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Evaluating Electrical Steels for Electric Vehicles

RINA

Electrical Steel

And their application to electric mobility

Rina Consulting - Centro Sviluppo Materiali Introduction

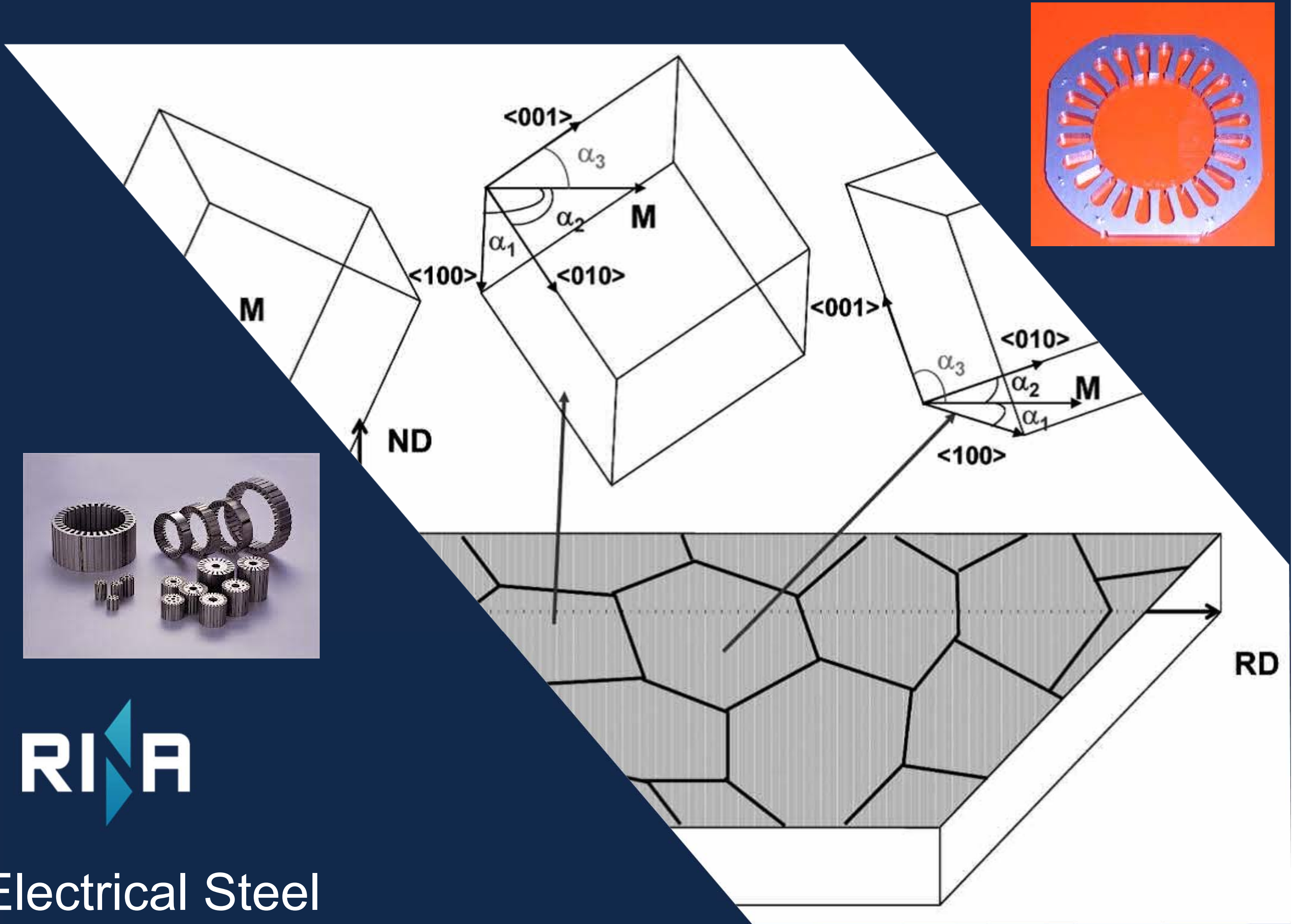
CSM was started in 1963, as CORPORATE research centre of FINSIDER (nationalized steelmaking corporation).

CSM experience on Electrical Steel started at beginning of 70's of last century, in cooperation with Finsider's Terni Plant,

Nationalized steelmaking industry was privatized in 1994, so it was CSM.

CSM nowadays is a fully private innovation center with extensive experiences for the development of materials and relative production processes. WITH A WIDE EXPERIENCE IN ELECTRICAL STEEL.

It is part of RINA Group (in its branch RINA-CONSULTING), which is a global provider of classification, certification, testing, inspection, training, advisory and research services.



Electrical Steel

And their application to electric mobility

Electrical steel is used as material for magnetic core of electric machines.

GOES: transformers
NOES: rotating machines

Differently from major part of steels, it is not used because of its mechanical properties, but because of its magnetic properties:

-POWER LOSSES: **P**
(efficiency of electric machine)

-POLARIZATION: **J**
(power-torque density of electric machine)

World production of Electrical steel

In 2017 the world production of ***[Non grain oriented]*** **Electrical steel has been ~13 Mtons, less of 1% of world steel production (1,7Btons)**

Automotive applications

Sold cars and commercial veicles in 2017

$$\sim \mathbf{100 \cdot 10^6}$$

Considering

80kg/motor

this makes **8 Mtons** *of Electrical steel*

> 50% of present market

Efficiency of Electric machines

(100kW automotive traction motor)

