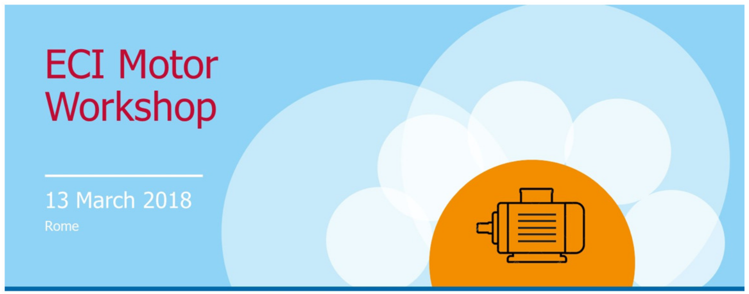
UNIVERSITY OF L'AQUILA

DEPARTMENT OF INDUSTRIAL AND INFORMATION ENGINEERING AND ECONOMICS

High Efficiency IE4 line-start PM motors

M. Villani



Introduction

The Super-premium efficiency **IE4** is the current target of motor manufacturers.

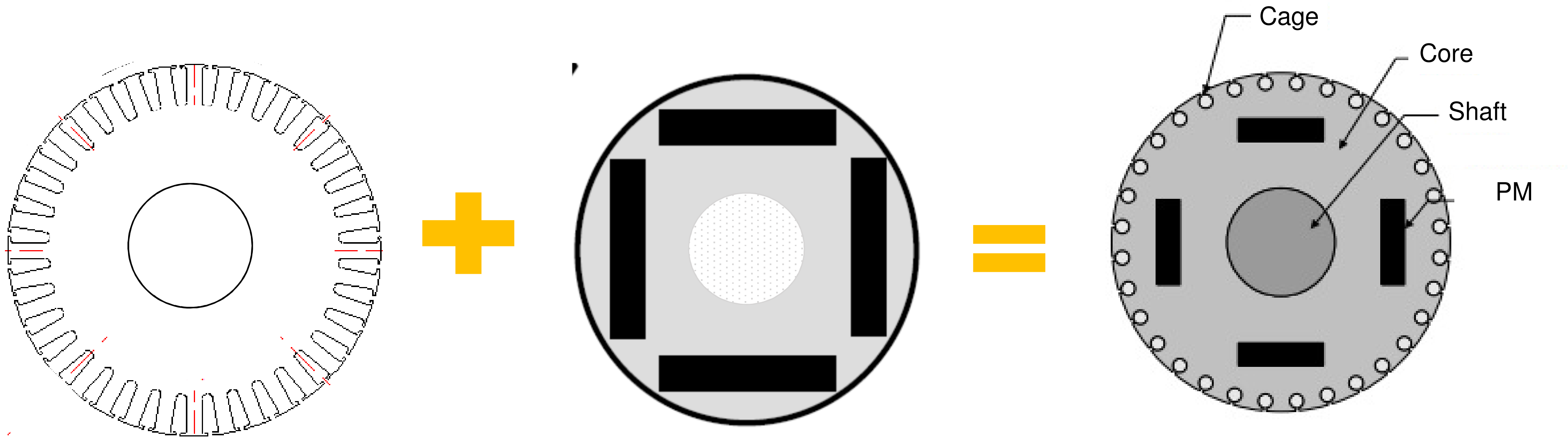
The efficiency improvements achieved with Induction motors have been mostly accomplished by adding material. In order to achieve high efficiency levels, it has been recognized that a **different technology** must be employed.

Inverter-fed PM motors or Synchronous reluctance motors are the likely technology to reach IE4 levels.

For **constant speed** applications the **Line-start PM motor** (LSPMM) is a viable solution to reach **IE4** efficiency levels without inverter.

High efficiency, low losses (resulting from the elimination of rotor losses) make LSPPM suitable in high-duty applications and it is a potential **competitor** to Induction motor especially for **small rated power**.

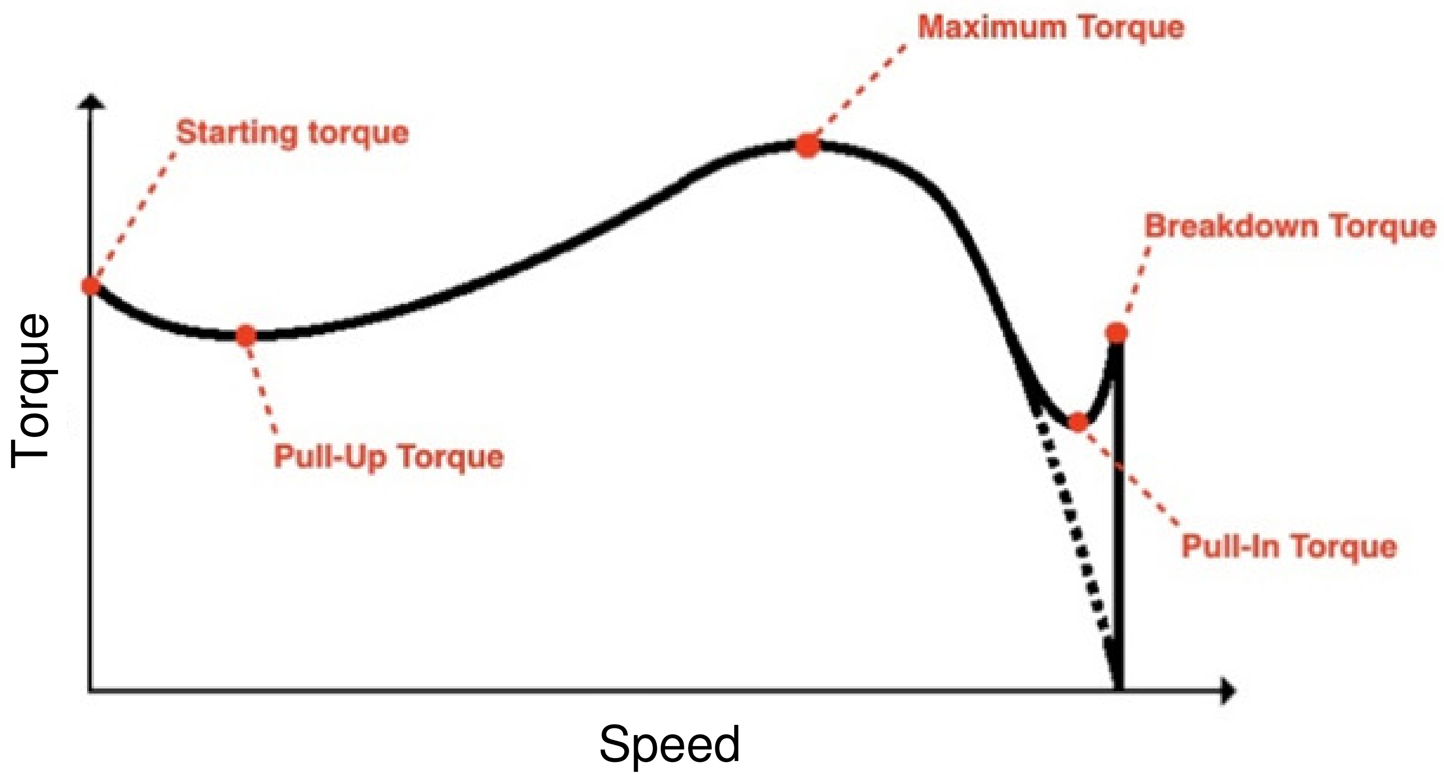
The line-start PM motor is like an **hybrid** between a squirrel cage induction motor and a synchronous motor with PM



