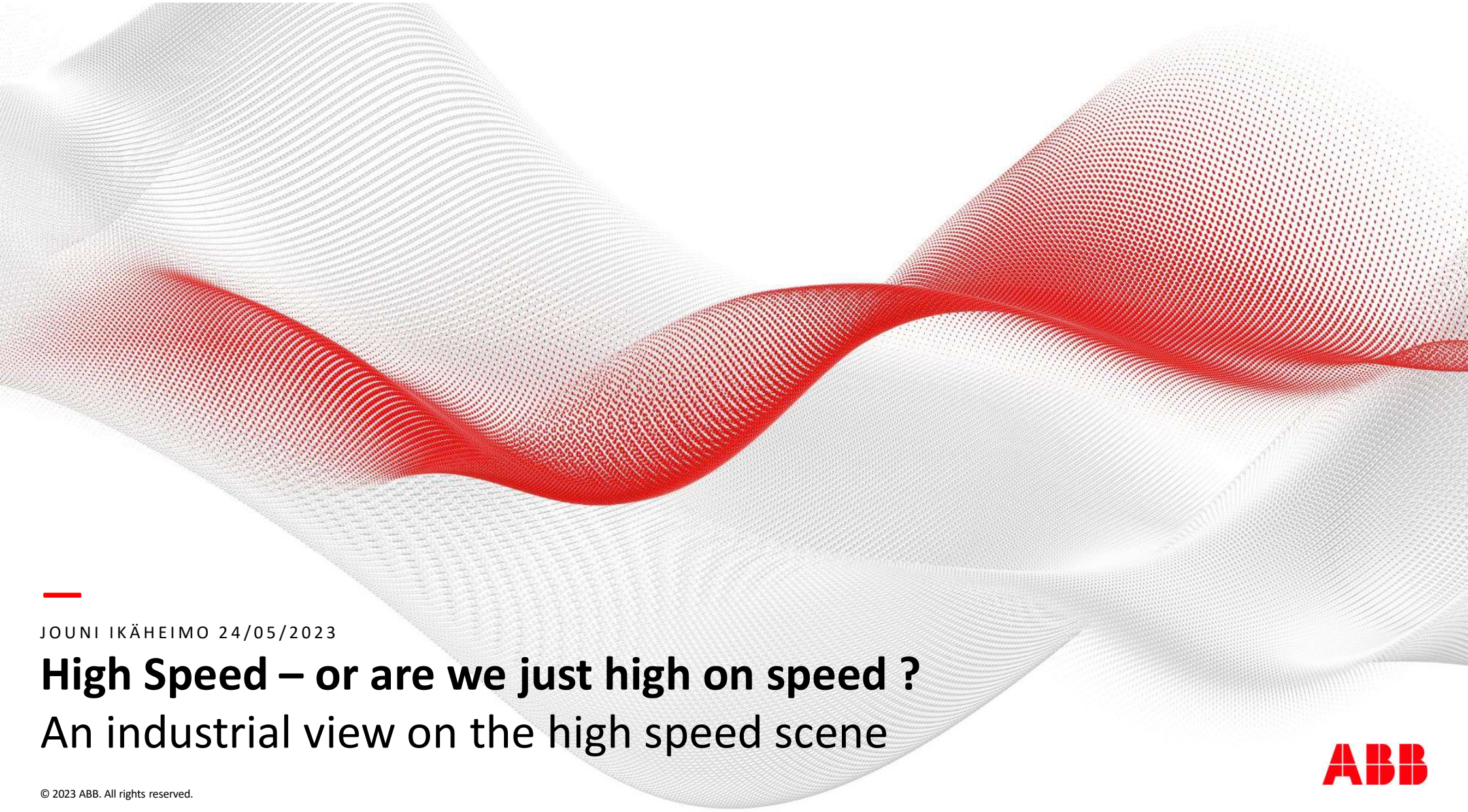


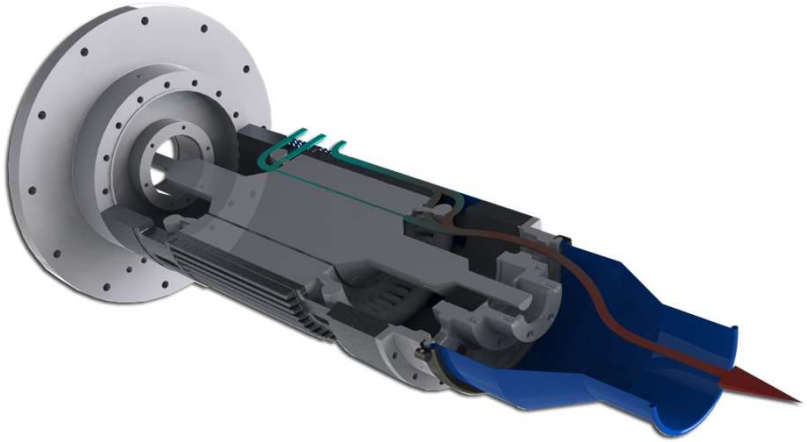
JOUNI IKÄHEIMO 24/05/2023

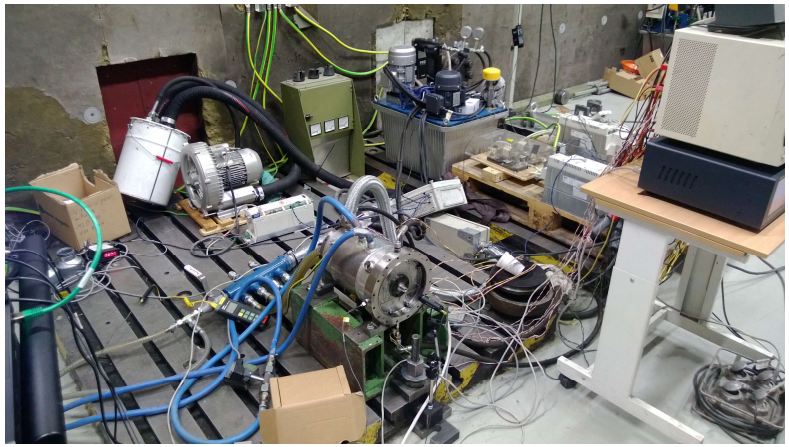
High Speed – or are we just high on speed ?

An industrial view on the high speed scene

High Speed
Introduction

- My definition of High Speed motor = a completely customized customer specific design, not modified from catalogue products
- In order to meet the speed and output requirements, one needs to introduce new technologies that are not present in the catalogue motors.
- In 2010's ABB carried out a technology development program where several prototypes utilizing these technologíes were built and tested.
- In a technological sense, the development program has been a fascinating journey.
- But has it been useful ?





”normal day at high speed testing”

