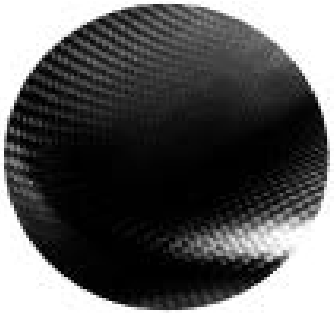
HSD
MECHATRONICS

Design optimization for high efficiency induction motor in electro-spindle application

Marco Apuzzo (electrical machine designer)

More Value for Your Machine



Part 1
HSD presentation



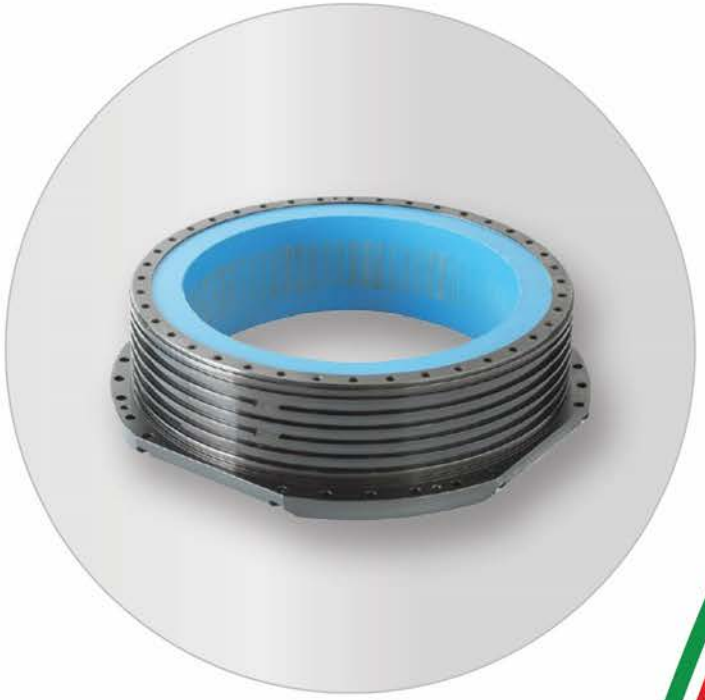


HSD MECHATRONICS

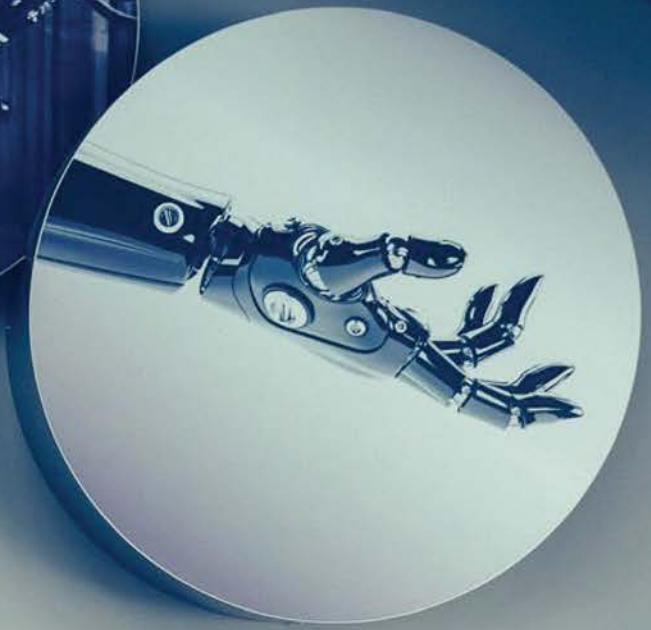
A perfect combination of innovation & high technology

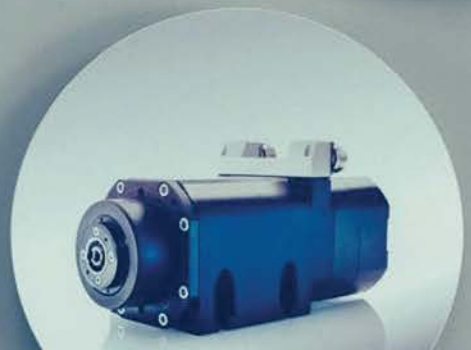
From 1991, HSD SpA Mechatronics designs and produces technologically advanced, high precision components for milling, boring and cutting operations on a wide range of materials (wood, aluminium, plastic, marble, glass and metal):

- Automatic tool change electrospindles
- Manual tool change electrospindles
- 2 Axis Heads
- Right angle heads for electrospindles
- Boring heads
- Servomotors with integrated driver control
- Multi-functional units



DIRECT DRIVE STATOR





HEADQUARTERS
Gradara, Italy

From design to production 4.0. The headquarters of Gradara hosts all design, prototyping and production activities. A surface of over 8.000 m^2, a technologically innovative structure designed with the aim of creating a stimulating and comfortable working environment, capable of communicating the philosophy of a company that has always expressed innovation, dynamism and focus on quality.

HSD - A COMPANY IN CONSTANT EVOLUTION

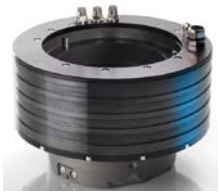
- 1991 HSD Foundation
- 1996 Electronic division
- 2001 HSD USA
- 2002 HSD Deutschland
- 2006 Beginning of metal Electrospindles production
- 2008 HSD China
- 2009 Winner technology with EROD project for develop Synchronous electrospindles
- 2012 Development e-core Technology Industry 4.0
- 2014 Development Direct Drive Technology
- 2016 HSD S.korea

Product Portfolio (1 of 3): Two-axis head

AEROSPACE

AUTOMOTIVE

WINDOWS & FURNITURE



Direct Drive two-axis heads and «C» axis

«Gear driven» **Direct Drive two-axis heads**

Product Portfolio (2 of 3): Electrospindle

AEROSPACE

CONSUMER ELECTRONICS

Electrospindles for metal applications
And composite materials

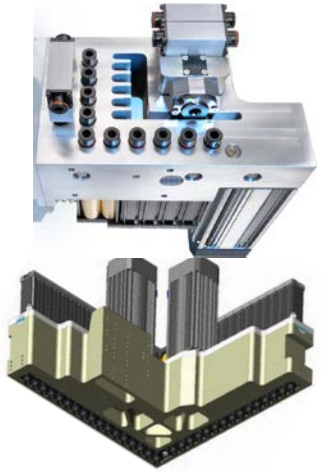
AUTOMOTIVE

Glass & Stone applications
Electrospindles

WINDOWS & FURNITURE

Wood and Plastic applications
Electrospindles

Product Portfolio (3 of 3)