$$\eta = \frac{P_{mec}}{P_{el}}$$

~ 96%

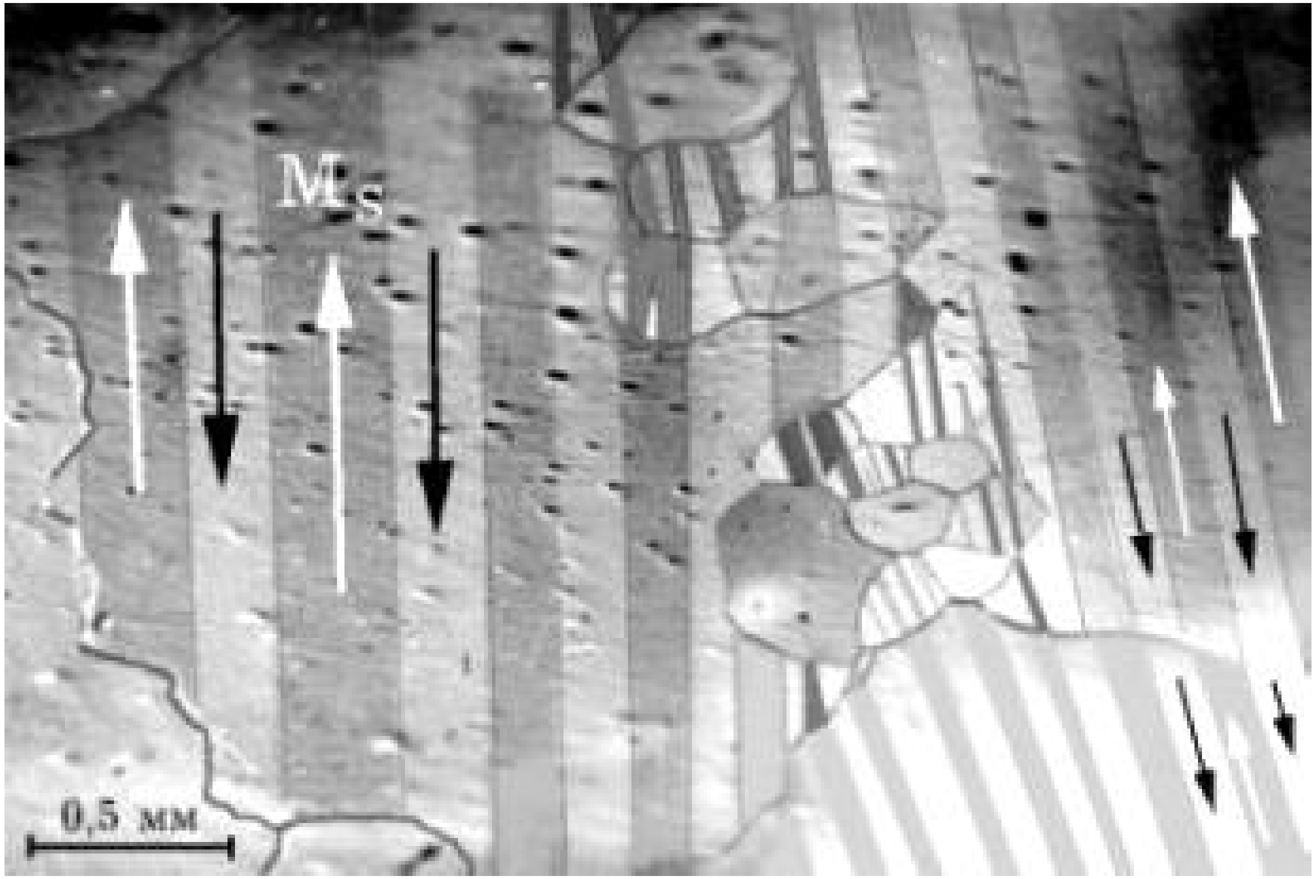
Motor for electric vehicle, liquid cooled

Main Factor

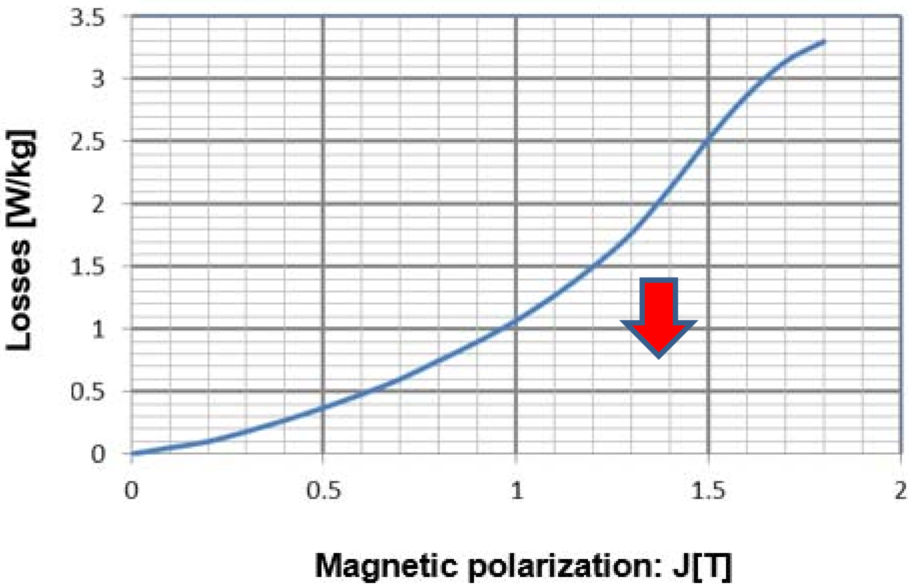
$$P_{el} = P_{mec} + L_{mec} + \boxed{L_{Wires}} + L_{Iron}$$

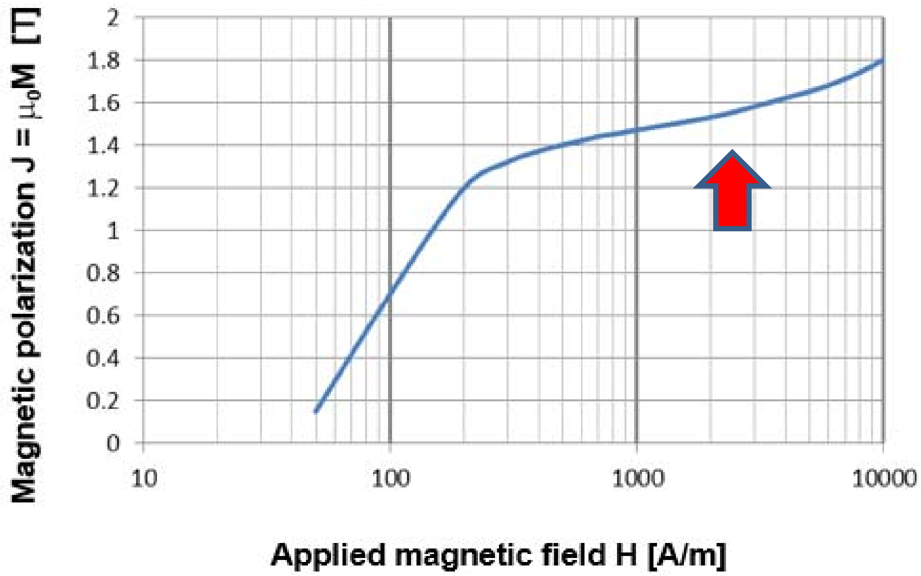
Losses reducing the efficiency

Magnetic domains in a polycrystalline material



Characteristic curves (M250-50 A)