ABB IEC Low voltage motors

At a glance

#2 global manufacturer of IEC LV motors

~2,900 employees worldwide

>1 million motors shipped globally in a year

~7,000 customers

>50 countries ordering ABB motors

7 ABB manufacturing locations

1.9% of revenues invested in Research and Development

4.1% employed in Research and Development

IEC Low voltage motors

Wide product portfolio for any industry and application

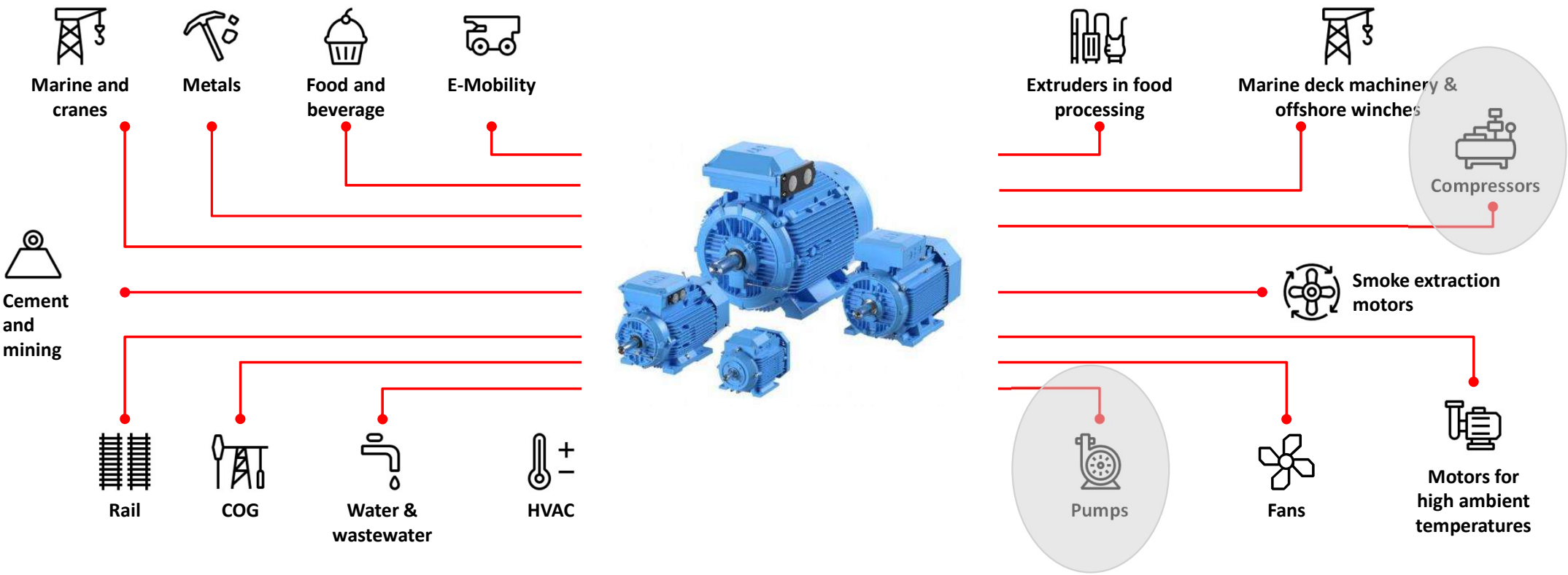


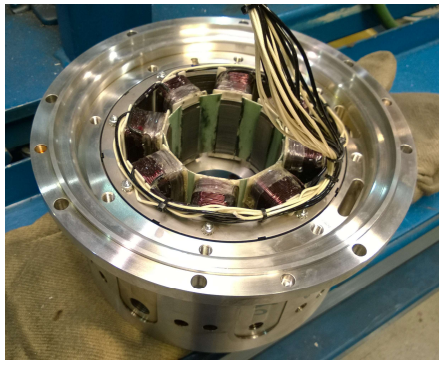
ABB motor factory in Vaasa

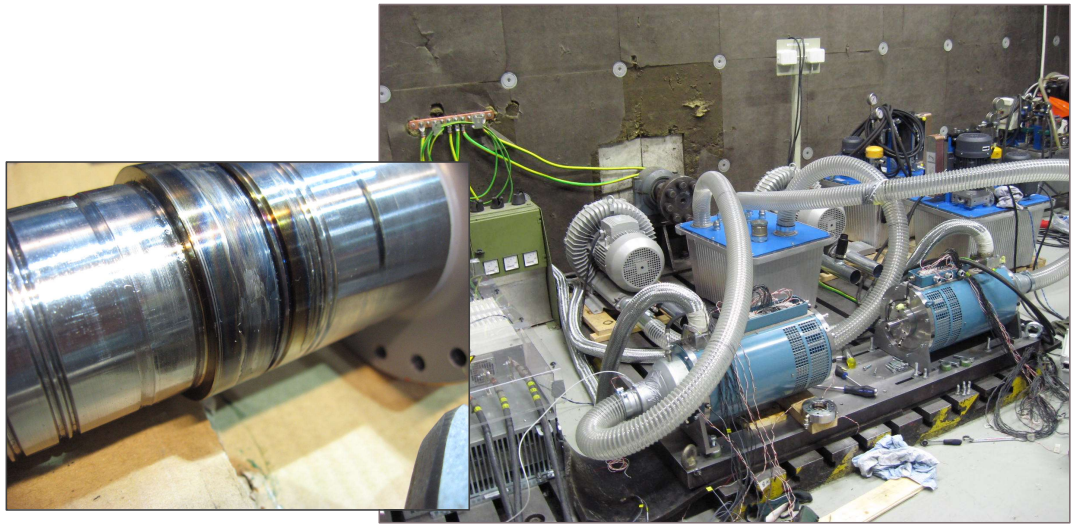
- Production in Finland since 1889 and in Vaasa since 1944
- Some 600 highly educated professionals with world class competencies
- Yearly production of around 75,000 units, out of which 25,000 are different
- Full range of tailored IEC low voltage motors for different segments and applications
- All motors are engineered or configured to order to meet the customer specifications with full documentation and testing capabilities
- Average batch size: 2 motors/order line
- 17 frame sizes – IEC 71 to 500, up to 2 000 kW

