileo Galilei was teaching in Padua)

- Now the 797th Academic Year is running!

- *11,000 students are enrolled in the Engineering undergraduate and Graduate courses*

- The Department of Industrial Engineering hosts **The Laboratory for Electroheat of Padua (LEP)**

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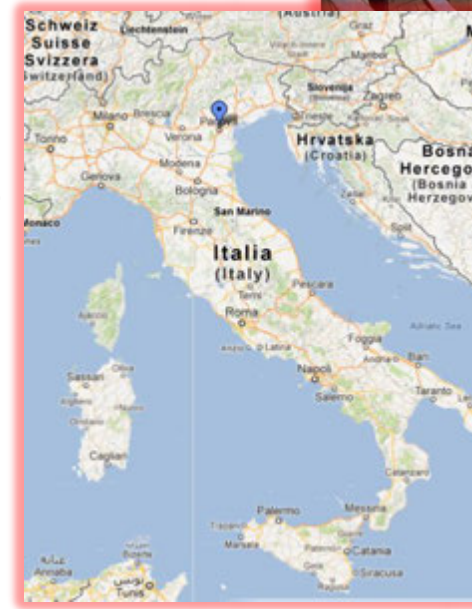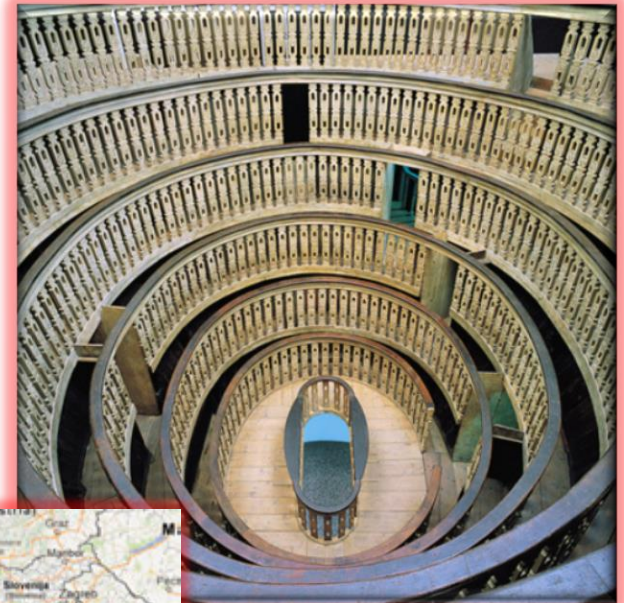
Laboratory for Electroheat

- The **Laboratory for Electroheat** (LEP) of Padova University has been established in 1969 by prof. Ciro Di Pieri, emeritus professor, and developed by Prof. Lupi, emeritus too, who has been retired since 2010.

- The research activity of the Laboratory has always been devoted to the **industrial applications of electroheat technologies** and, in particular, to direct and indirect resistance heating, medium- and high-frequency induction heating and dielectric/microwave heating.

- A close cooperation exists among Laboratory, manufacturers and end users of electroheat equipments and processes, in the frame of research contracts on specific topics.

- **LEP has also a lot of international agreements with universities and research centers all over the world**

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Inovalab

- InovaLab is a **spin-off** company of **Padova University**, founded in **2004** by two researchers of the Department of Electrical Engineering, with a long experience in the field of **Electroheat applications**.

- The mission of InovaLab include **technology transfer** to industry and the development of **innovative processes and prototypes** by using modern **simulation software**, specific **laboratory testing**, and taking advantage of **high level team skills**.

- InovaLab is the **R&D center** for many companies; **co-operation** is the main word used in InovaLab. The customer is a partner and InovaLab is not only a supplier but a real R&D center outside/inside the customer facilities, with skills, tools, instrumentation and personnel which can be involved in the projects.
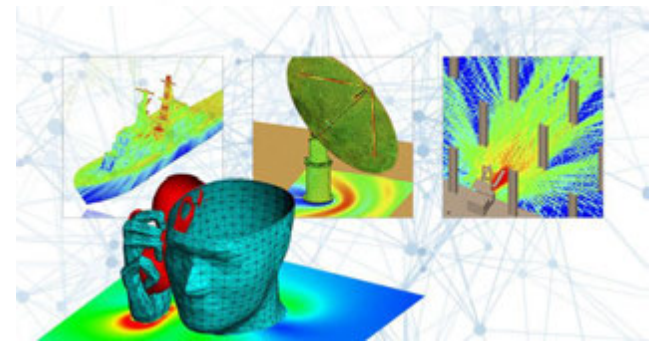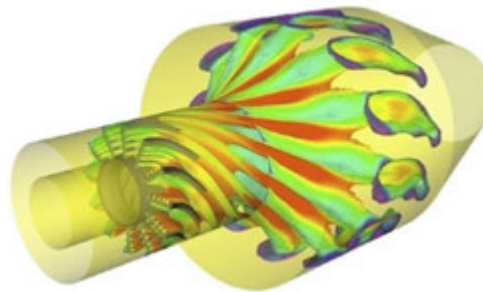
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Inovalab and Lep facilities and instrumentation