Best materials

Electric machine efficiency

Best materials

Torque/power density of electric machine

Different iron losses components

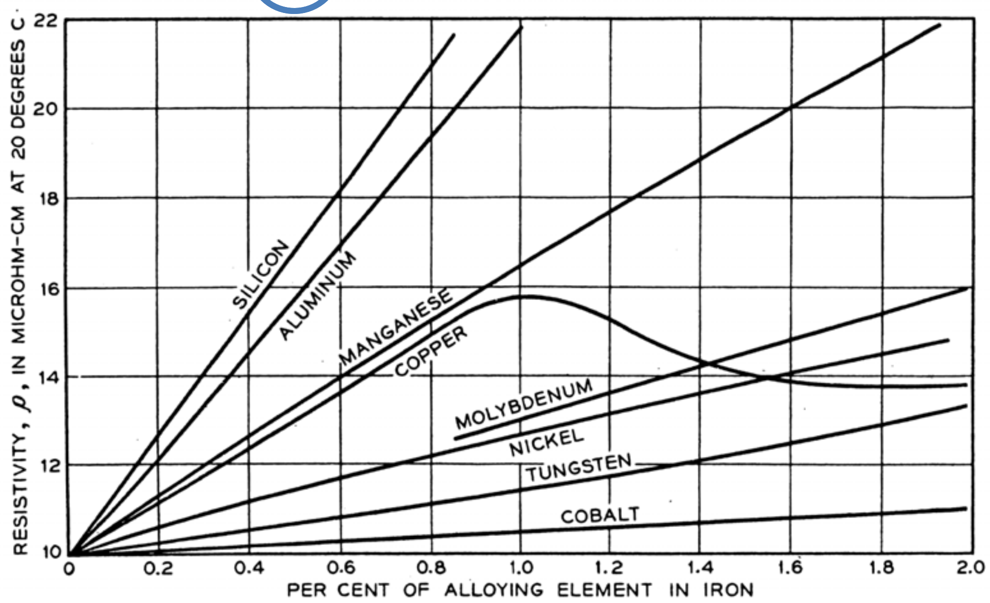
$$P_{el} = P_{mec} + L_{mec} + L_{Wires} \boxed{+ L_{Iron}}$$

$$L_{Iron} = \boxed{L_h f} + \boxed{\frac{\pi}{6}\frac{d^2}{\rho}(B_{\max} f)^2} + \boxed{8(B_{\max} f)^{3/2}\sqrt{\frac{GSV_0}{\rho}}}$$

Losses for hysteresis
Classic dynamic losses
Anomalous losses

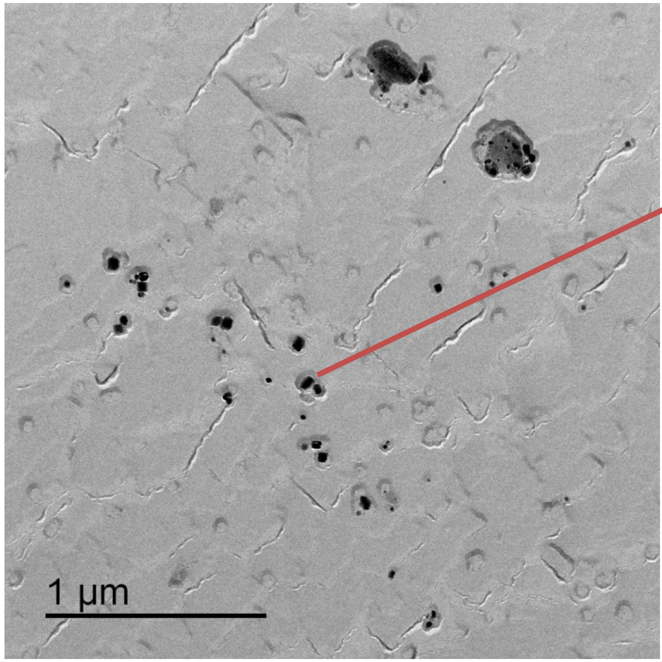
Effect Of Different alloying elements on Resistivity

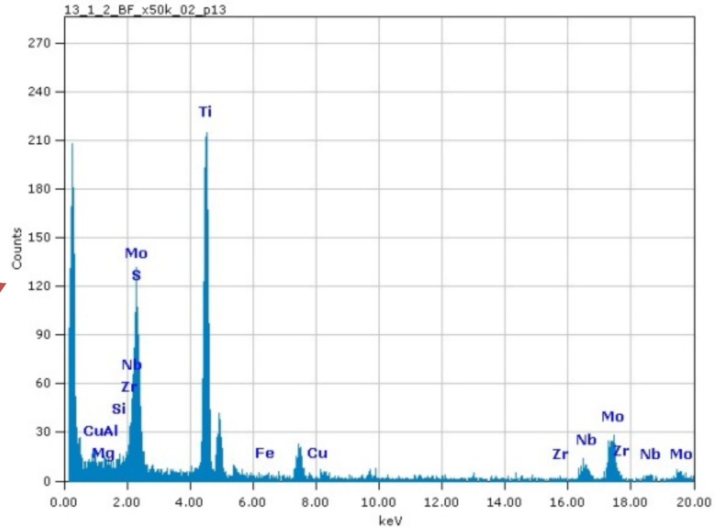
$$L_{Iron} = L_h f + \frac{\pi}{6}\frac{d^2}{\rho}(B_{\max} f)^2 + 8(B_{\max} f)^{3/2}\sqrt{\frac{GSV_0}{\rho}}$$



For this reason Si, Al, Mn, are used as alloy elements in electrical steel

Second Phases (TEM)





$$L_{Iron} = \boxed{L_h f} + \frac{\pi}{6}\frac{d^2}{\rho}(B_{\max} f)^2 + 8(B_{\max} f)^{3/2}\sqrt{\frac{GSV_0}{\rho}}$$