The presence of squirrel-cage in the PM rotor makes it capable to start **without drive**; then, the motor runs at synchronous speed (slip=0).

To successfully starting and synchronizing process for the LSPMM the **squirrel cage design** is important.

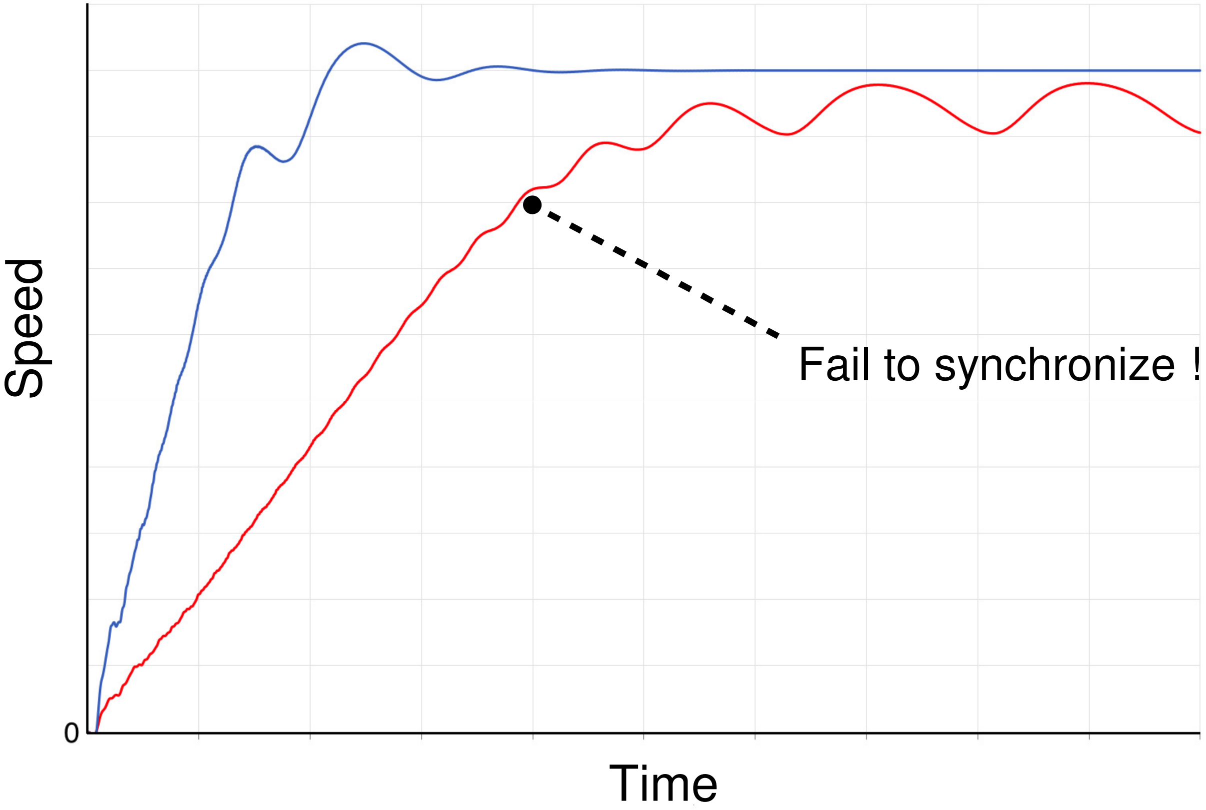
Typical Torque vs. Speed curve



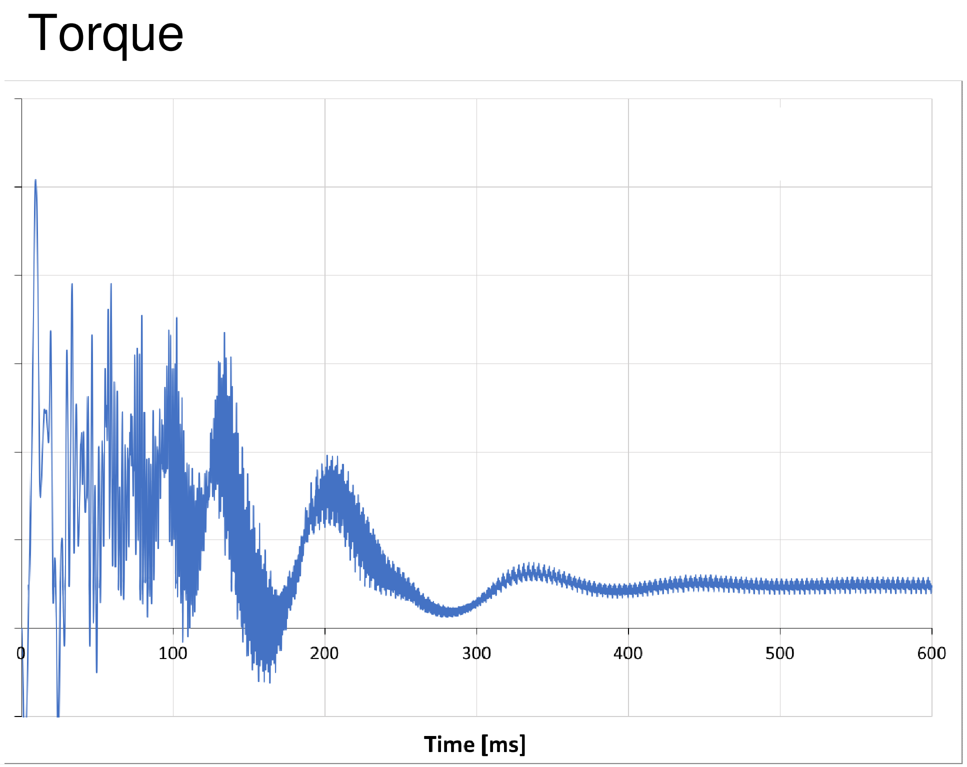
It is a combination between the torque of the induction and the synchronous machine. What really characterizes the self-starting