- Several multicore workstations with up to 400 GB RAM and 32 cores processors

- Simulation software

  Altair suite:

  - FLUX 2D-3D
  - FEKO
  - ACU Solve
  - COMSOL multiphysics
  - Labview
  - Matlab

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Aluminium billet heater

Aluminium billet preheating contest

In the **extrusion industrial plant** aluminium billets are **preheated** at about **400-500 °C** before being pushed through a shape die. Frequently to have an **isothermal extrusion process** a conical temperature distribution along the billet axis (named **"taper"**) is required.

Today the main heating technologies used for aluminium are:

- **Gas furnaces** with low thermal **efficiency** of **40-45%**, high CO_2 emission but with cost competitiveness (low gas cost)

- **Traditional induction technology** where the magnetic field is generated by water cooled multi turn coils; with **efficiency** of **55%** because the aluminium is non-magnetic and high conductive material.

- An **improvement** of **induction technology** is proposed by some authors in which the **billet is forced to rotate inside a transverse DC magnetic field** produced by **superconductive coils**. This approach has high **efficiency** about **85%** but requires complex and expensive setup (cryogenic system, superconductive magnets, very robust rotating system with large braking torque) and the application in industrial case is very difficult.

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Concept of Aluminum billet heater proposed by InovaLab

The technology proposed by **InovaLab** in collaboration with the **University of Padua** consists to **clamp an aluminum billet inside a rotating system of permanent magnets**. This solution (patented by InovaLab) with respect to the traditional technologies (Gas and Induction heater) allows:

- The achievement of **high efficiency** about 30% higher respect to the traditional induction heater without using water cooling

- a best temperature profile along the billet axis (**taper**) **splitting** the **rotor machine** in **several modules** which rotate at **different speeds in opposite direction to reduce the braking electromagnetic torque** on Al billet.

The first industrial scale prototype for 200 mm diameter, 500 mm length aluminum billet with rated power of 55 kW **has been realized** in 2011 at University of Padua.

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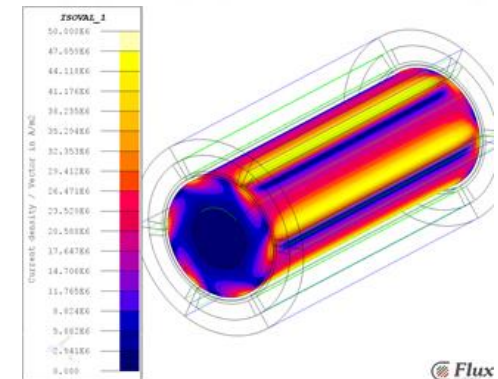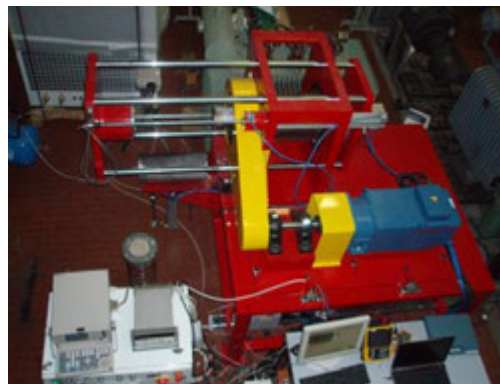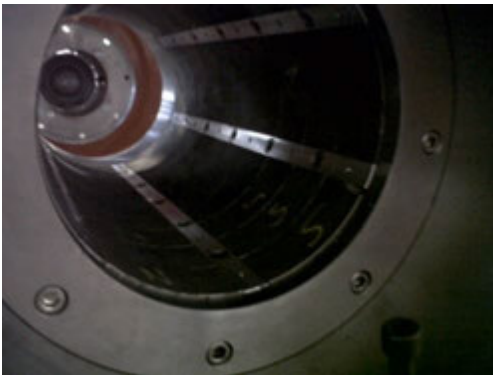
Magnheat project

Magnheat & Life + program

The LIFE programme is the EU's funding instrument for the environment and climate action. The general objective of LIFE is to contribute to the implementation, updating and development of EU environmental and climate policy and legislation by co-financing projects with European added value.

In particular Magnheat project was a LIFE+ Environment Policy & Governance program.