Boring heads, Multifunciton units, aggregates for wood, alluminum, plastic, glass & stone applications

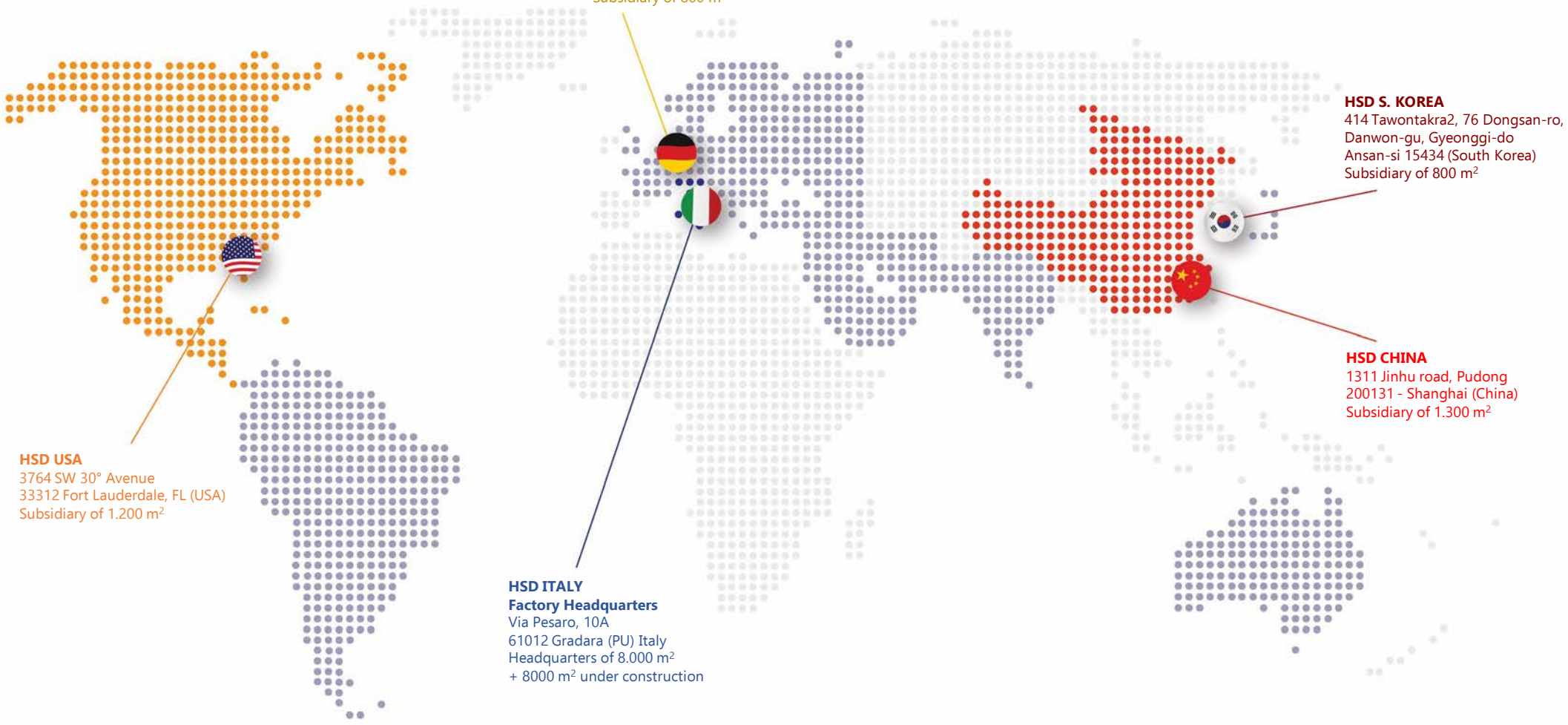
WINDOWS & FURNITURE

Smart Motors, «Electronic equipment»
Rotors & Stators, Direct Drive Motors

Some references

HSD GLOBAL NETWORK

Global network with owned subsidiaries in the main markets
in order to provide the customer with immediate and qualified support.



HSD DEUTSCHLAND
Brückenstrasse, 32
D-73037 - Goeppingen
(Germany)
Subsidiary of 800 m²

HSD S. KOREA
414 Tawontakra2, 76 Dongsan-ro,
Danwon-gu, Gyeonggi-do
Ansan-si 15434 (South Korea)
Subsidiary of 800 m²

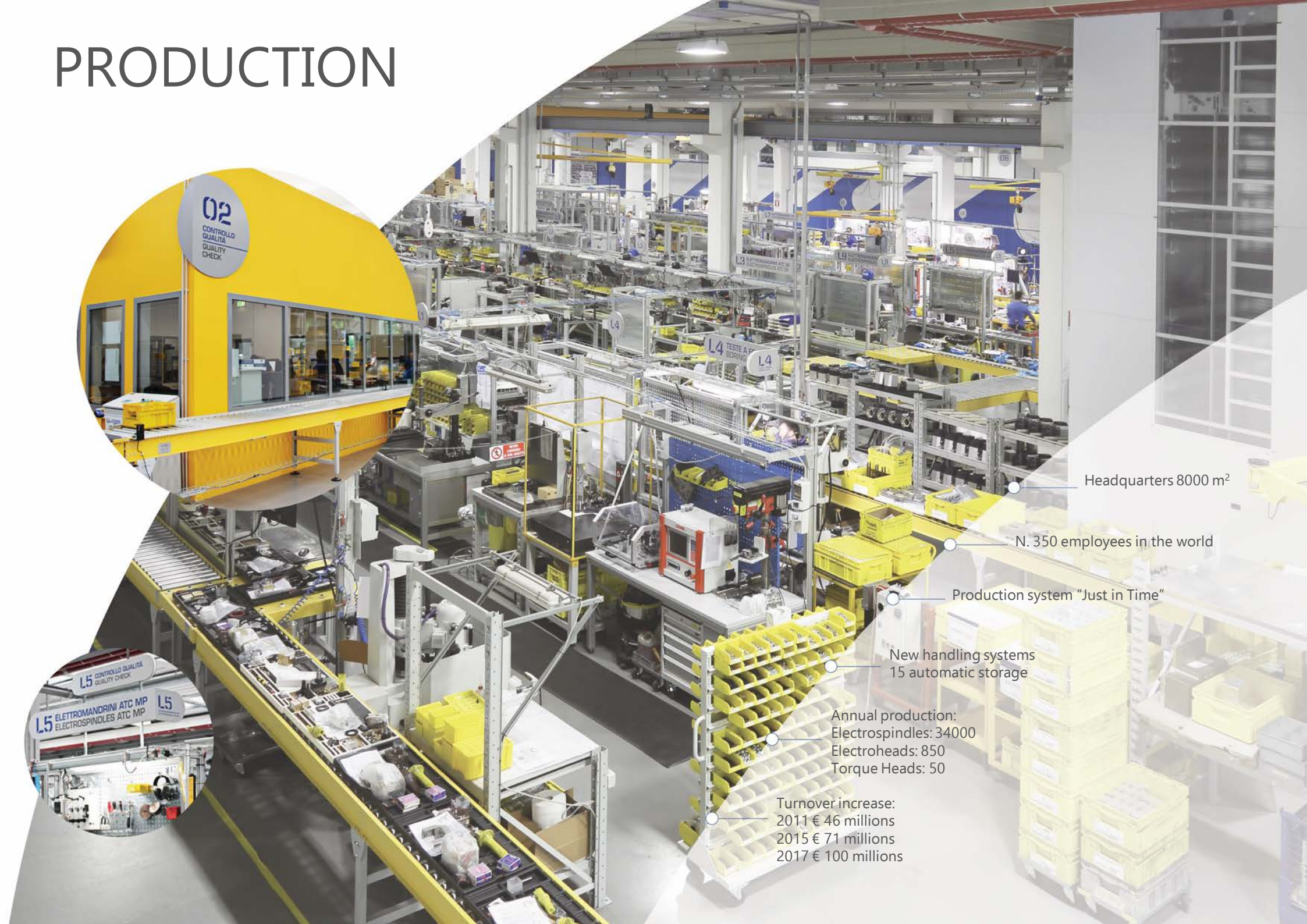
HSD CHINA
1311 Jinhu road, Pudong
200131 - Shanghai (China)
Subsidiary of 1.300 m²