machine is the presence of the "pull-in" torque, that brings the rotor to operate at synchronous speed.

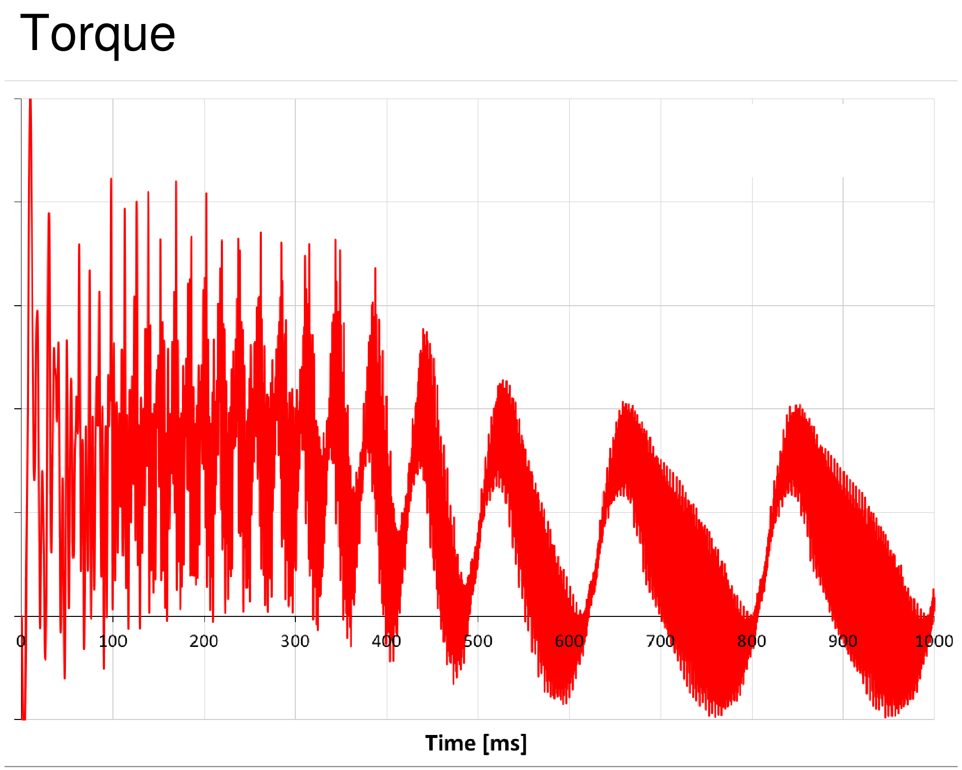
The **starting transient** of the LSPMM requires particular attention.
The synchronizing capability depends on the **inertia** of the load.

Loads with high inertia can cause the **failure** of the synchronization procedure, leading to unacceptable fluctuation of speed, torque and current. The operation in this condition should be strictly avoided.