Effect Of Grain Size

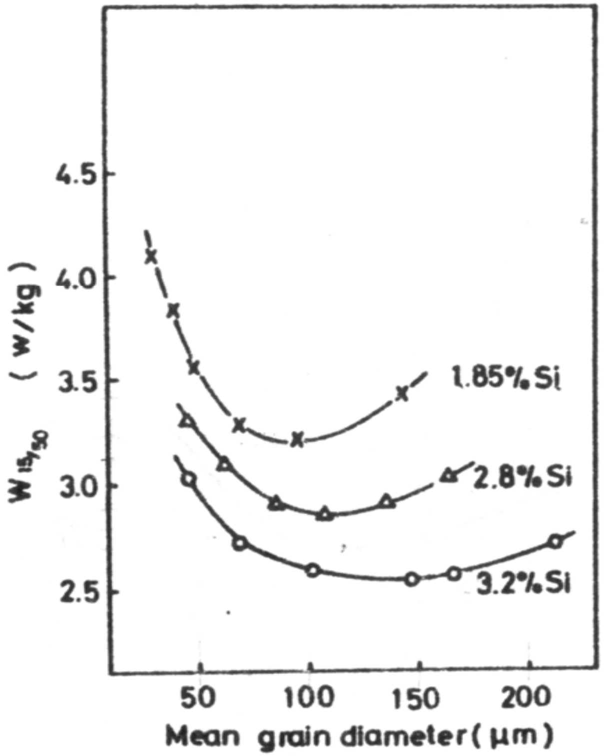
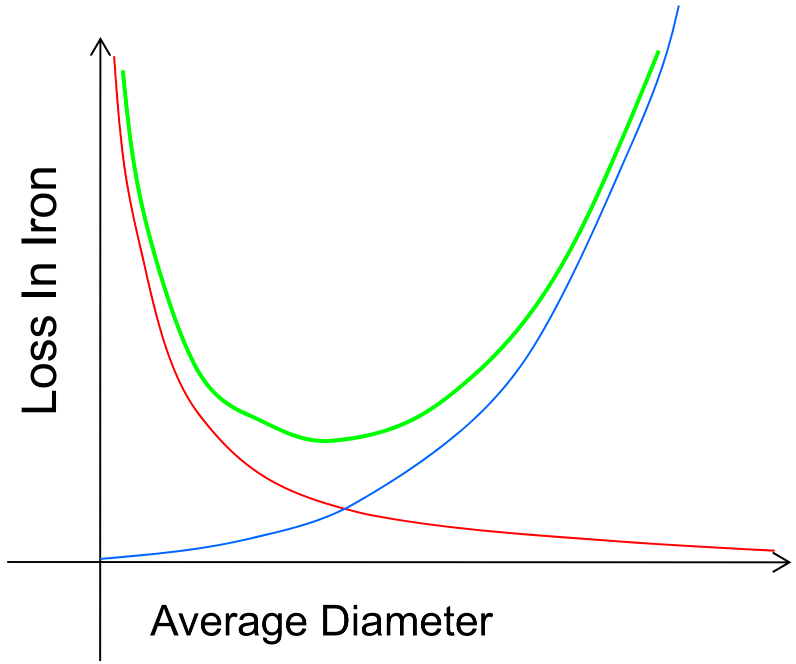
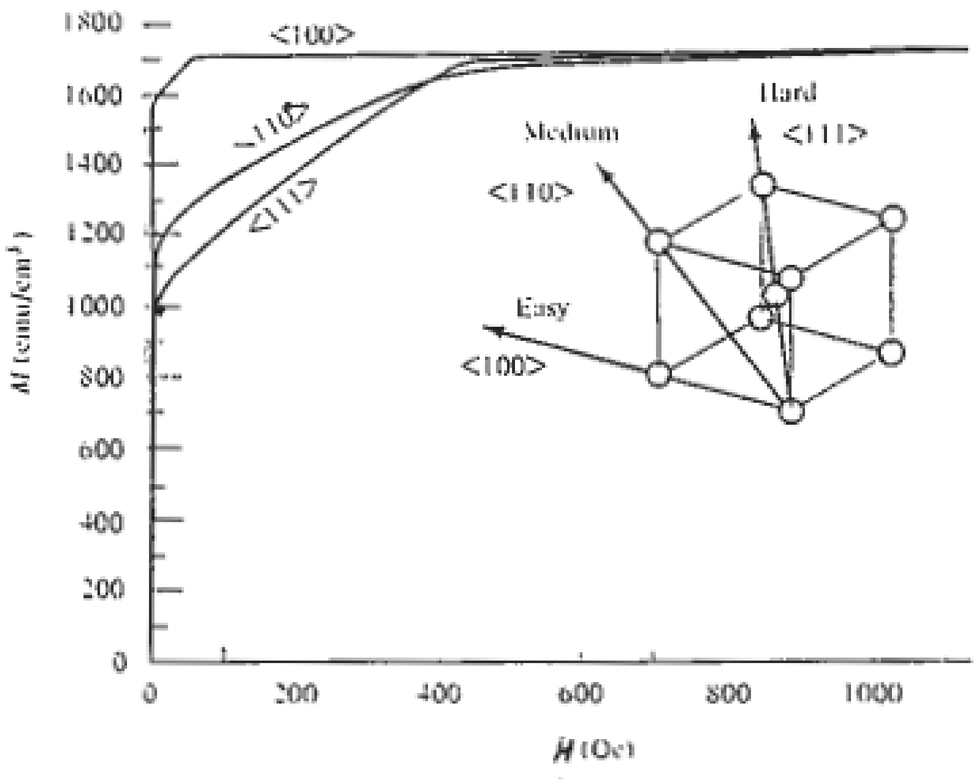


Fig.1 Influences of grain size on core loss of 1.85, 2.8 and 3.2% silicon steels

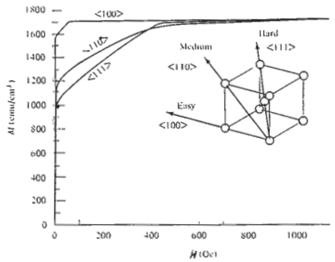


$$L_{Iron} = \boxed{L_h f} + \frac{\pi}{6}\frac{d^2}{\rho}(B_{\max} f)^2 + \boxed{8(B_{\max} f)^{3/2}\sqrt{\frac{GSV_0}{\rho}}}$$

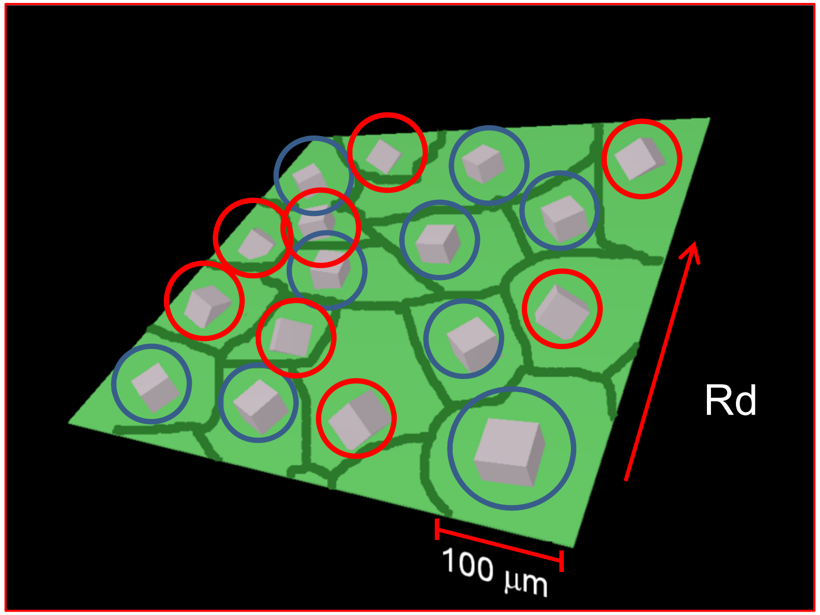
Effect of Crystalline Orientation



Effect of Crystalline Orientation



The favorable orientations are those for which the <100> direction is parallel to the rolling plane