HSD USA
3764 SW 30° Avenue
33312 Fort Lauderdale, FL (USA)
Subsidiary of 1.200 m²

HSD ITALY
Factory Headquarters
Via Pesaro, 10A
61012 Gradara (PU) Italy
Headquarters of 8.000 m²
+ 8000 m² under construction

HSD Headquarters **HSD Subsidiaries**

PRODUCTION



- Headquarters 8000 m^2
- N. 350 employees in the world
- Production system "Just in Time"
- New handling systems
  15 automatic storage
- Annual production:
  Electrospindles: 34000
  Electroheads: 850
  Torque Heads: 50
- Turnover increase:
  2011 € 46 millions
  2015 € 71 millions
  2017 € 100 millions

MECHANICAL WORKSHOP

The Mechanical Workshop is the heart of the HSD production. It's here that the main parts are milled, welded and turned ready for assembly lines, in order to ensure:

- Production Flexibility
- Lead time monitoring
- Quality control of finished components

TRAINING LAB

The HSD Training Lab has been established in 2017 within the headquarters of Gradara, with the aim of enhancing the skills of HSD staff, subsidiaries' specialists and customer technicians. The training area is divided into a theoretical training area and a laboratory for practical notions.

QUALITY & CERTIFICATIONS

HSD has always considered Quality one of its priorities. In the early 90s the company built a Quality Management System based on the highest international standards, gaining today the OHSAS 18001 and ISO 9001:2015 certification. Each model and component, during product development, is subjected to rigorous reliability testing by simulating the hardest working conditions a product could expect to face.

SERVICE & SPARE PARTS

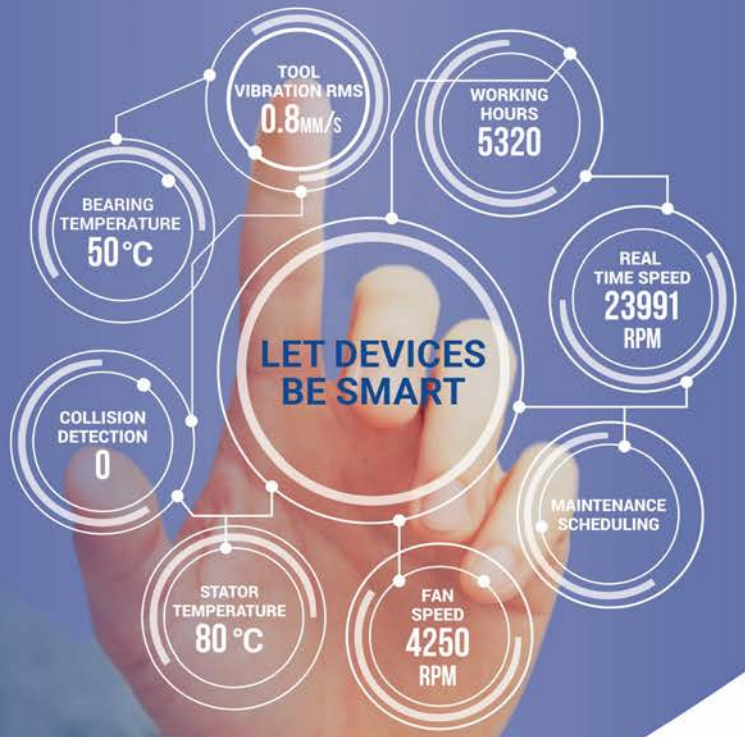
CODIFIED SPARE PARTS
IN AUTOMATIC WAREHOUSE

SHAFT KIT

HSD promotes and develops close and constructive relationships with customers in order to better understand their needs and improve its products and after-sales service through:

- Certified measuring and testing equipments
- Strict internal processing procedures
- Field technicians periodically updated at the HSD Training LAB
- Subsidiaries Global Network

RESEARCH & DEVELOPMENT



e-CORE™
Industry 4.0

NEW ELECTRONIC SOLUTIONS

DIRECT DRIVE 2 AXIS HEAD

Technological excellence combines with the integrated development of mechanical and electronic skills both in design, production and quality systems.

APPLICATIONS

HSD manufactures a wide range of products and solutions dedicated to many different applications.

AUTOMOTIVE

AEROSPACE

CONSUMER ELECTRONICS

ROBOTICS

FURNITURE & BUILDING

AUTOMOTIVE

High power, fast and compact Electrospindles & Direct Drive Heads
for the Automotive sector.