Torque vs. Time



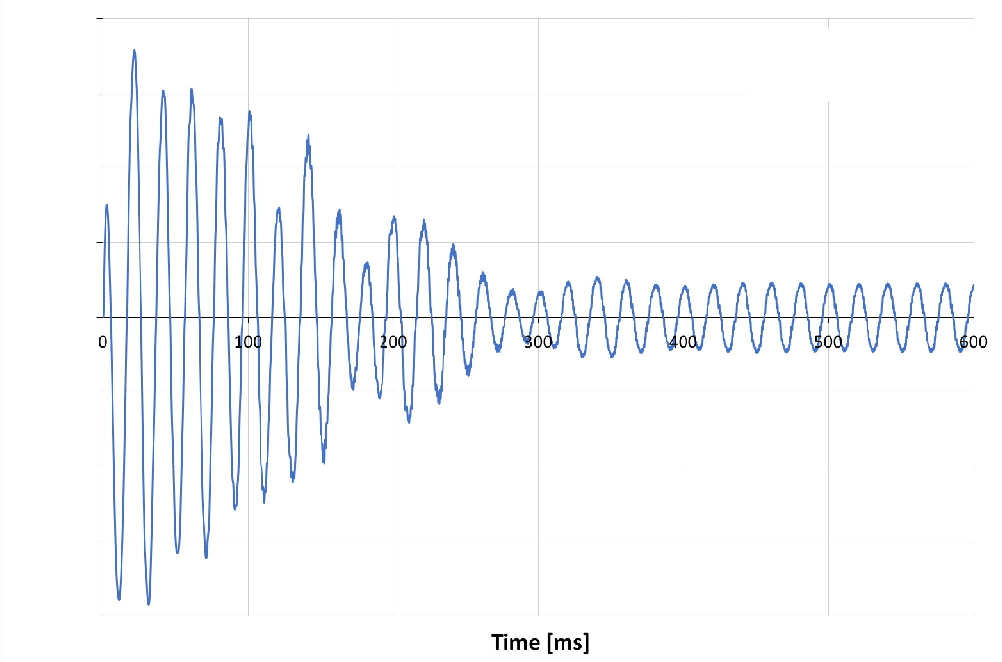


Successfull pull-in

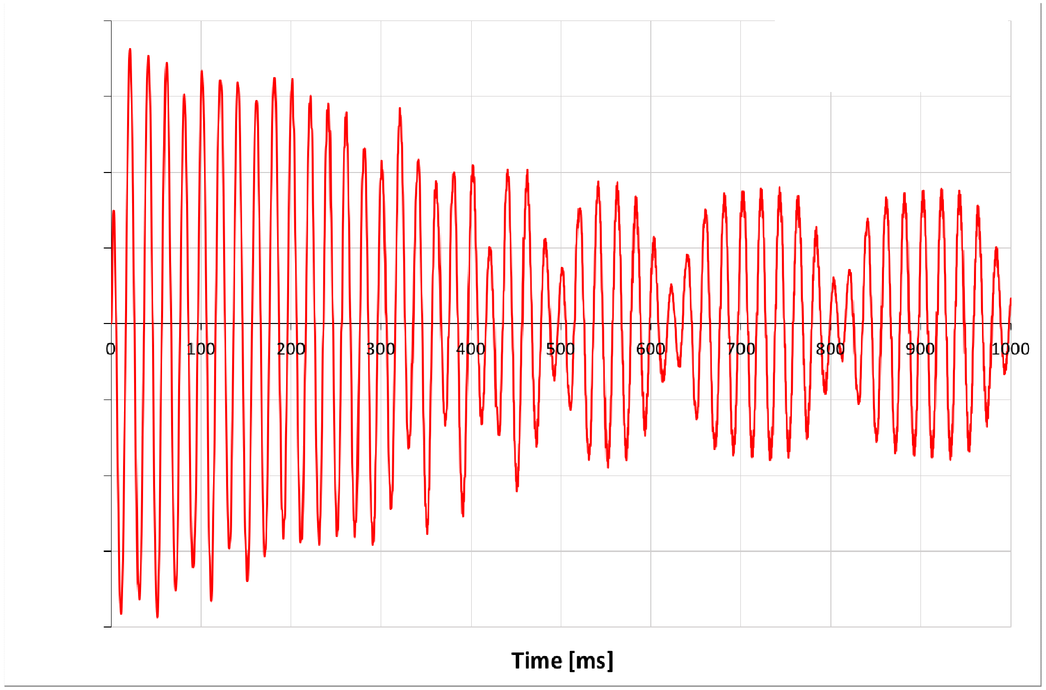
Unsuccessfull pull-in

Phase current vs. Time

Current



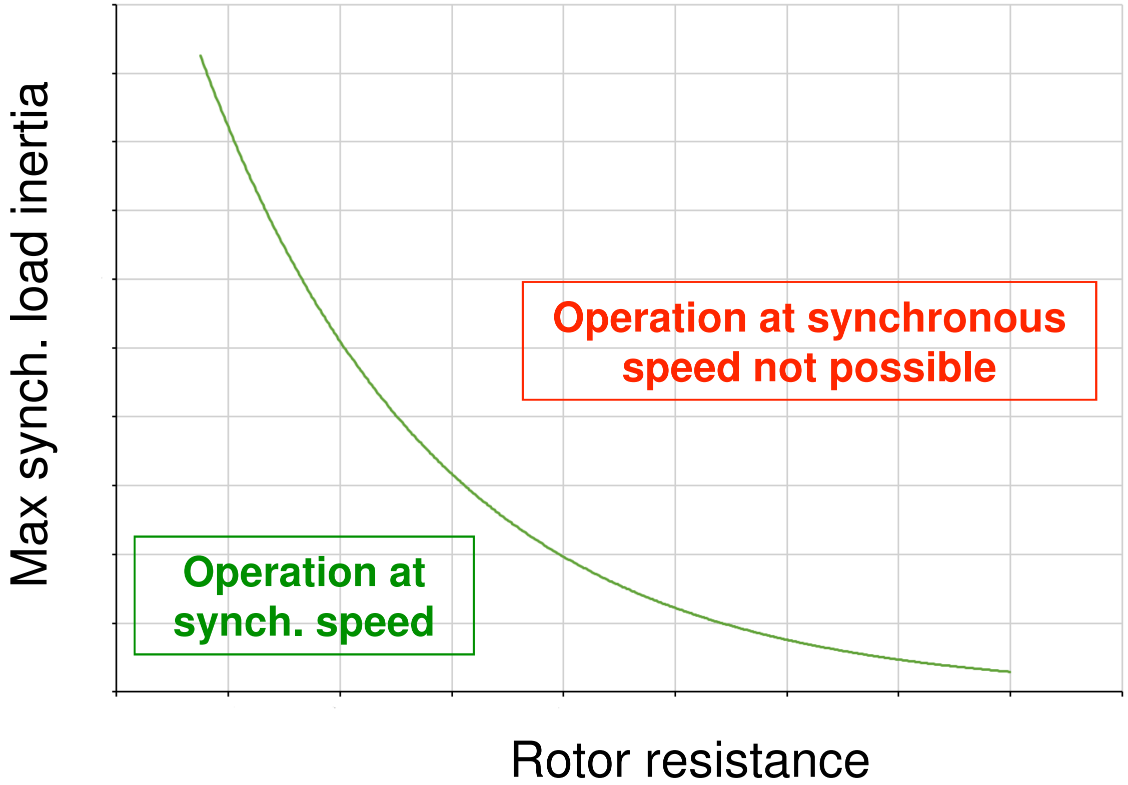
Current



Successfull pull-in

Unsuccessfull pull-in