It co-financed innovative or pilot projects contributing to the implementation of European environmental policy and the development of innovative policy ideas, technologies, methods and instruments.

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Magnheat project

MagnHeat project **aims to demonstrate** the **first full scale industrial application** of a novel concept of DC induction heating furnace, which has never been applied so far, **based on rotating permanent magnets for Aluminium extrusion**. Such technology has been developed through a combination of eco-design and engineering, exploiting and valorizing **R&D activities carried out by the coordinating beneficiary** (**INOVALAB**).

Technical performance, environmental and economical benefits of MagnHeat induction prototype has been proven in a concrete **large scale industrial production line (PANDOLFO)**. Established methodology for **environmental impact and thermo economic assessment** have been used to gather quantitative results **(CIRCE).** The national association of Aluminium industries **(ASSOMET**) has been involved to gather the attention of all **relevant stakeholders** and ensure proper **dissemination and promotion** of the action through the EU.

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Magnheat Technology description

The concept of the technology is the rotation of permanent magnets around the billet. The design of the heater has been done by mean electromagnetic and thermal FEM simulation.

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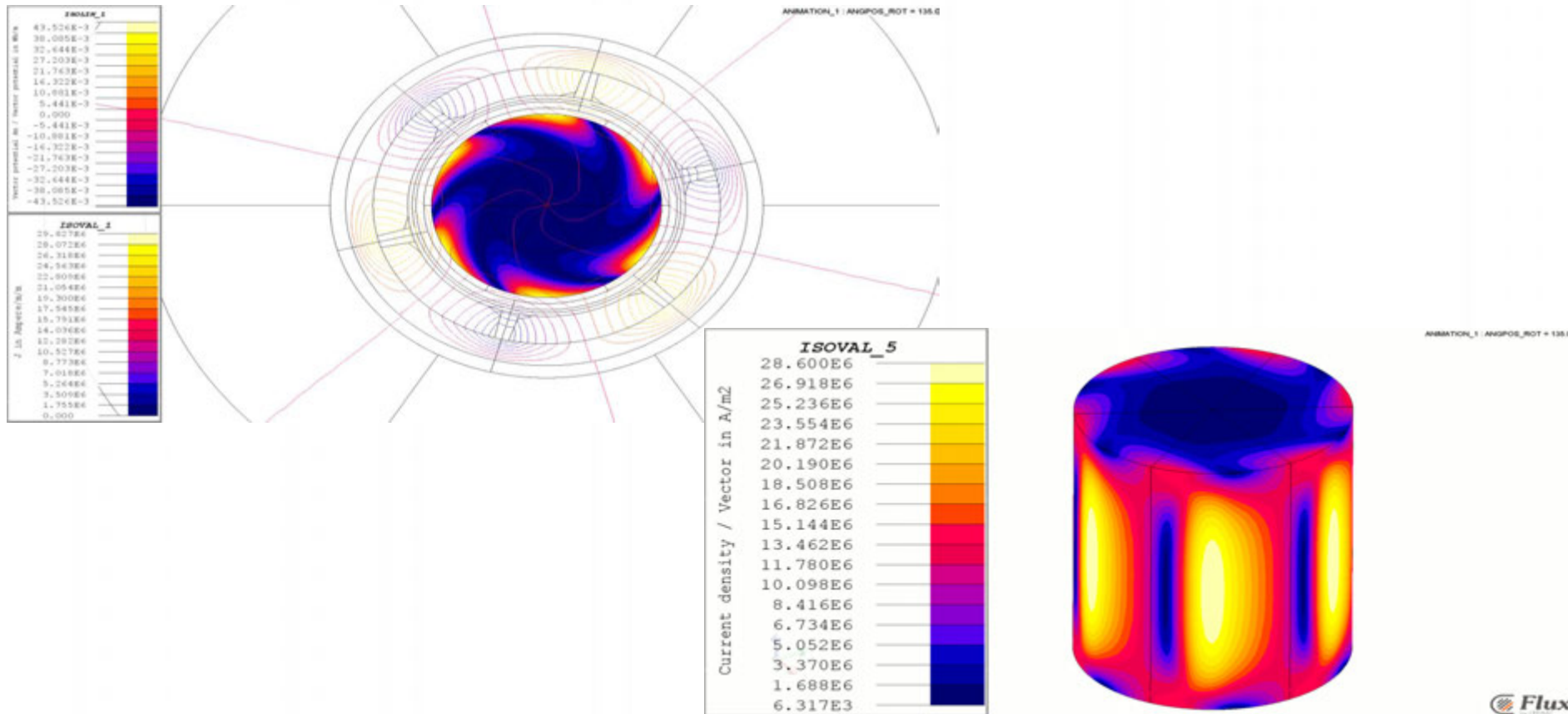
Specification of the first industrial prototype.