ES332
HSK A40/E40
Body Diameter:150mm
Torque S1:10,3Nm
Power S1:13kW
Max Speed:
24000rpm Grease
32000rpm Air-oil

ES510
HSK A63/A100
Body Diameter: Ø180mm
Torque S1: from 38 to 95,5Nm
Power S1: from 24 to 70kW
Max Speed:
18000rpm Grease
28000rpm Air-oil

HST610 DIRECT DRIVE
DOUBLE SIDED
Max. Speed Axis A;C: °/sec 180;180
Clampling torque Axis brakes A;C:Nm 1800/2000
Weight: Kg 290

AEROSPACE

High performance, fast and compact Electrospindles & Direct Drive Heads for the Aerospace sector.

HST810
DIRECT DRIVE
DOUBLE SIDED
Max. Speed Axis A;C:
°/sec 180;180
Clampling torque Axis brakes A;C:
Nm 4000/4000
Weight: Kg 740

ES550
HSK A63
Body Diameter: Ø210mm
Torque S1: 124Nm
Power S1: 26kW
Max Speed: 18000rpm

ES575
HSK A63
Body Diameter: Ø230mm
Torque S1: from 34,5 to 170Nm
Power S1: from 25 to 100kW
Max Speed: from 10000 to 30000rpm

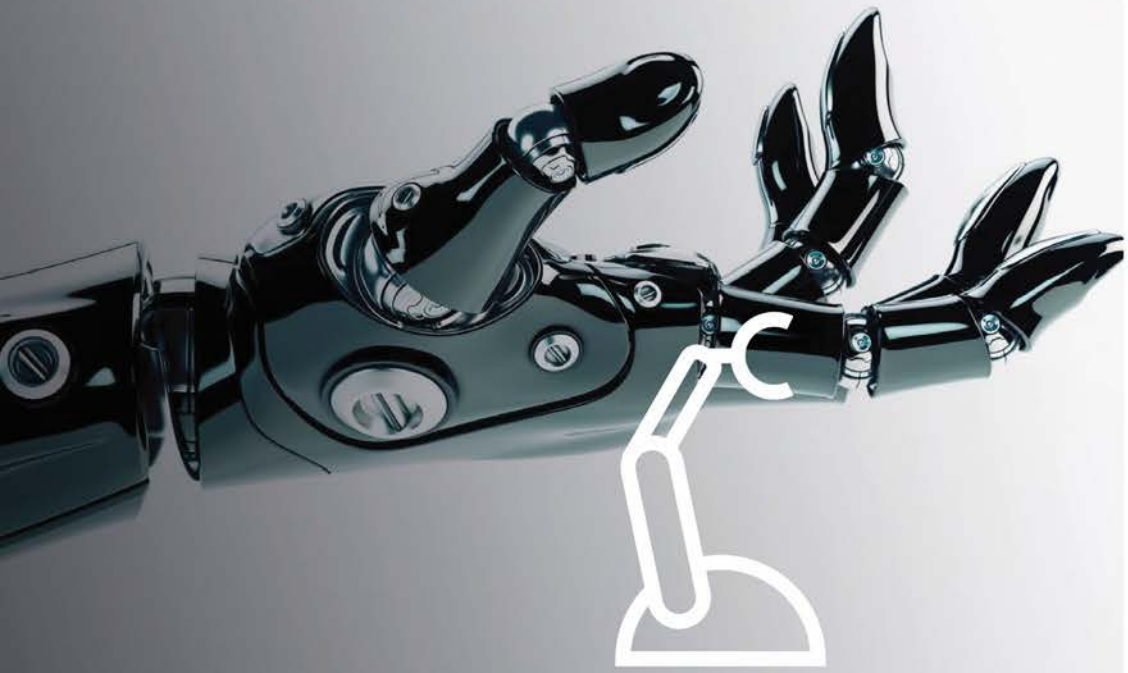
CONSUMER ELECTRONICS

Low vibration, Fast and precise Electrospindles & 2 Axis Heads
for the Consumer Electronics sector.

ES327
HSK E25
Body Diameter: Ø80mm
Torque S1: 1Nm
Power S1: 3kW
Max Speed: 50000rpm

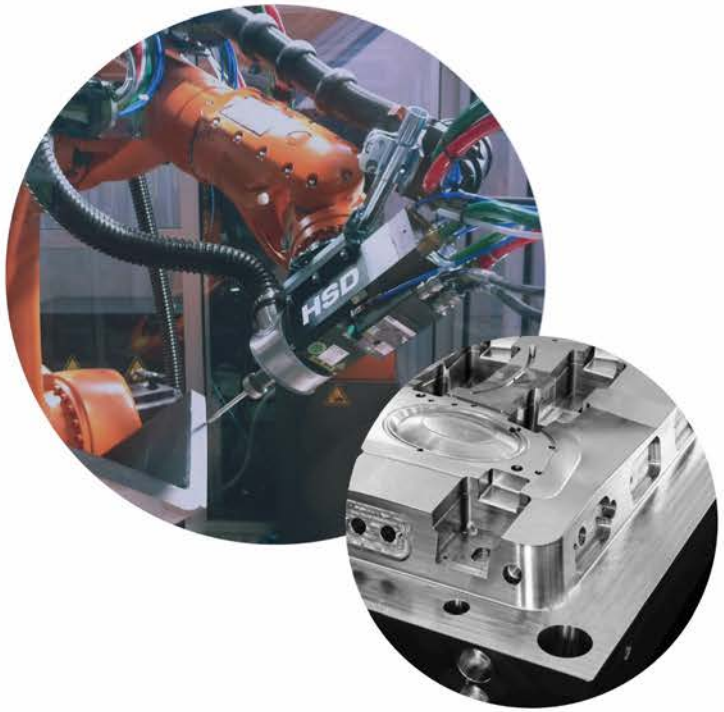
ES351
HSK E32
Power: 6,5 kW
Torque S1: 5,2 Nm
Max Speed: 40000rpm

HST570 DIRECT DRIVE
Max. Speed Axis A;C: °/sec 180;180
Clampling torque Axis brakes A;C: 342/342 Nm
Weight: Kg 150



ROBOTICS

Fast, compact and precise Electrospindles & 2 Axis Heads
for the Robotics sector.