High Speed Program

In early 2010’s, a technology program was carried out to solve the technological challenges

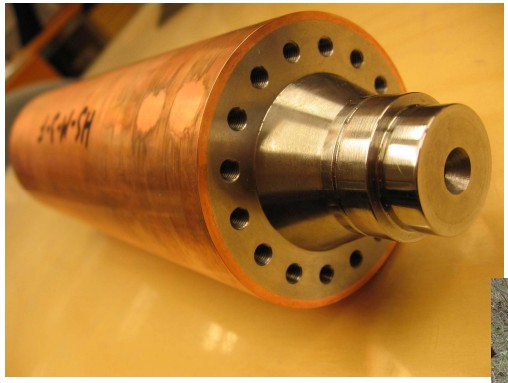
- Electrical design and motor technology
- Cooling
- Bearings & lubrication
- Vibration control; AMB





Motor technology
Explosion welded induction rotors

- Explosively welded construction:
- The cage = a copper cylinder is implosion welded over a steel shaft.
- Rotor is longer than stator – ends of the cylinder act as short circuit rings.
- Suitable for smaller motors and very high speed (surface speed over 200 m/s)
- Requires special arragements, location, handling of explosives etc.
- Very robust construction
- Relatively easy machining operation after the welding



Motor technology

Permanent Magnet Prototype Rotor Manufacturing Sequence (ABB Baldor)

Radial Arc Magnets from VAC

Shaft Machined @ UniGear, Canada

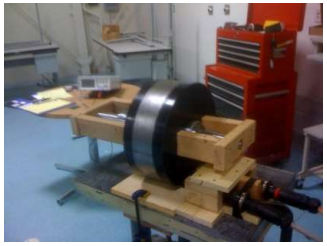
Magnets Epoxy Bonded to Shaft @ AT Lab

Magnet OD Ground @ Clinton Industries, KY

IN718 Sleeves Formed, Machined, Heat Treated and Final Grind @ FlowTurn, OH

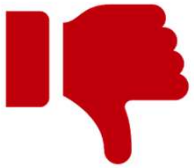
IN718 Sleeve Shrunk Fit onto Rotor (1200 F, .025in Interference), Special Press and Furnace built @ RGG, GA

Precision Balanced and Spun Tested to 33,000 rpm, 150 C @ The Balancing Company, OH



Magnetized with Prototype Tooling @ LE USA, MI

Final OD Grinding @ UniGear, Canada

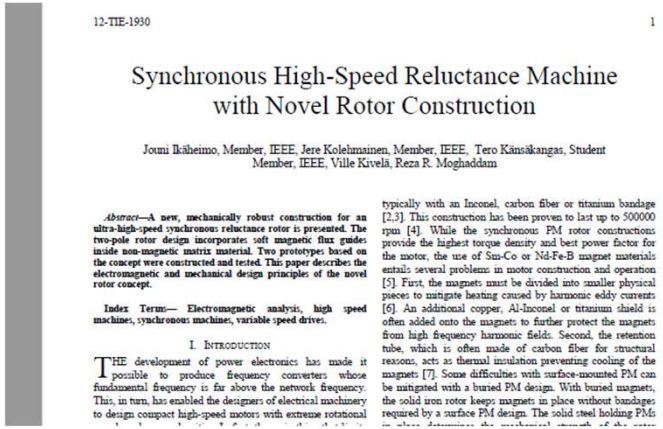


Decision:

This is not our way to go

Motor technology
High Speed SynRM (Ladybug)

- 2-pole synchronous reluctance rotor
- The entire shaft will be cast !
- Soft iron bar array embedded in aluminium bronze matrix
- Works, but construction involves a very difficult management of molten bronze (temp > 1100 C, shrinkage > 2 %)
- When the process is tuned for good yield, this is really low-tech operation
- All the quality defects are easy to spot



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Synchronous High-Speed Reluctance Machine with Novel Rotor Construction

Jouni Ikäheimo, Member, IEEE, Jere Kolehmainen, Member, IEEE, Tero Känsäkangas, Student Member, IEEE, Ville Kivelä, Reza R. Moghaddam

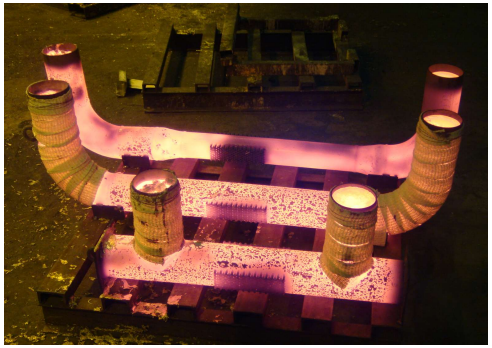
Abstract—**A new, mechanically robust construction for an ultra-high-speed synchronous reluctance rotor is presented. The two-pole rotor design incorporates soft magnetic flux guides inside non-magnetic matrix material. Two prototypes based on the concept were constructed and tested. This paper describes the electromagnetic and mechanical design principles of the novel rotor concept.**

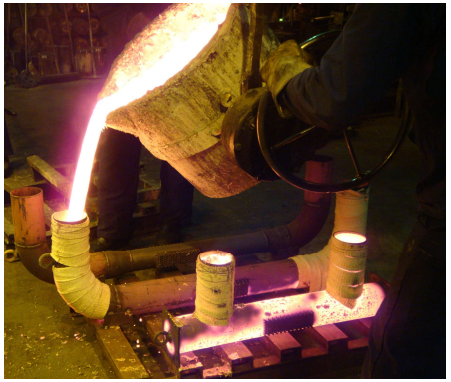
Index Terms— Electromagnetic analysis, high speed machines, synchronous machines, variable speed drives.

I. Introduction

THE development of power electronics has made it possible to produce frequency converters whose fundamental frequency is far above the network frequency. This, in turn, has enabled the designers of electrical machinery to design compact high-speed motors with extreme rotational

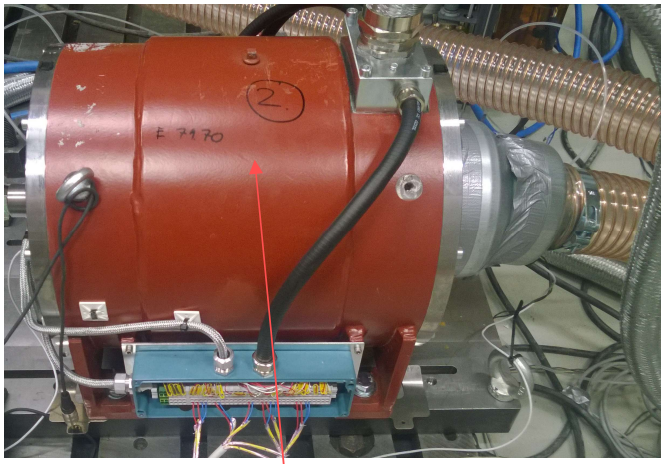
typically with an Inconel, carbon fiber or titanium bandage [2,3]. This construction has been proven to last up to 500000 rpm [4]. While the synchronous PM rotor constructions provide the highest torque density and best power factor for the motor, the use of Sm-Co or Nd-Fe-B magnet materials entails several problems in motor construction and operation [5]. First, the magnets must be divided into smaller physical pieces to mitigate heating caused by harmonic eddy currents [6]. An additional copper, Al-Inconel or titanium shield is often added onto the magnets to further protect the magnets from high frequency harmonic fields. Second, the retention tube, which is often made of carbon fiber for structural reasons, acts as thermal insulation preventing cooling of the magnets [7]. Some difficulties with surface-mounted PM can be mitigated with a buried PM design. With buried magnets, the solid iron rotor keeps magnets in place without bandages required by a surface PM design. The solid steel holding PMs