Aluminum alloys	6060-6063-6005A-6082-3103-1070A-1050				
Billet diameter	254	[mm]	Productivity (taper ΔT 100 °C)	45	[billet/h]
min. billet length	400	[mm]	Productivity (taper ΔT 140 °C)	35	[billet/h]
max. billet length	1350	[mm]	Productivity from T ambient	11	[billet/h]
min. billet weight	54.7	[kg]	Power supply	3 phase 400 [V]	
max. billet weight	184.7	[kg]	Minimum Heating Time	55	[s]
Output limit temperature	550	[°C]	Maximum power in Al billet	350	[kW]
Input typical temperature	400	[°C]	Number modules	5	-
ΔT max from ambient temperature	520	[°C]	Module power	110	[kW]
ΔT max for taper	140	[°C]	Maximum input power	550	[kW]

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Sizing of single module: FEM 2D analysis

➢ The **electromagnetic sizing** of **rotor module** of permanent magnet heater has been carried out using **FLUX2D** model with transient magnetic application coupled with **Got-it** tool for **optimizing** the **use of magnets and the performance**.

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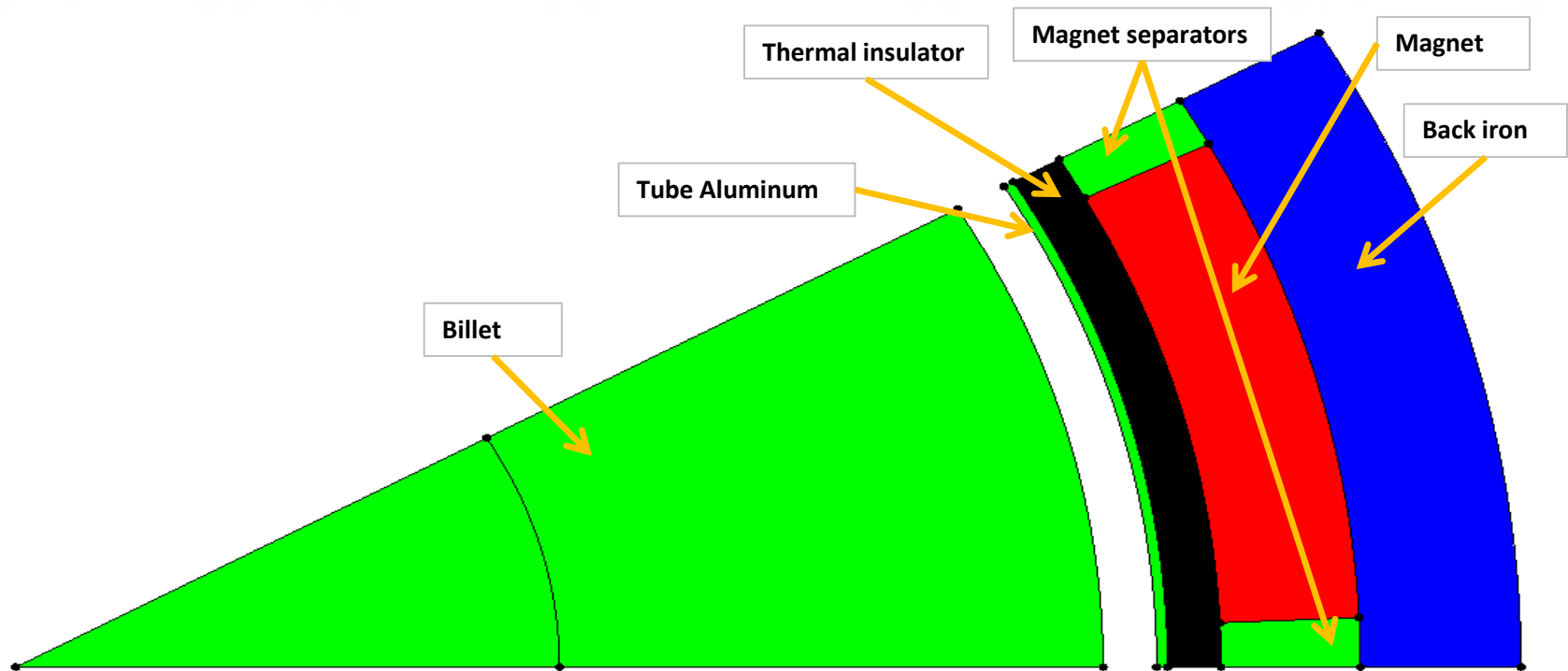
2D transient magnetic model.