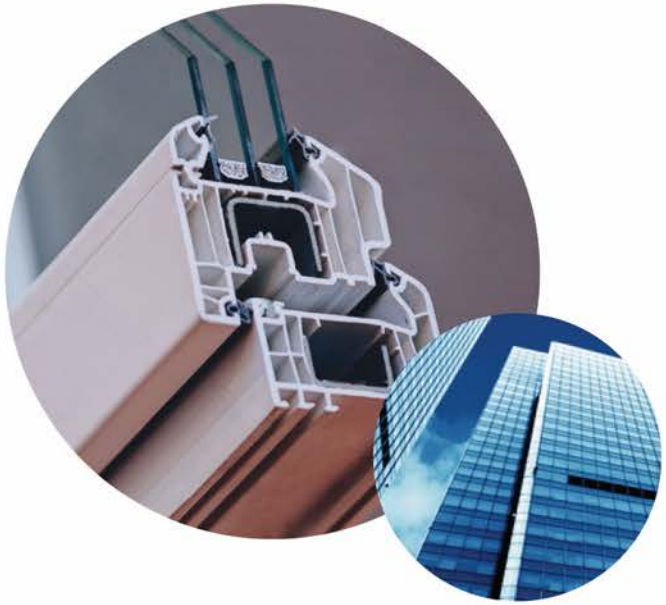
ES334
BT30/HSK E40
Body Diameter: Ø120mm
Torque S1: 5,7Nm
Power S1: 3,6kW
Max Speed: 30000rpm

ES368
HSK E40/F50/F63
Power S1: from 6,5 to 11kW
Torque S1: from 3,4 to 8,7Nm
Max Speed: from 20000 to 36000rpm

ES789
HSK F63/A63
Power S1: 25kW
Torque S1: 23,9Nm
Max Speed: 24000rpm

FURNITURE & BUILDING

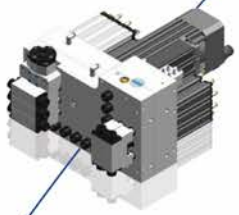
From the Electrospindle to the 2 Axis Heads; from the Aggregate to the Boring Units, HSD has a wide range of solutions for the Windows & Furniture sector.



Aggregates for drilling, milling & cutting.

Automatic & Manual Tool Change Electrospindles

2 Axis Head Direct Drive



CNC Boring Heads with horizontal, vertical spindles & blade group

Part 2
Design optimization for high efficiency induction motor in electro-spindle application

Customer data input

PERFORMANCE REQUIREMENTS

- 26 kW at 2000÷7500 rpm
- >200 Nm peak torque
- Efficiency > 90%
- 10 kW at 18000 rpm
- Drive maximum output frequency ≤ 1200 Hz

OUTLINE REQUIREMENTS

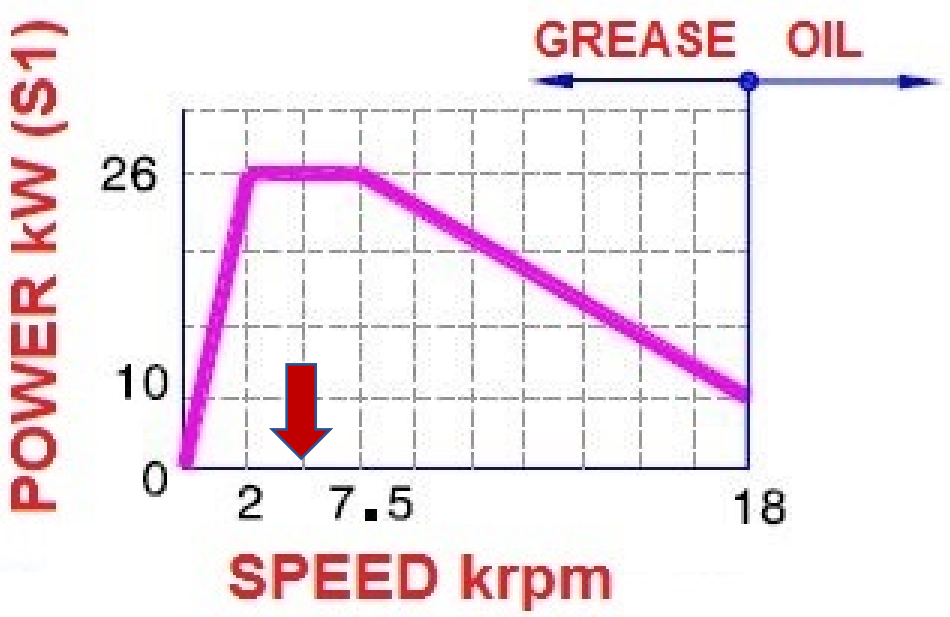
- Overall Lenght < 800mm
- Overall Diameter < 220mm
- Water cooling
- Thermal class F

Customer data input – General Scenario

1. Estimated annual volume: 10 – 15 electrospindles
2. Market price of 1 electrospindle: below 20,000€
3. Time to market: 18-20 weeks

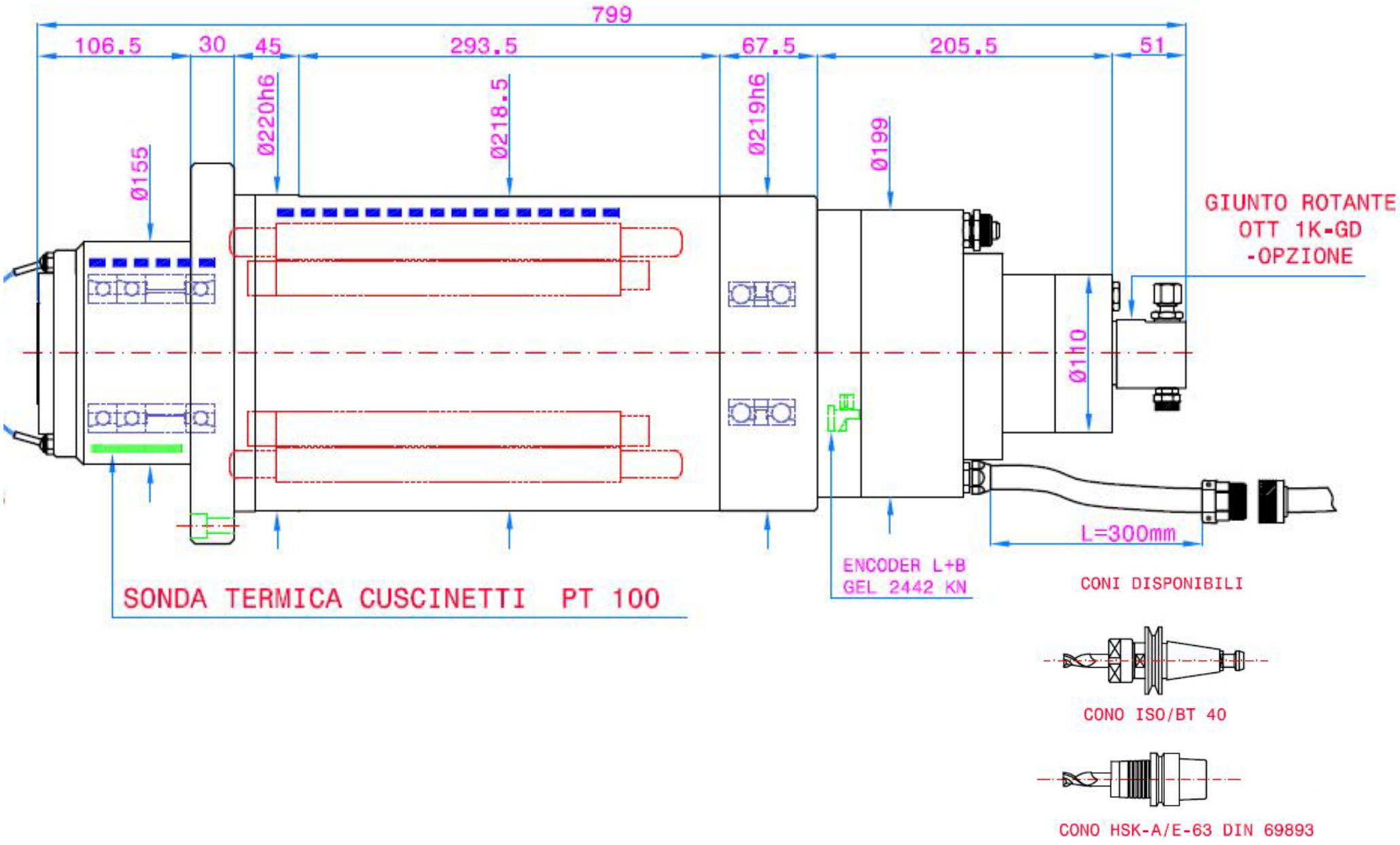
It implies to use standard (NOT CUSTOM MADE) motor geometry design, evaluate the use of the rotor design for other application