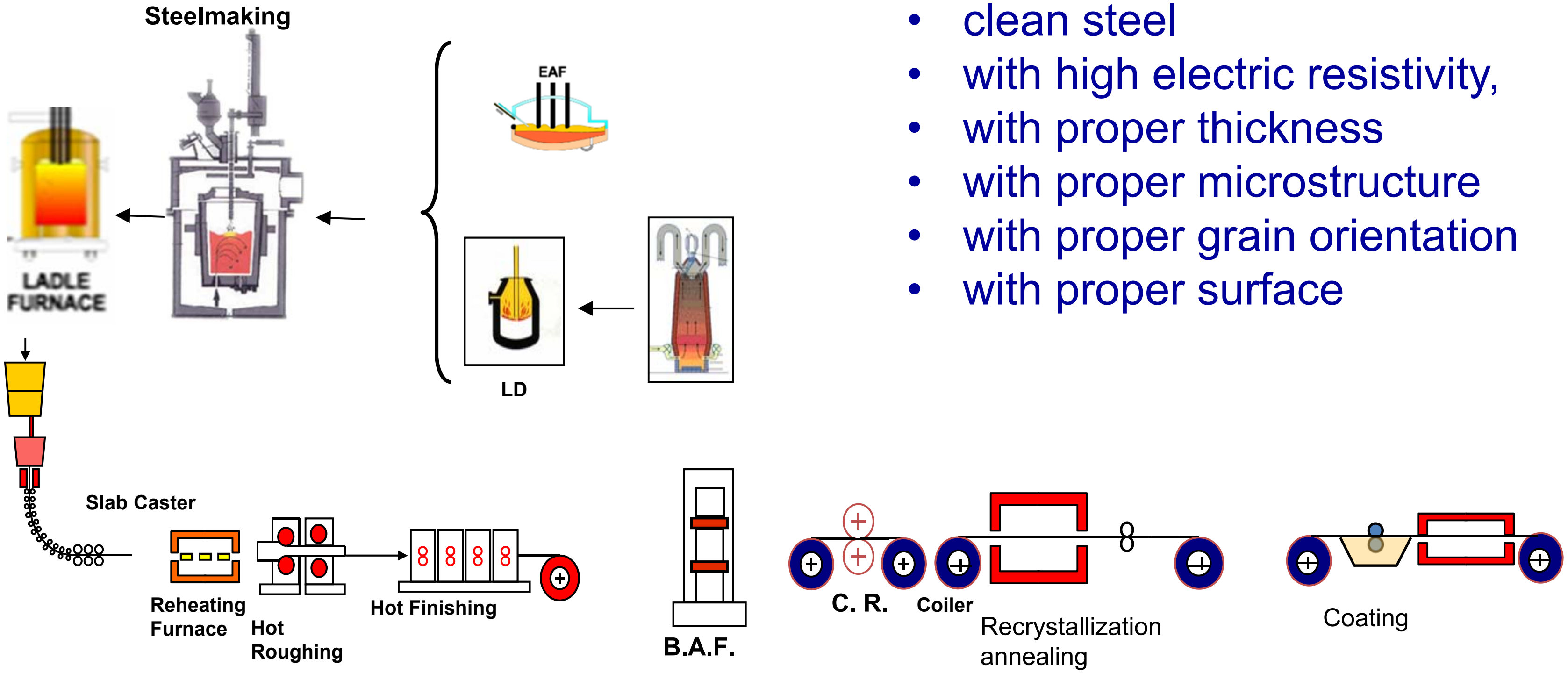
Favorable orientations

Non favourable orientations

NGO production cycles

The aim of the metallurgy of NGO electrical steel is to produce:

- clean steel
- with high electric resistivity,
- with proper thickness
- with proper microstructure
- with proper grain orientation
- with proper surface



Automotive applications

Engine for HV/EV

Power range : 50 - 100 kW

Up to 300 kW for high power commercial application

High torque (low speed)
High power (high speed)
Working frequency : up to 1000Hz or higher.

Losses very important: low thickness material (0.20 mm-0.35 mm).

Typical core weigth 0,5-0,75 kg/kW

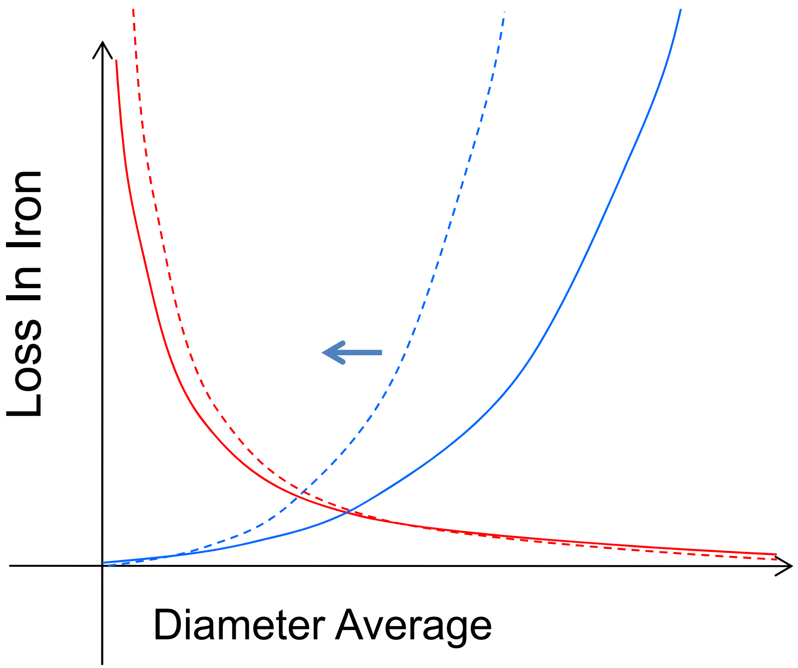
Characteristics of the lamiations in case of high frequency applications

$$L_{Iron} = \boxed{L_h f} + \boxed{\frac{\pi}{6}\frac{d^2}{\rho}(B_{\max} f)^2} + \boxed{8(B_{\max} f)^{3/2}\sqrt{\frac{GSV_0}{\rho}}}$$

Losses for hysteresis
Classic dynamic losses
Abnormal losses

- High resistivity $\Rightarrow$ High Si and Al
- Classical losses are depending on square of frequency and on square of thickness low thickness material is necessary to compensate the effect of frequency.

Characteristics of the lamiations in case of high frequency applications



$$L_{Iron} = \boxed{L_h f} + \frac{\pi}{6}\frac{d^2}{\rho}(B_{\max} f)^2 \boxed{+ 8(B_{\max} f)^{3/2}\sqrt{\frac{GSV_0}{\rho}}}$$

At high frequency the anomalous losses grow more than hysteresys losses.