The **model simulated** is relative of only **one magnetic pole**

The input variable used in the optimization are:
- Magnet thickness **Hm**
- Number of magnetic pole **Np**
- Rotation speed **RPM**

The output **metrics** are:
- The weight of permanent magnets **Wmag**
- The power transferred in the Al billet **PAl**
- The electromagnetic braking torque **Cem**

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Optimization result

The problem is **multi objective** with the following **goal functions** that are minimized:

- **OF1=Wmag/PAl**
- **OF2=PAl-Ptarget**

Note: the optimisation is done with the 2D FEM model to reduce the computation time, one solution 2D takes about 3 min. and one solution 3D takes about 2 h and 20 min; but the model 2D is approximated because it don't take into account the real distribution of flux density along the axis direction on the billet surface. This distribution is reproduced correctly only in the 3D model. The difference between 2D and 3D model is about 20% for the geometric configuration chosen, so to obtain by the optimisation tool a correct result the power target will be increased of 20%.

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3D transient magnetic model.

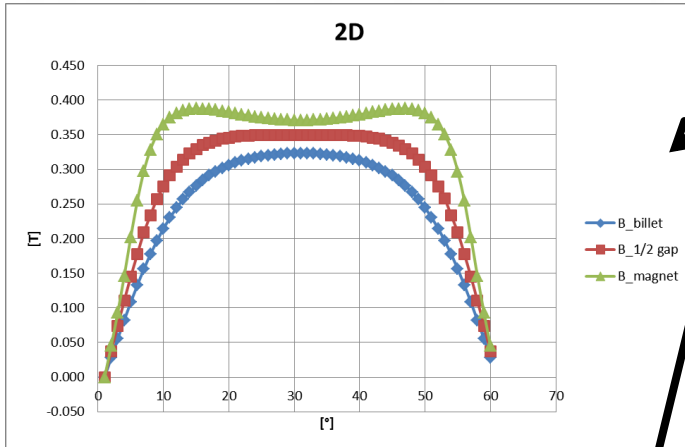The **model simulated** is relative of only **one magnetic pole**
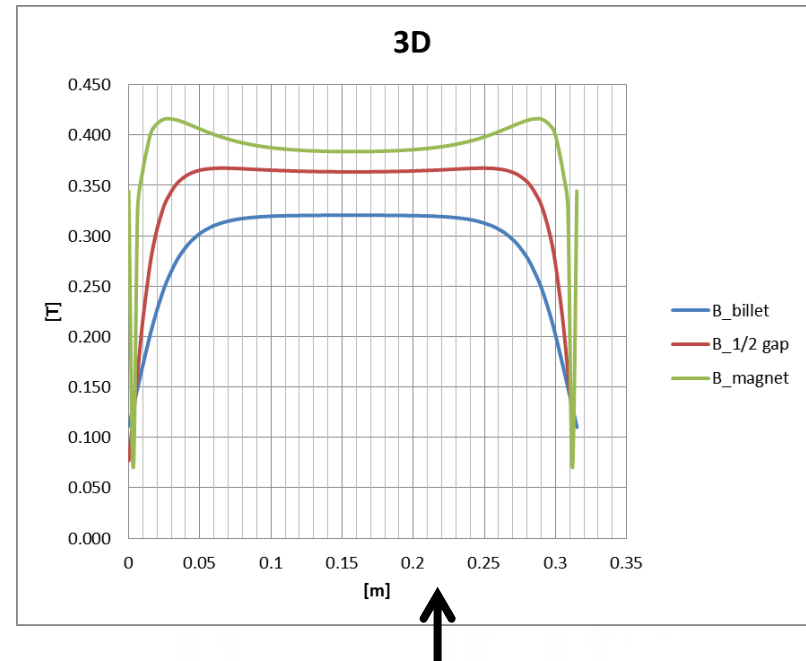