Performance requirements

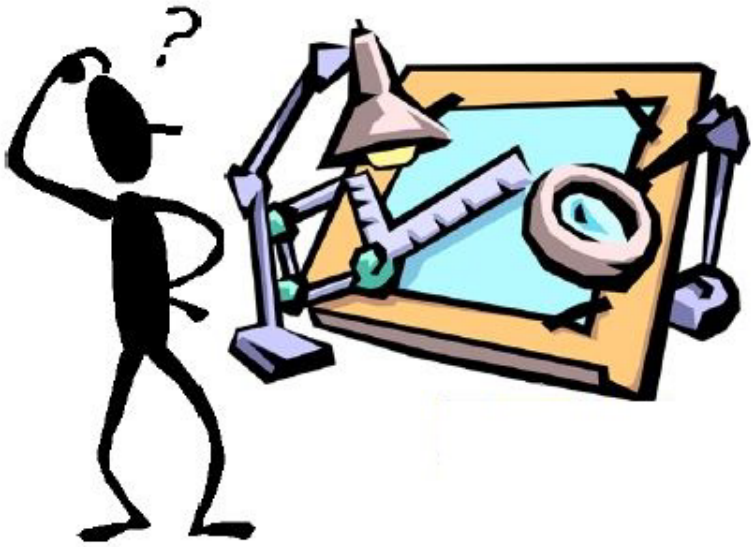


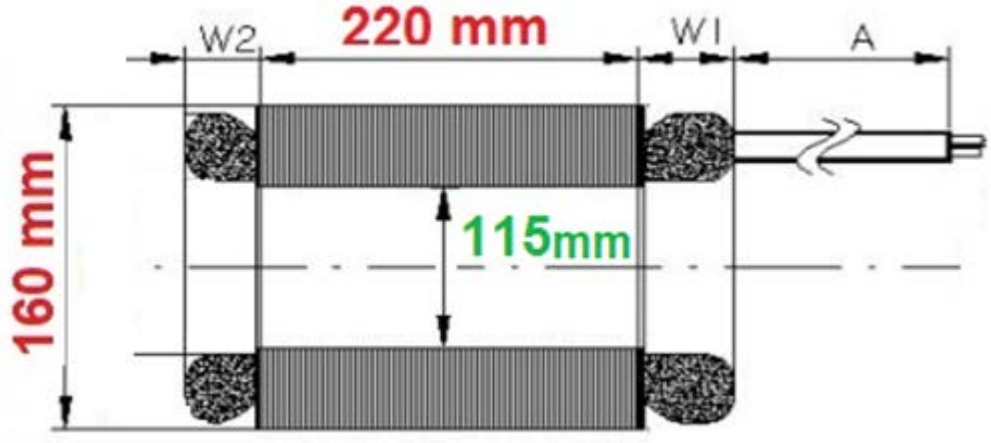
380 V at 4500 rpm to optimize the efficiency

Size constraints



Initial Sizing





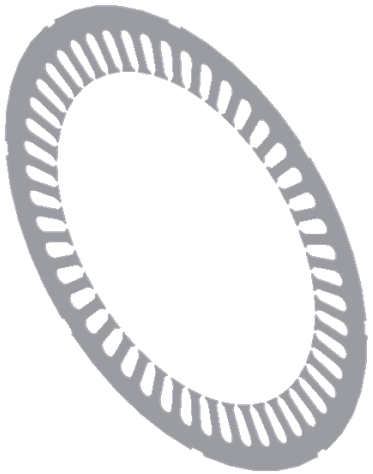
- ✓ Poles = 8
- ✓ Peak torque > 200 Nm
- ✓ Possa Formula:

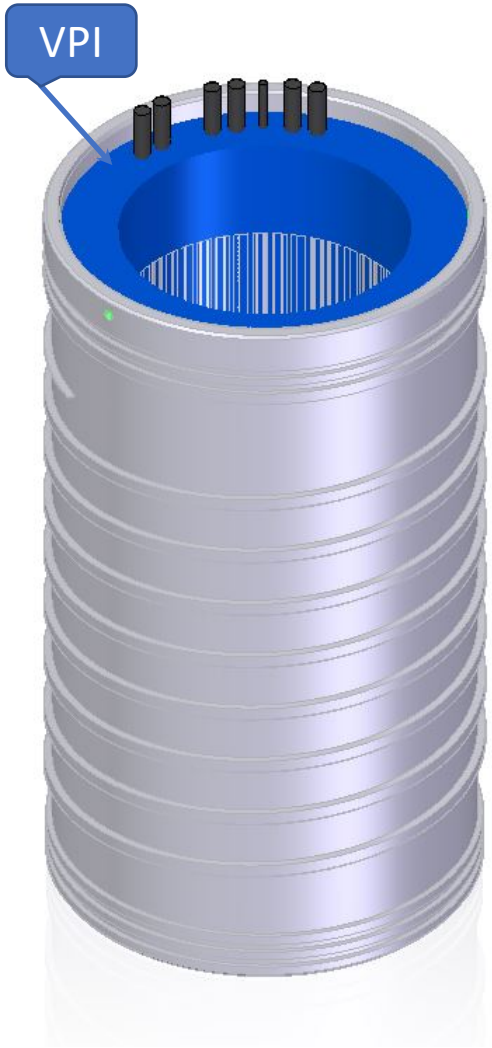
$$\phi \approx 1,3\ 10^{-3}\ \frac{T_{pk}^{0.55}}{p^{1,1}} \qquad \phi = B_{max}\frac{D_{int}L_{stk}}{p}$$