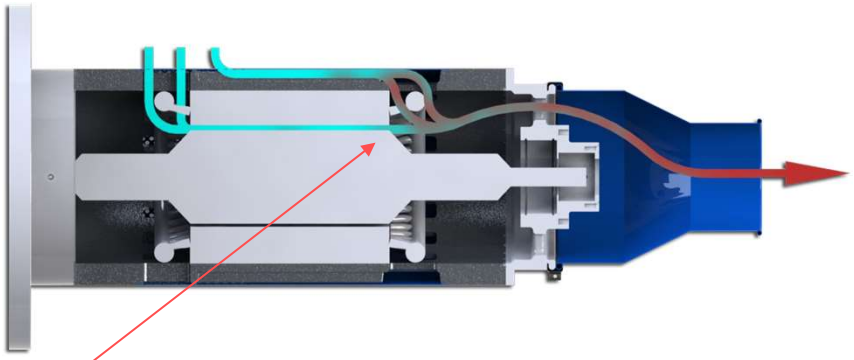


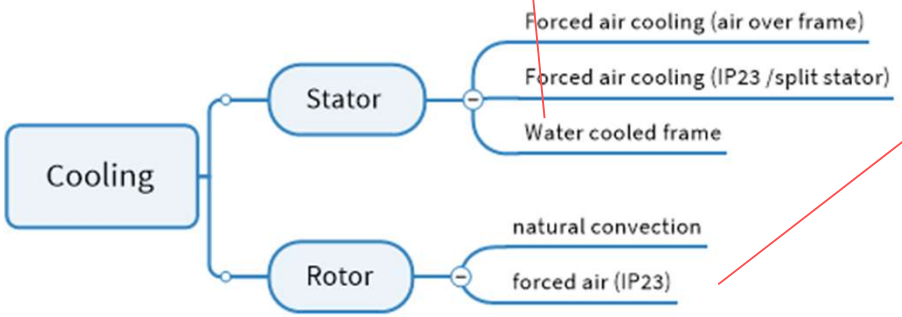


Cooling

- High speed motors are typically forced air ventilated due to high rotor losses
- This requires a separate blower, adding to the package cost.