Geometry put on 3D model

Back iron

Al billet

Magnet separators
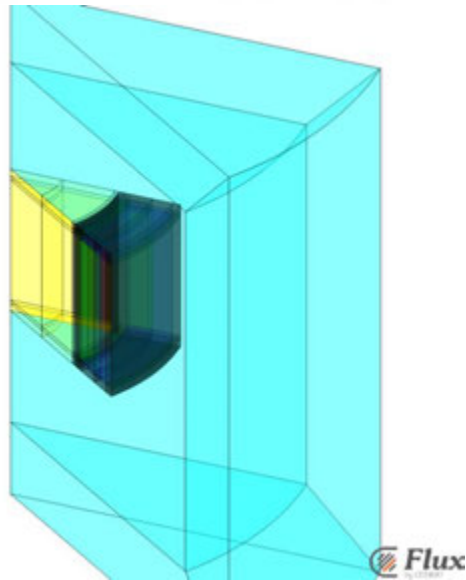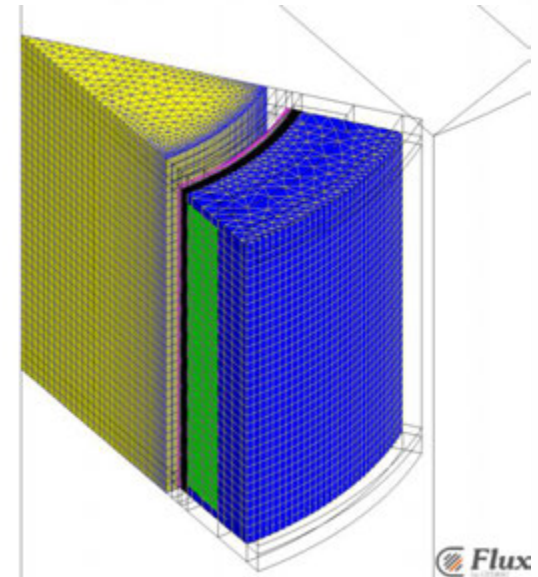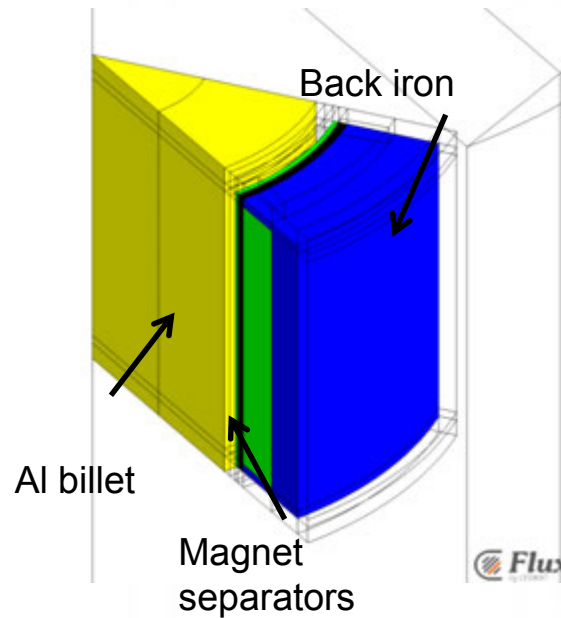
Mesh used on 3D model

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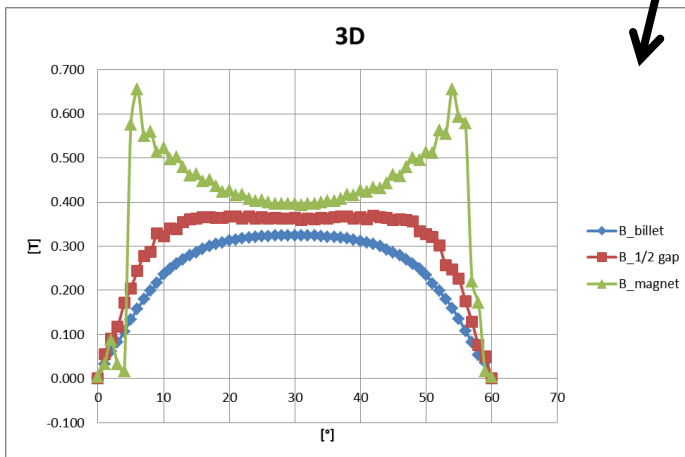
Comparison between 2D and 3D FEM model

Comparison of flux density distribution in the radial direction in a transversal section

Flux density distribution in the axial direction for the 3D model

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Electromechanical performance of optimized module

➢ The **optimized module** has the following **performance** in function of **rotational speed** (2D-3D model).

- ■ **T** electromagnetic braking torque
- ■ **P** power transferred in the Aluminum billet