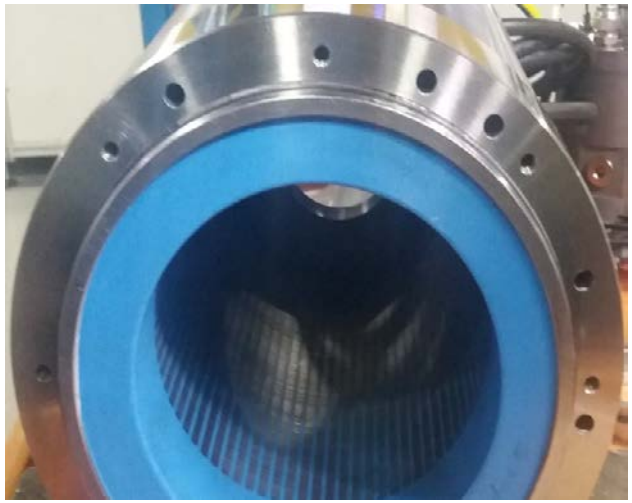
- ✓ Airgap induction: 0.85 T (hp)
- ✓ Fixed the stack lenght to 220 mm
- ✓ Output: Dint ≈ 117 mm

Stator geometry

De	[mm]	160
Di	[mm]	115
Nslot	[-]	48
Poles	[-]	8
Lstk	[mm]	220

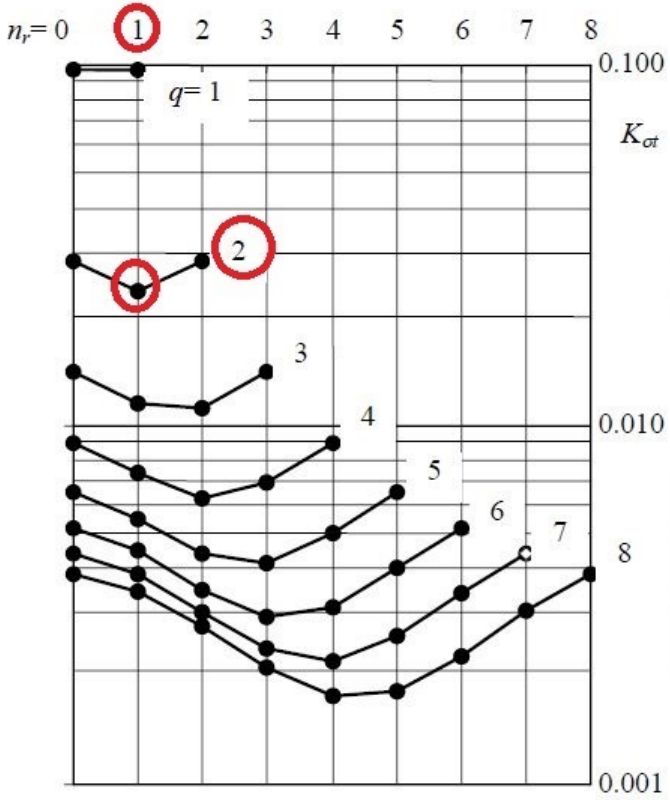






Stator design

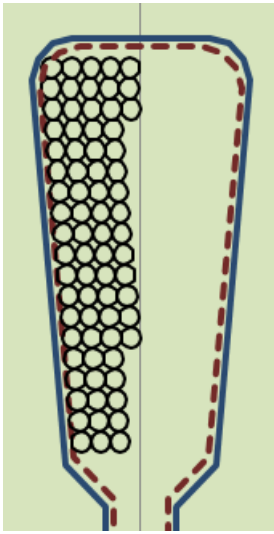
- 3 phase overlap winding with throw 5 → Short pitch winding = 1 (in order to reduce the flux airgap leakage)
- q= 2 slot/pole/phase
- 8 Parallel in order to increase the slot fill factor



$$K_{\sigma t} = \frac{Lt - Lm}{Lm}$$

Lt = total inductance
Lm = magnetizing inductance (h=1)

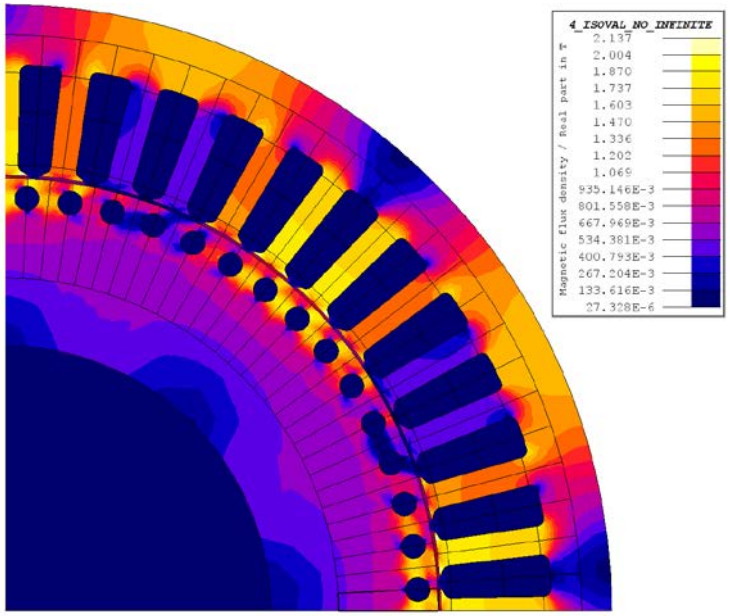
Example of slot fill factor

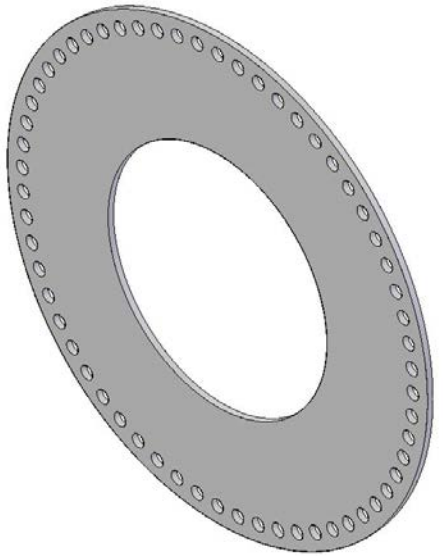


Copper rotor geometry

- Copper conducibilty is higher than Aluminum
- Usually for copper rotor we use round bars