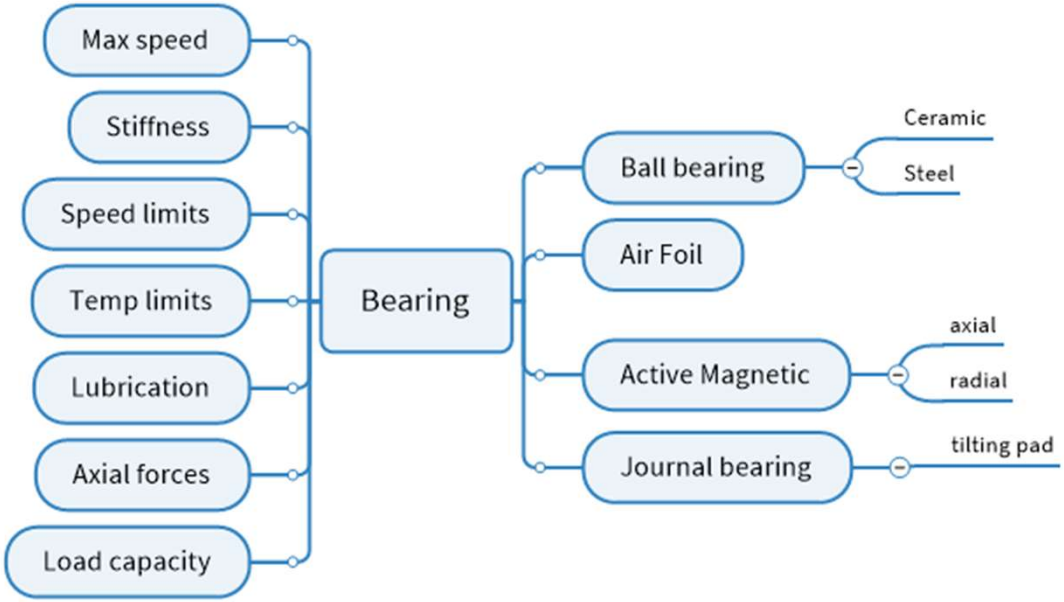




Cooling can be a combination of different techniques

Bearings and lubrication

- Bearing is by far the most complicated part of the design
- Criticality mode (sub/supercritical) determines the type of the bearing and its size.
- Together with speed/output requirement it is often the bottleneck of the design
- In some known cases, the customer has had to abandon a physical contact bearing and go to active magnetic bearing (-> $$$$)
- Ball bearings are typically lubricated using oil mist lubrication or circulating oil lubrication
- Leak prevention is difficult due to high pressure differences



So, was it successful ?

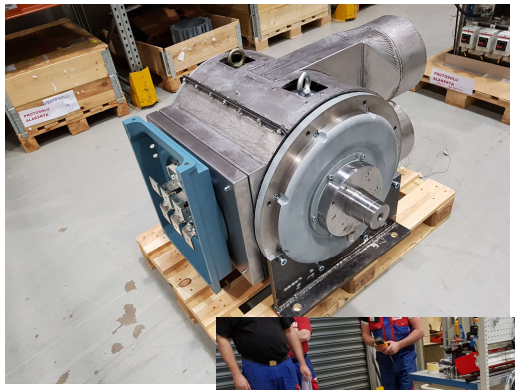
- Customer 1: 300 kW @ 12000 rpm. One motor sold.
- Customer 2: 20 kW @ 50000 rpm (EGR turbo application). No business. (the customer opted for mechanical turbo)
- Customer 3: 40 kW @ 40000…50000 rpm. Joint development but only prototypes were delivered.
- Customer 4: 90 kW @ 21000 rpm. One motor sold.
- Customer 5: 165 kW @ 14500 rpm. Two motors sold.
- Customer 6: several prototypes 35…90 kW / 4000…6000 rpm. Some prototypes sold.

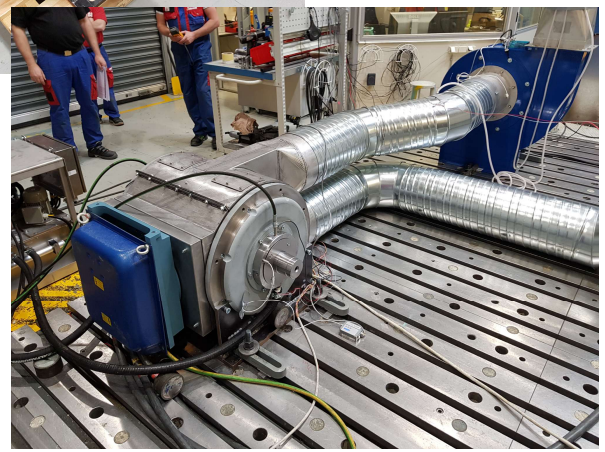
In many cases, the customer was interested about high speed but not capable of assimilate the technology.