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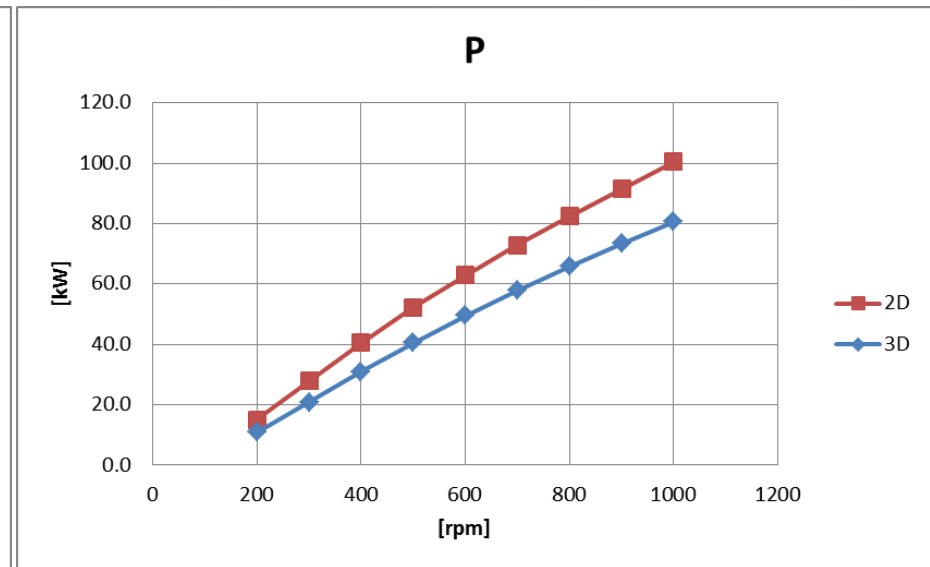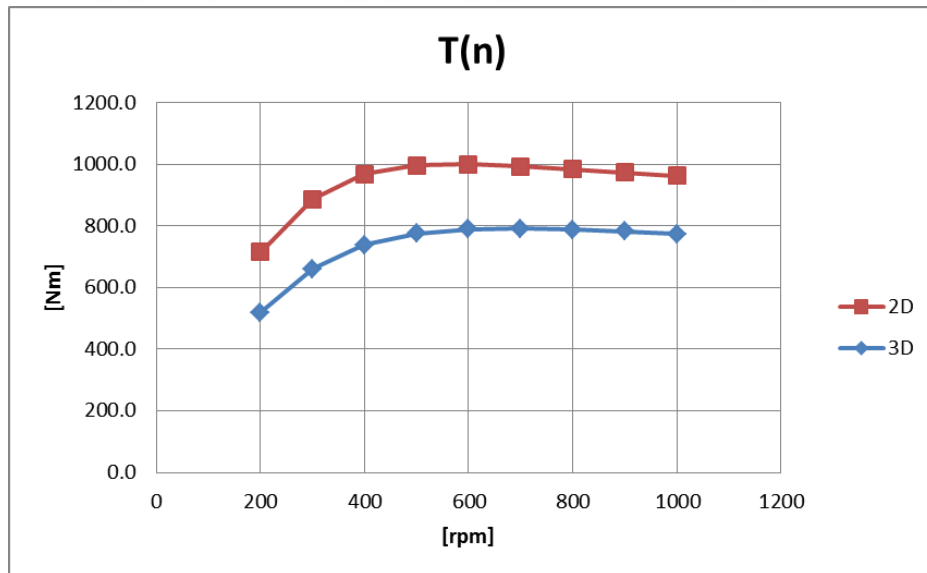
3D transient thermal model