As a consequence the oprimal grain size decreases

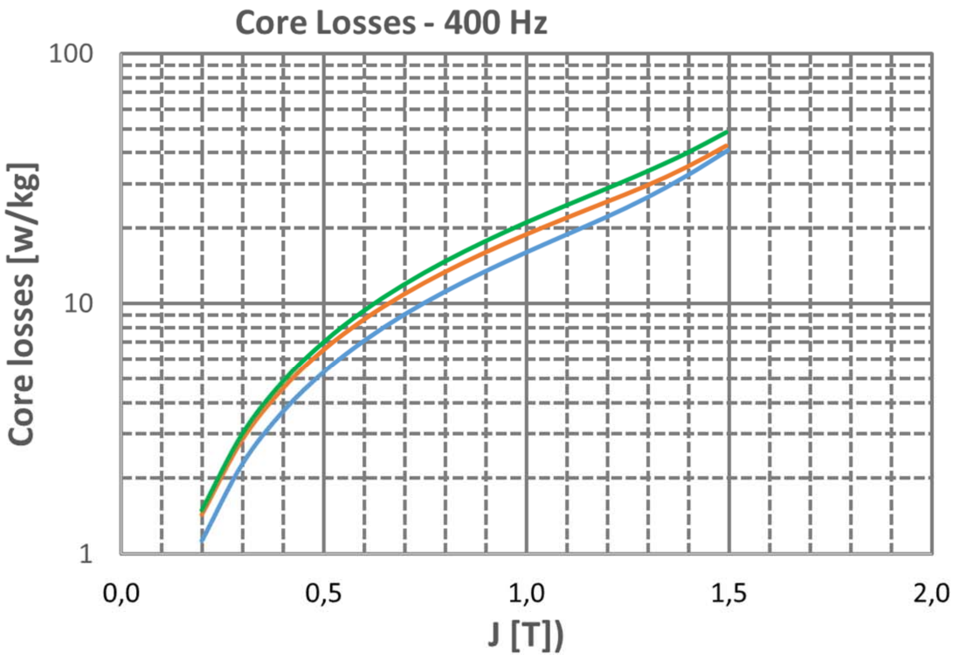
ReFreeDrive Project Objective

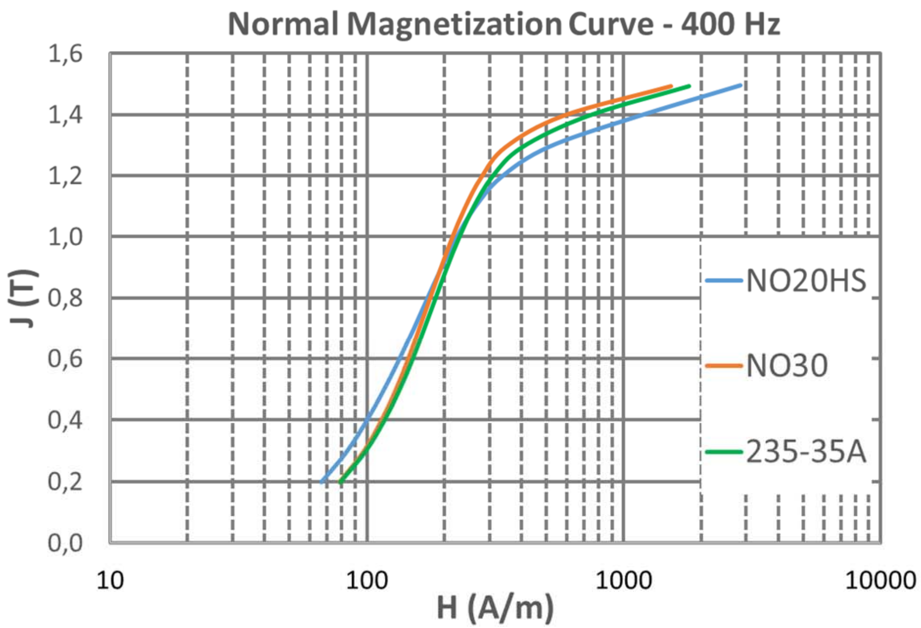
The main aim of this project is to develop **rare earth-free traction technologies** beyond their current state-of-art, with a strong focus on industrial feasibility for mass production, targeting lower costs with higher specific torque and power density

Project partners

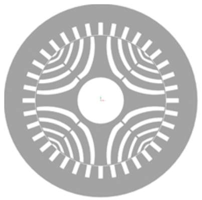
Participant No *	Participant organisation name, Short Name	Country
1 (Coord.)	Fundación CIDAUT, CID	Spain
2	European Copper Institute, ECI	UK
3	Motor Design Ltd, MDL	UK
4	Università dell'Aquila, UAQ	Italy
5	IFP Energies nouvelles, IFPEN	France
6	Rina Consulting - Centro Sviluppo Materiali, CSM	Italy
7	Tecnomatic , TEC	Italy
8	Mavel Powertrain Ltd, MAV	Italy
9	Breuckman, BREU	Germany
10	Aurubis, AUR	Germany
11	R13 Tecnology Srl, R13	Italy
12	Privé Srl, PRI	Italy
13	LIMCAR, LIM	Italy
14	Jaguar Land Rover, JLR	UK

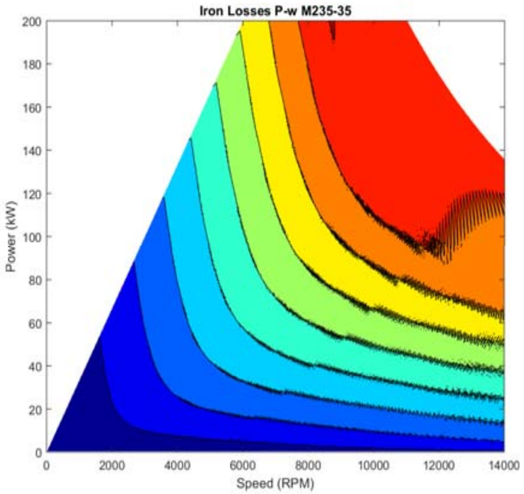
Characteristic curve measured after laser cutting at 400 Hz



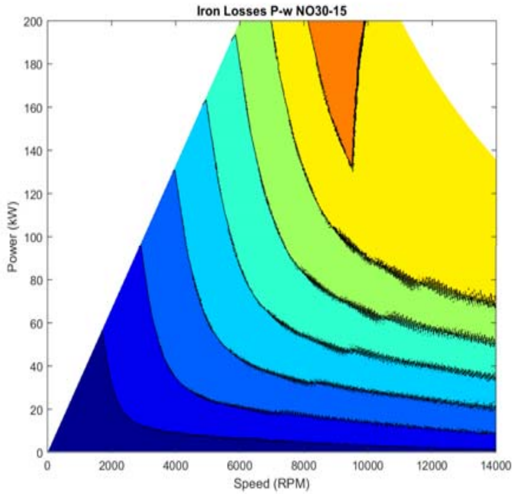


Core losses in Synchronous Reluctance motor 6pole-54slots 200kW (peak)