The maximum load inertia that it is possible to garantee (for a given load torque) depends heavily on the **squirrel cage resistance.**



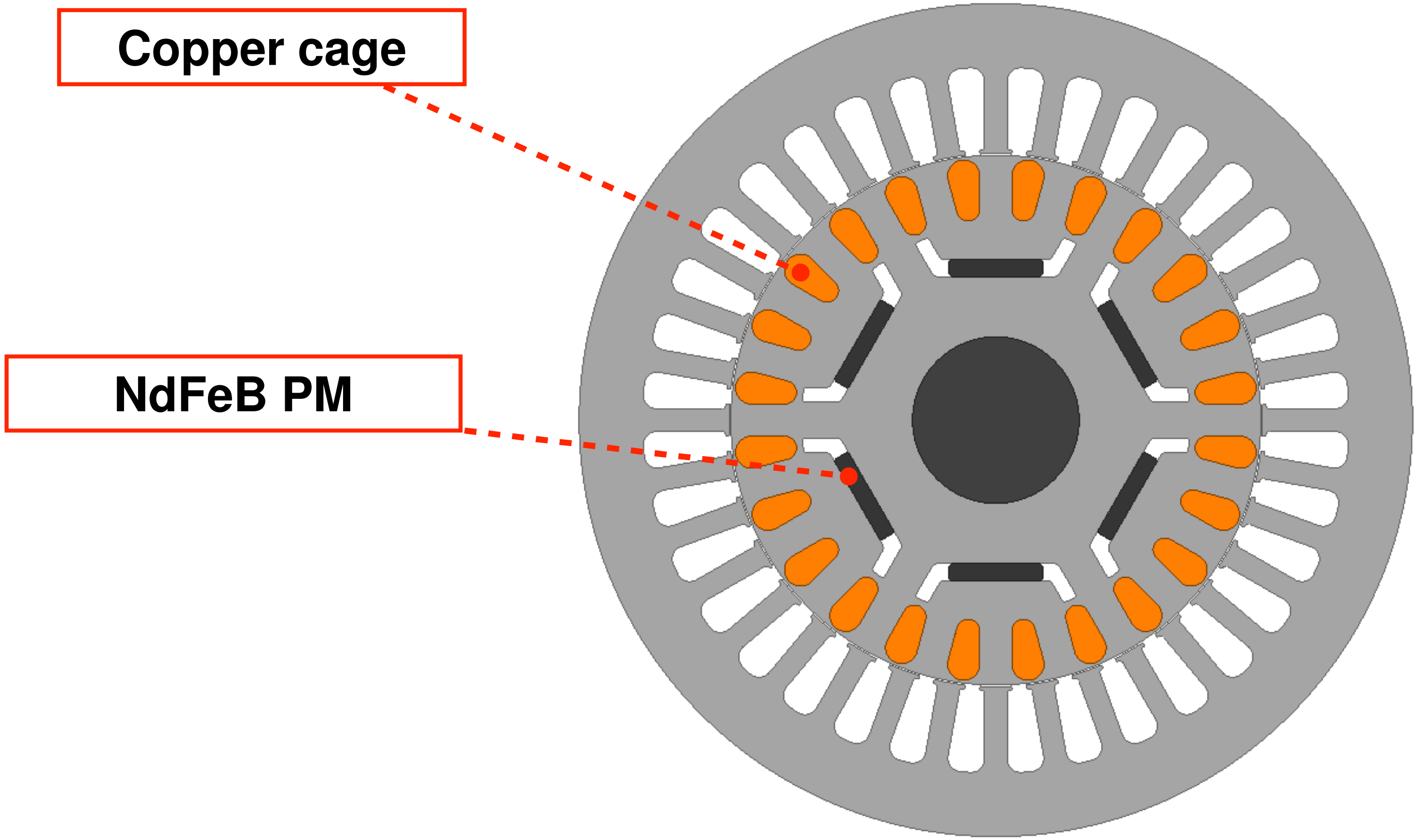
The adoption of a **die-casting Copper rotor** can significantly improve the starting performance, improving the range of applications of the LSPMM.