- A **3D simplified transient thermal model** is solved to predict the **temperature** distribution in the **billet**. Since the process involves a small temperature variation (about 100 °C from 400 to 500 °C) the **variation** of **resistivity** is neglected and it is considered **constant** at an **average value**.
- The induced power density has a radial and azimuthal distribution (a) that rotates following the magnetic rotation. However the power density put in the thermal model (b) is an average value in an electric period of real instantaneous distribution. The average value is calculated for each nodes using a python script.
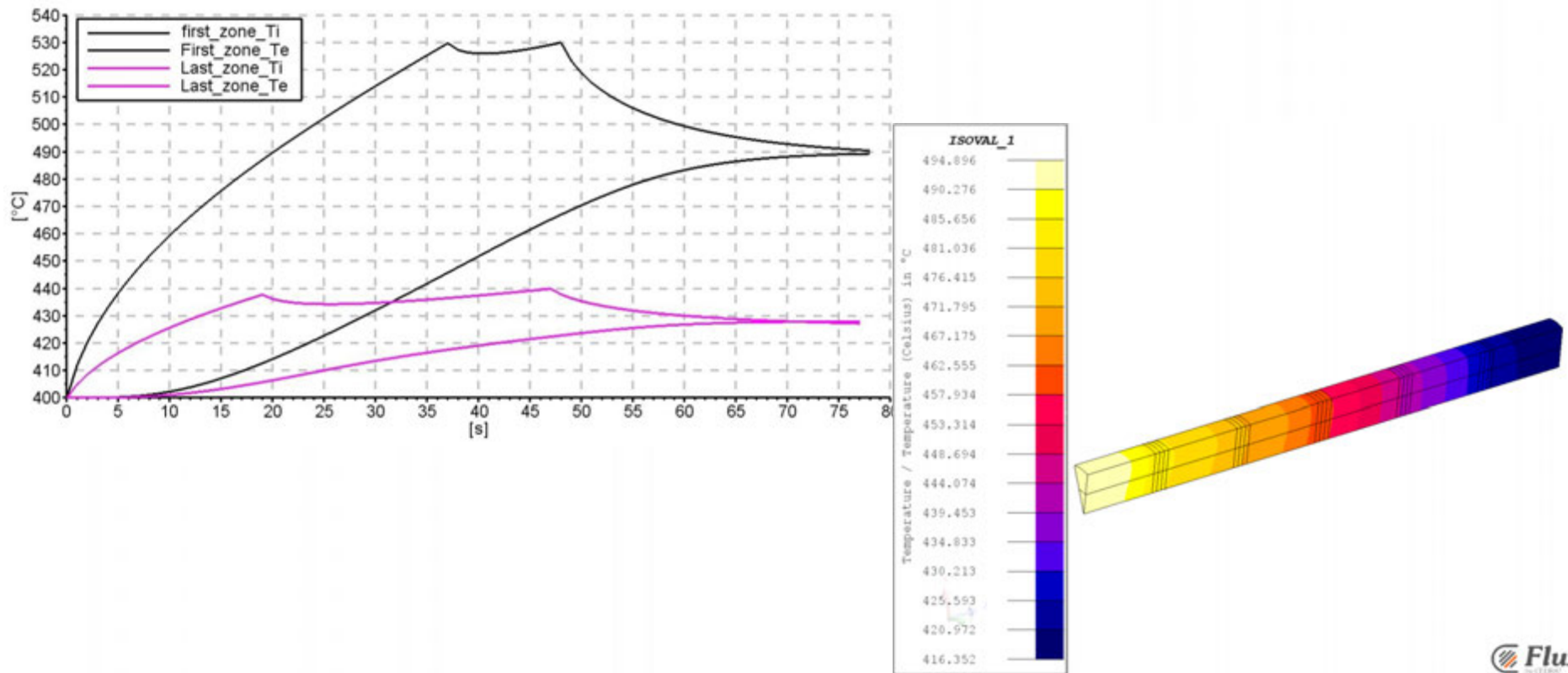

(a)

(b)
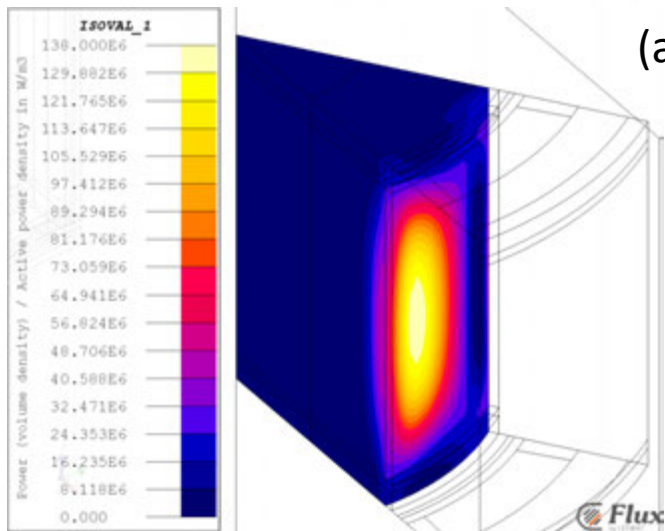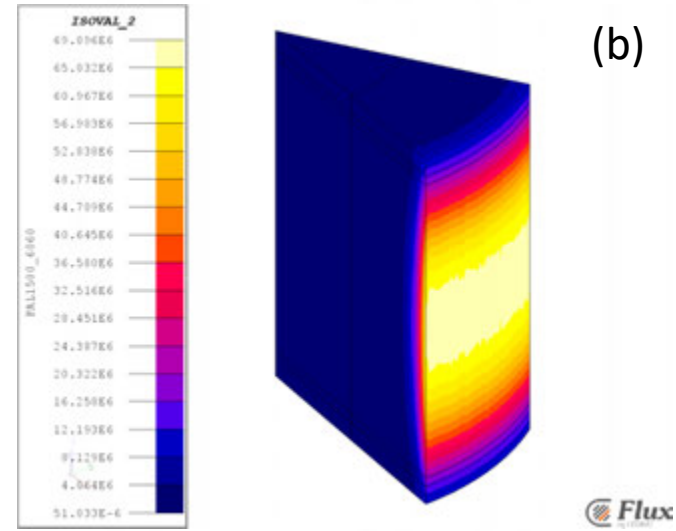
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Thermal transient result

Thermal transient as function of time. The curves describe the temperature on the surface Te and axis Ti evaluated on the top and bottom part of billet.

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Heater realization

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