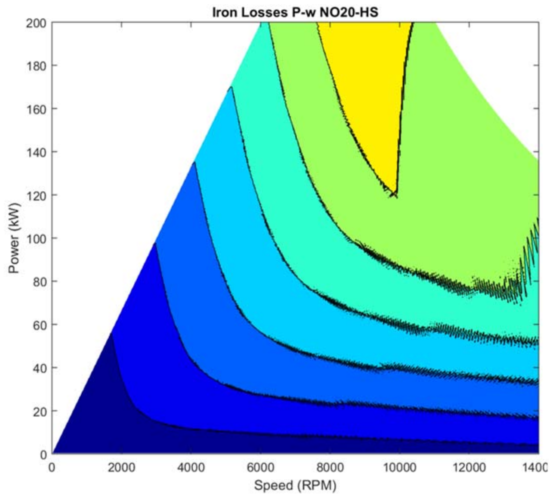




M235-35A



NO 30



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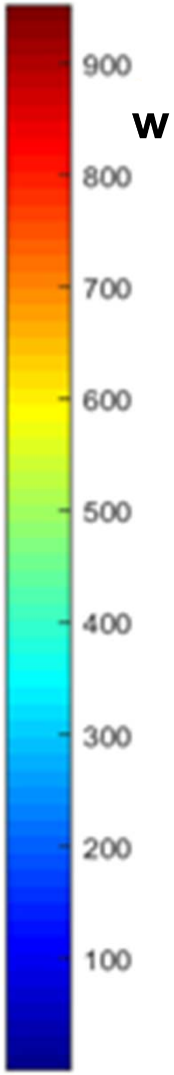
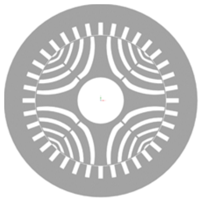
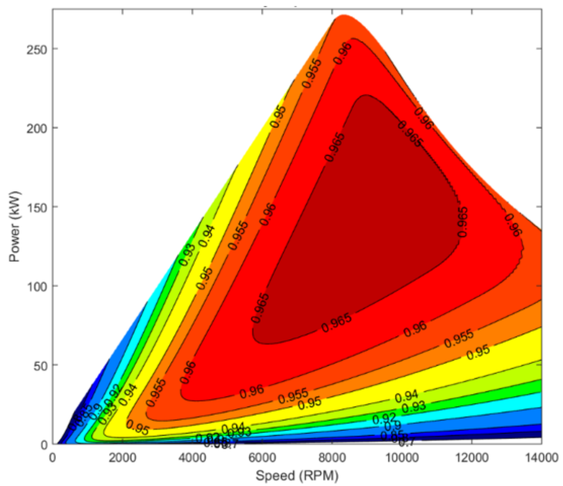


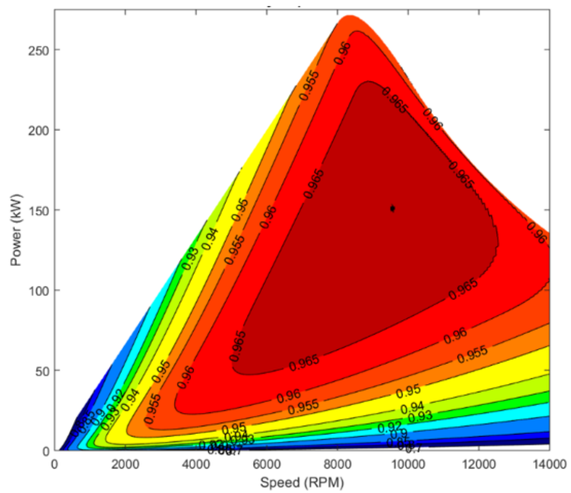
Efficiency in Synchronous Reluctance motor 6pole-54slots 200kW (peak)



ReFreeDrive



M235-35A



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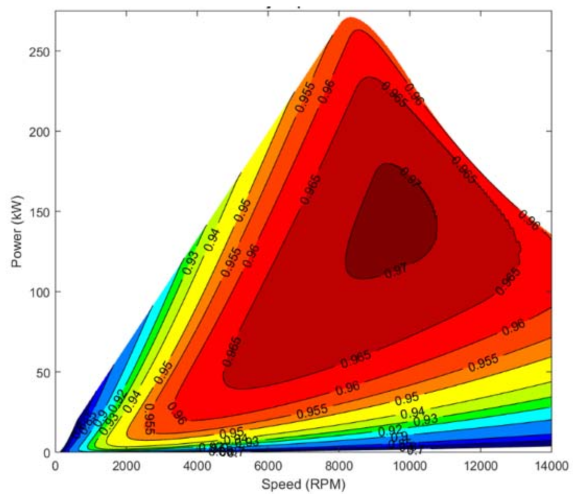

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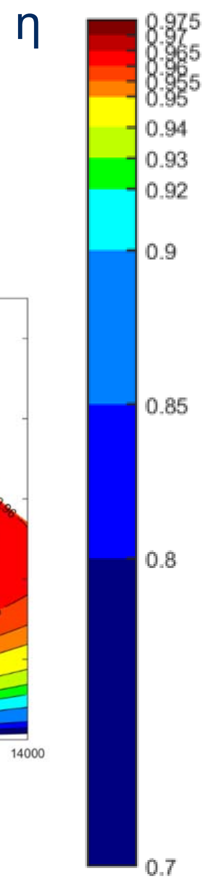
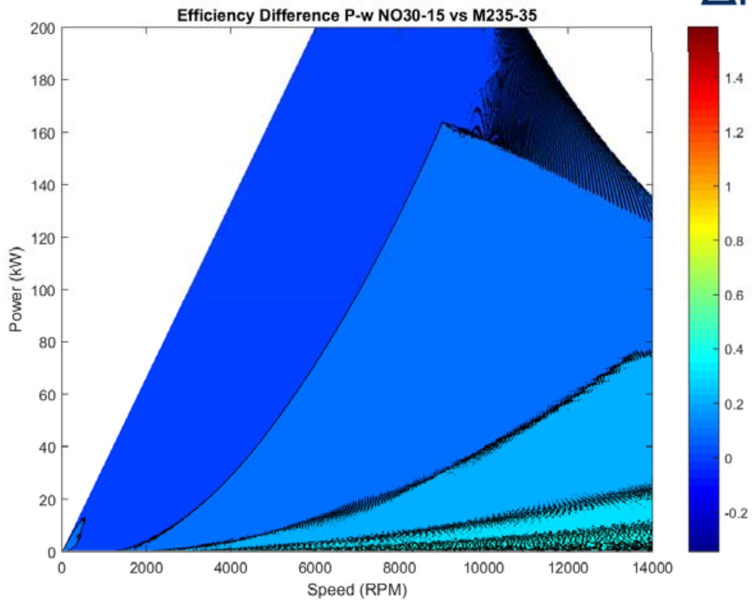


Gain of overall efficiency of 6pole-54slots 200kW reluctance motor realized with NO30 and NO20 respect M235