Design

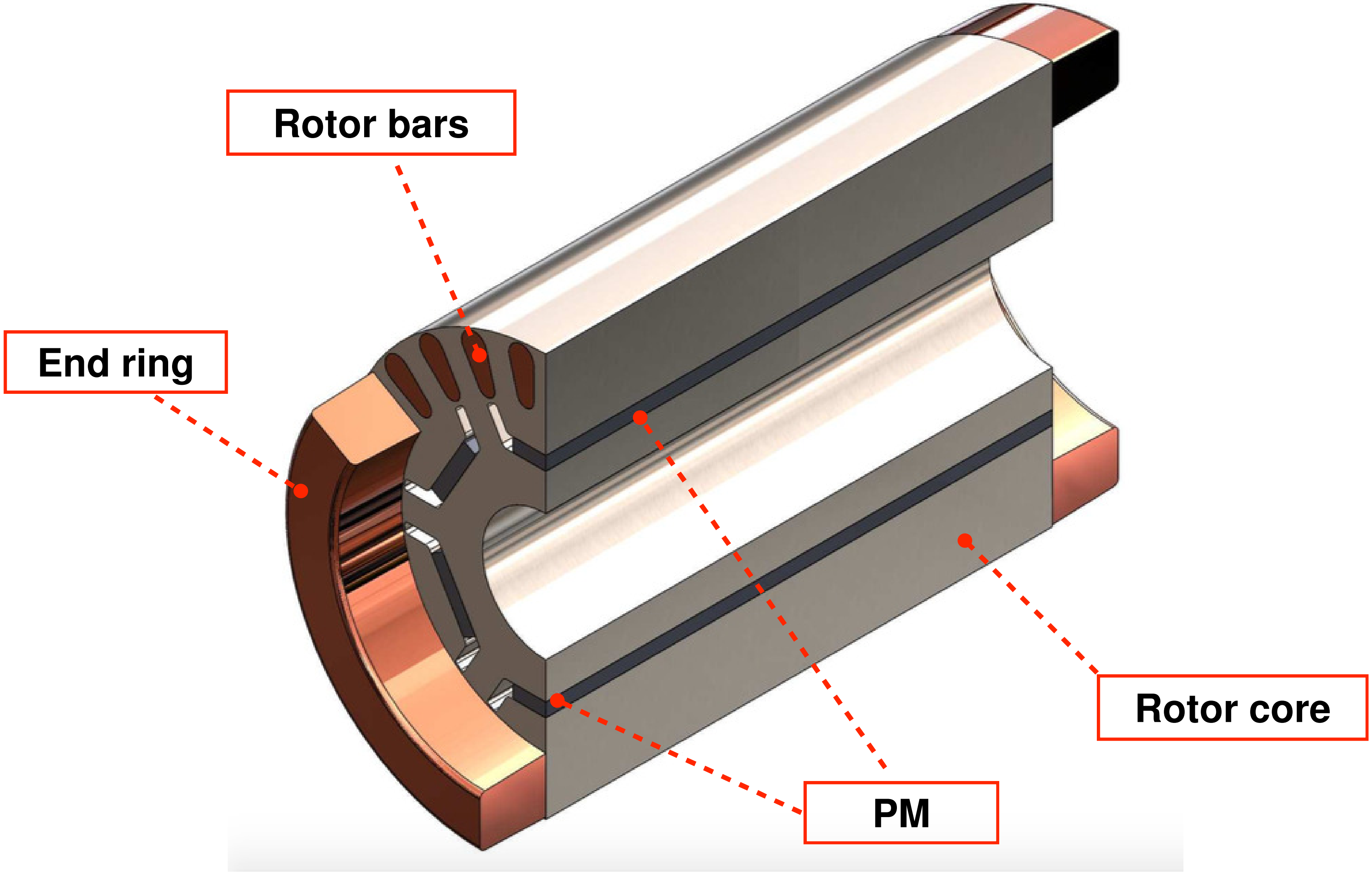
The design of high performance LSSRM should ensure a certain compromise between an adequate starting performance in the asynchronous operating region and efficiency at synchronous operation.

The **transient Finite Element analysis** has been taking on an increasingly important role in the design of the LSPMM.