Case Runtech 600 kW @ 10000 rpm

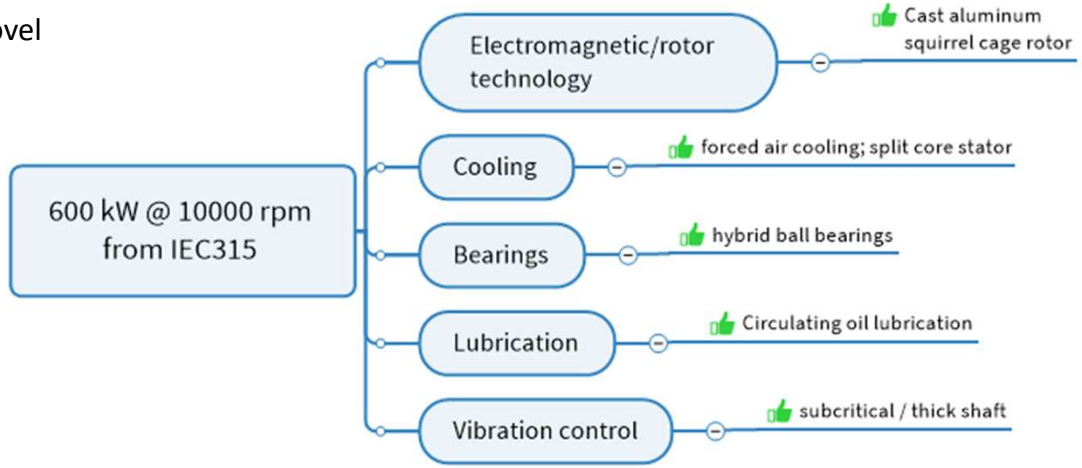
A success story

- Finally, in 2018, ABB got an enquiry from GardnerDenver Runtech for a vacuum blower high speed motor.
- It was almost immediately clear that a product can be created as the required technology was already mastered.





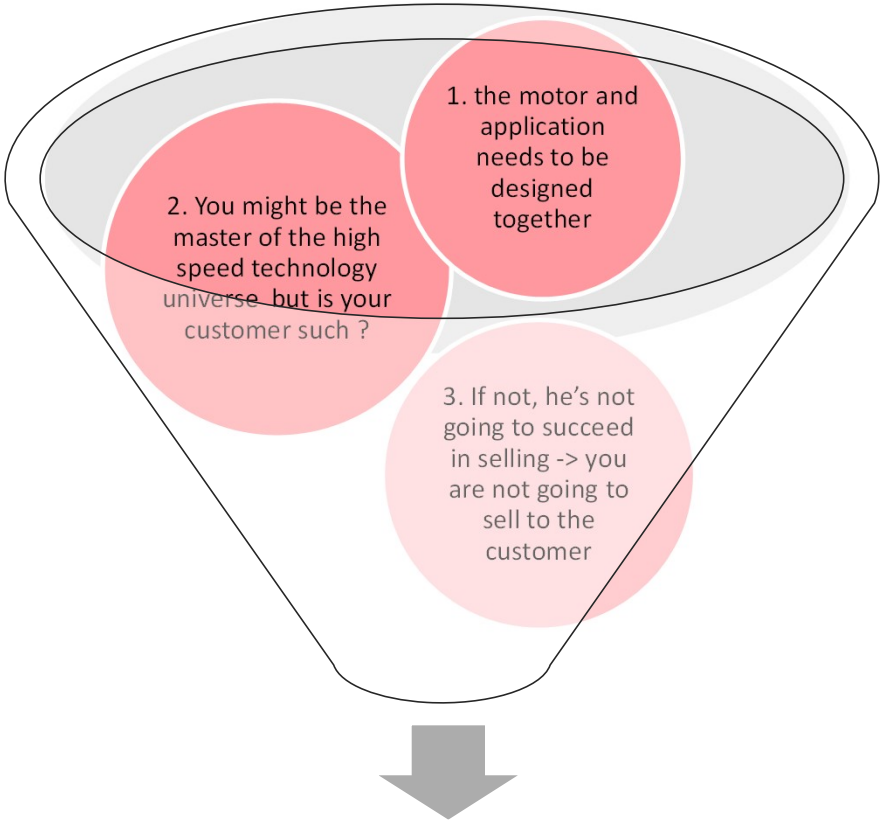
- The R&D project involved the development of several novel items and mfg techniques but it was successful in the end
- The cast AL rotor enables the machine to outperform massive solid iron rotor with a good cost efficiency



Making the design concept was straightforward once the basic tecnology blocks were tested

Lessons learned (?)

- A successful mastering of high speed project needs a good set of basic knowledge
- The interface between the application and the motors becomes many times heavily blurred
- *Ergo*, the motor and application needs to be designed together



To put it together, high speed is about market pull, not technology push