Δη %



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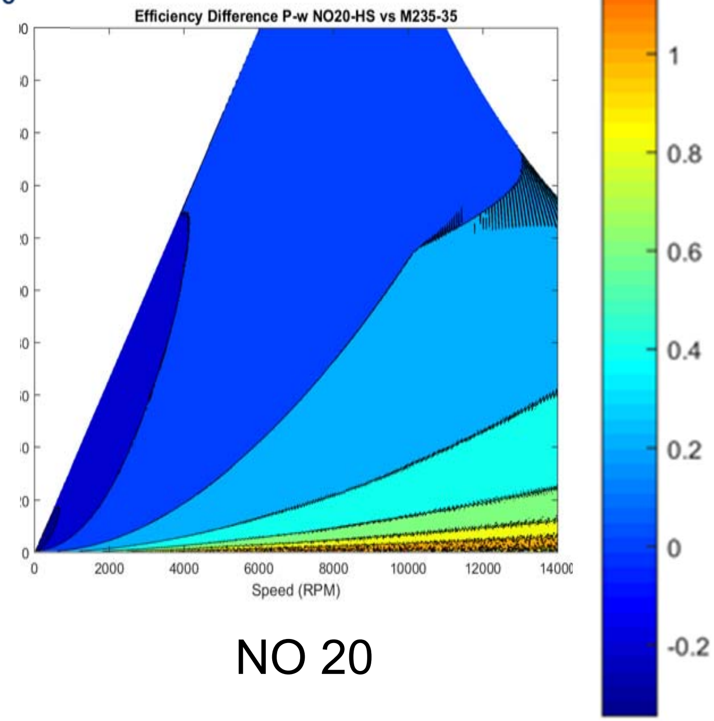
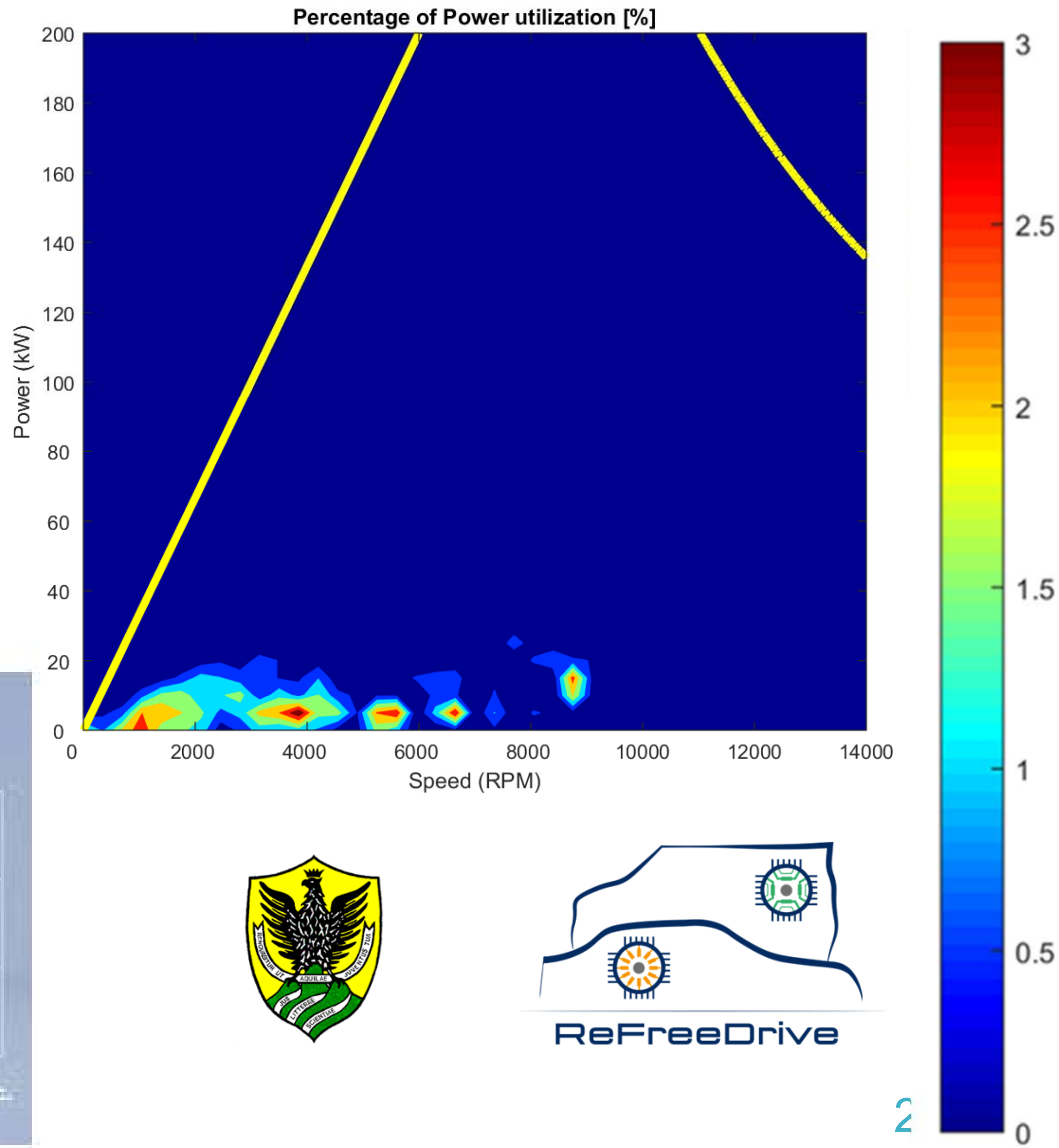
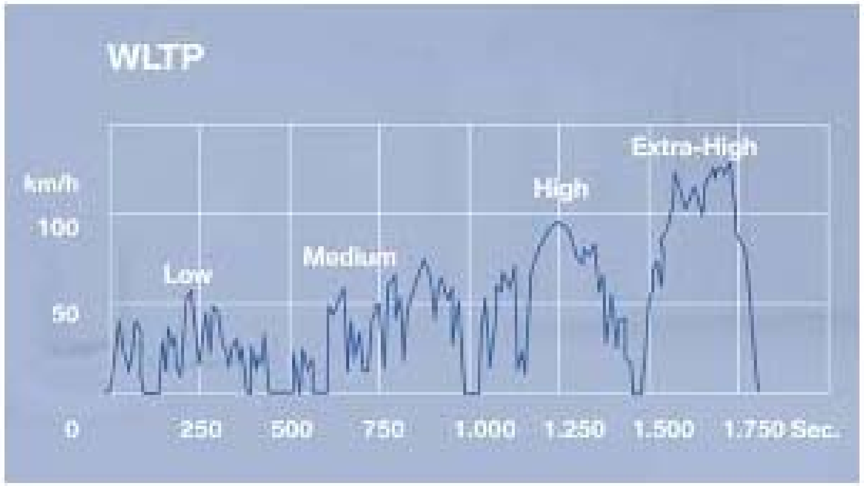


NO 20

Percentage of Power Utilization



WLTP reference driving cycle



Conclusions

- Thanks to R&D efforts performed by producers and academic institution nowadays there is a deep knowledge of the mechanisms determining the FeSi magnetic characteristics.
- Such a knowledge has allowed to develop high quality standardized product which can be found on the market.
- The growth of electric mobility gives to the materials producers the opportunity to develop products with specific characteristics, suitable for application in traction motors
- Magnetic characterization of commercial grades and study of influences on Motor Efficiency gives indications on necessary metallurgical improvement of NGO products for the future

Thanks for the Your attention!

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