A case study: 0.75 kW line-start PM motor, 6p, 400V/50Hz, **IE4**

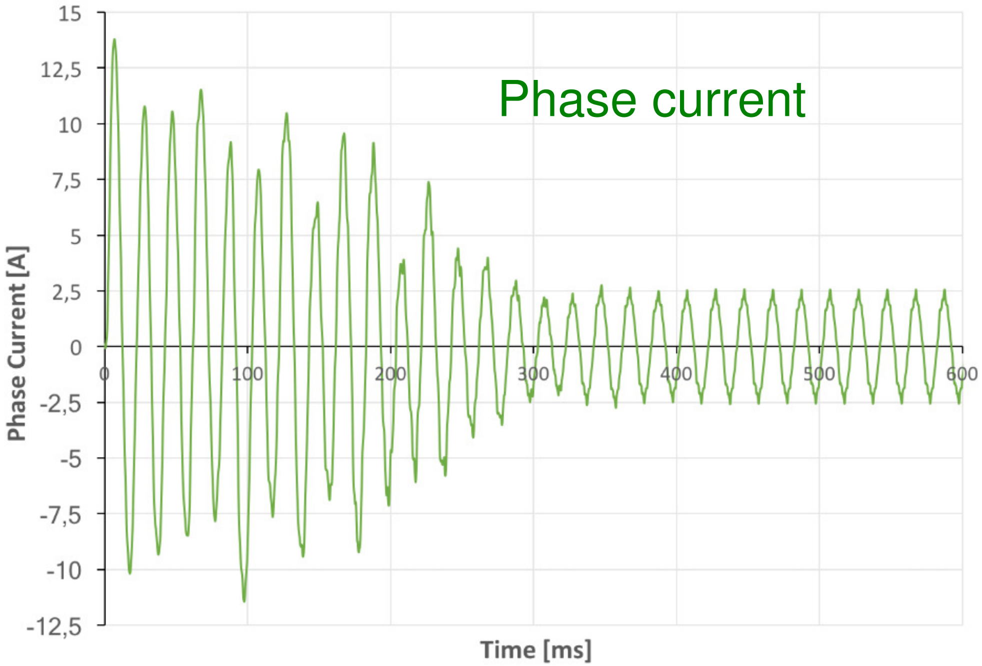


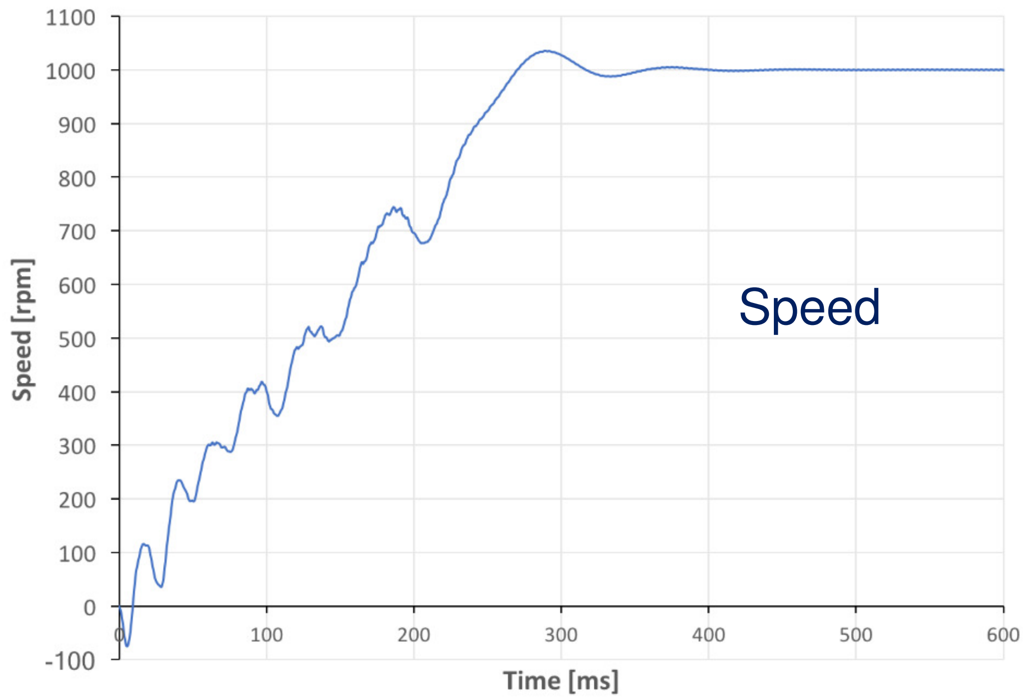
3D view of the rotor

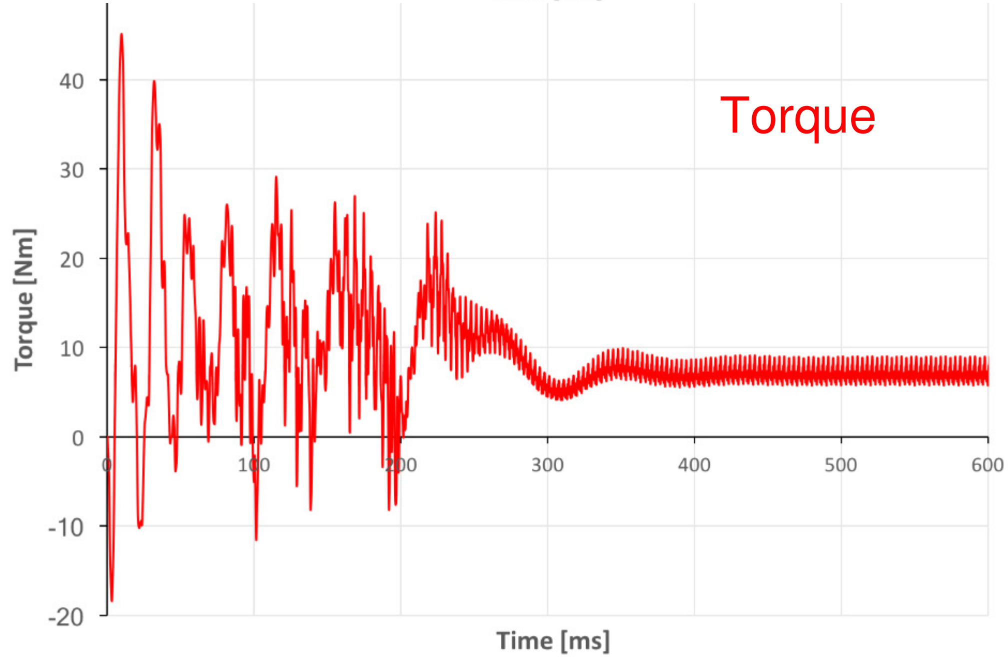


Transient Torque, Speed and Phase current vs. Time

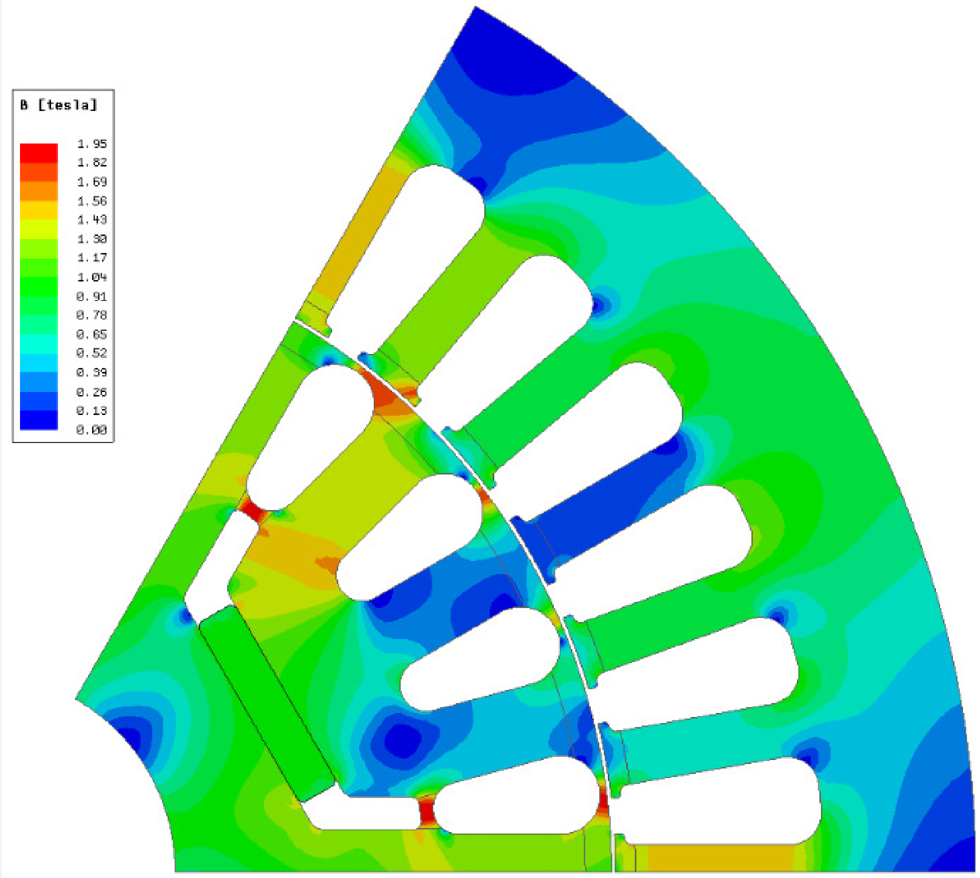
- Constant load Torque (7.2 Nm);
- Jload / Jrotor = 3





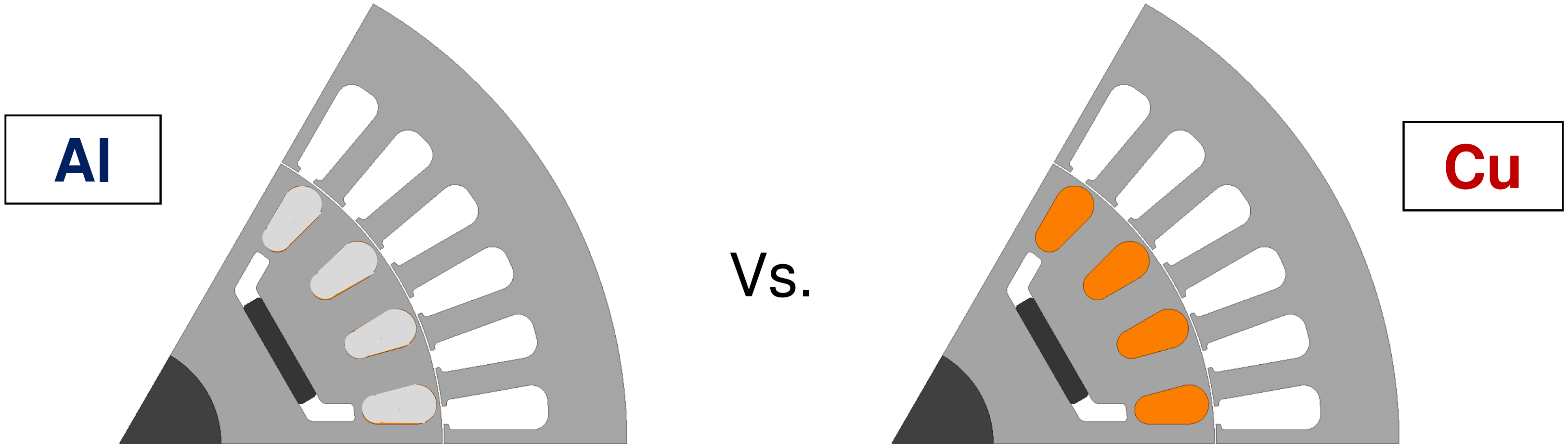


Flux density @ steady-state (synchronous speed)



Comparison IE4 LSPMM with Al and Cu die-casting rotor

0.75 kW, 6 pole, 400V/50Hz



- same design and rotor shape;
- same operating conditions (V, f, Torque, Temperatures)
- a constant load has been imposed (rated torque 7.2 Nm)

Performance @ steady-state and synchronous speed (slip = 0)

		Aluminium		Copper
Power	kW		0.75	
Speed	rpm		1000	
Phase current	Arms		1.62	
Losses in the rotor cage	W		≈ 0	
Total losses	W		152	
Efficiency	%		**83.1**	(IE4 = 82.7%)
Rotor weight	kg	3.6		4.5
Rotor inertia	kgm^2	$26\ 10^{-4}$		$37\ 10^{-4}$
Max synch. load inertia	kgm^2	$94\ 10^{-4}$		$224\ 10^{-4}$
Jload / Jrotor		3.6		6.0

- The Al squirrel-cage has a low rotor weight, but its high resistance results in a poor starting performance.
- Despite its weight, the Cu squirrel cage rotor is capable to operate a load with higher inertia ➡ wide range of applications !

Proposed Actions

It is difficult to reach high efficiency levels (**IE4**) with traditional Induction motor. The LSPMM could be a potential competitor.

- to promote the **high efficiency IE4** Line-start PM motor with **copper** cage for **constant speed** applications (no drive) especially in the low power ranges (→ general-purpose motors that operate more or less continuously).

- to demonstrate the advantages of copper cage respect to the Al cage (→ prototypes and tests).

Contribution UnivAQ → Modelling and design of LSPMM and experimental tests in the UnivAQ Laboratory