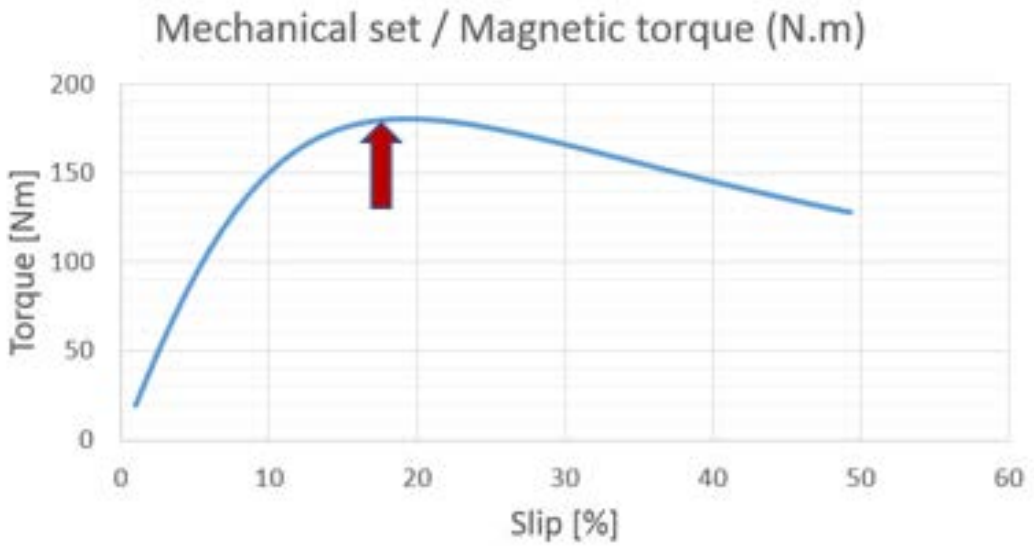
De	[mm]	114.2
Di	[mm]	80
Nslot	[-]	60
Lstk	[mm]	220





Round bars: results

- Peak torque < 200 Nm



- Peak torque decreases according to rotating speed in quadratic mode:

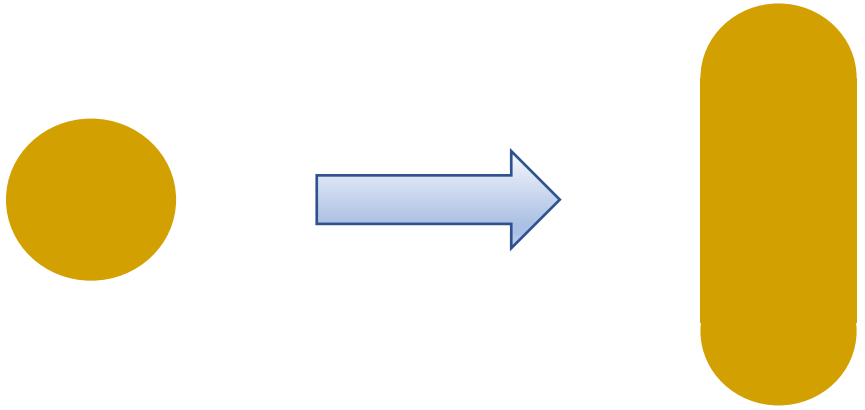
$$T_{n_{max}} \sim T_{n_{base}} \left(\frac{n_{base}}{n_{max}} \right)^2$$

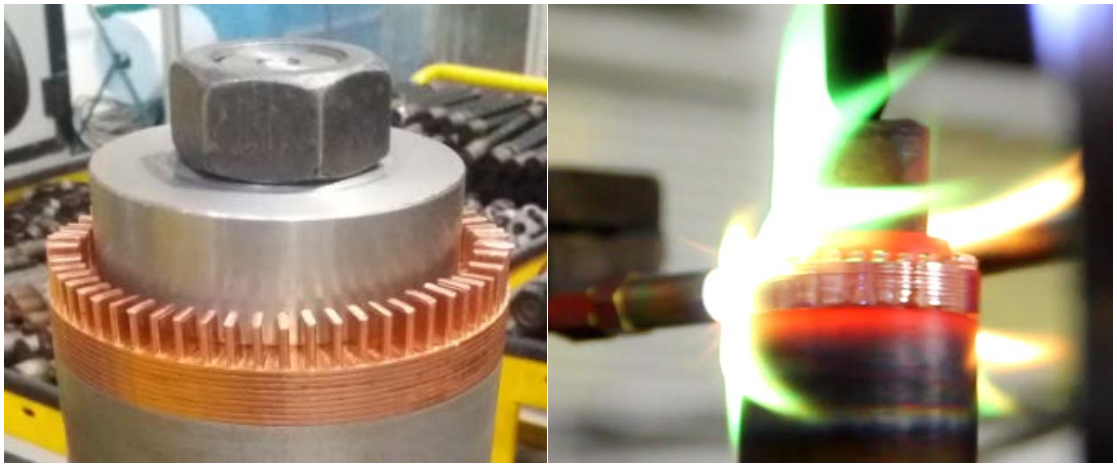
- At 18000 rpm: it could be critical to match the required perfomance

Rotor geometry optimization

Advantages:

- ☺ Bigger slot/copper section
- ☺ Low rotor resistance
- ☺ Low Joule losses
- ☺ Easy of construction
- ☺ Useful for different application (like round shape with many combination stator/rotor slots)

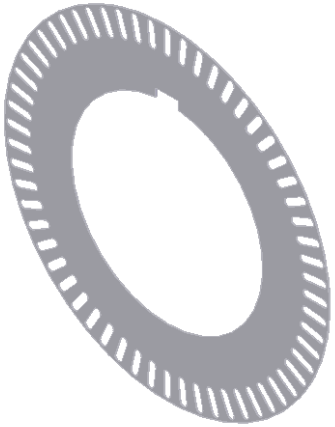




Copper rotor geometry

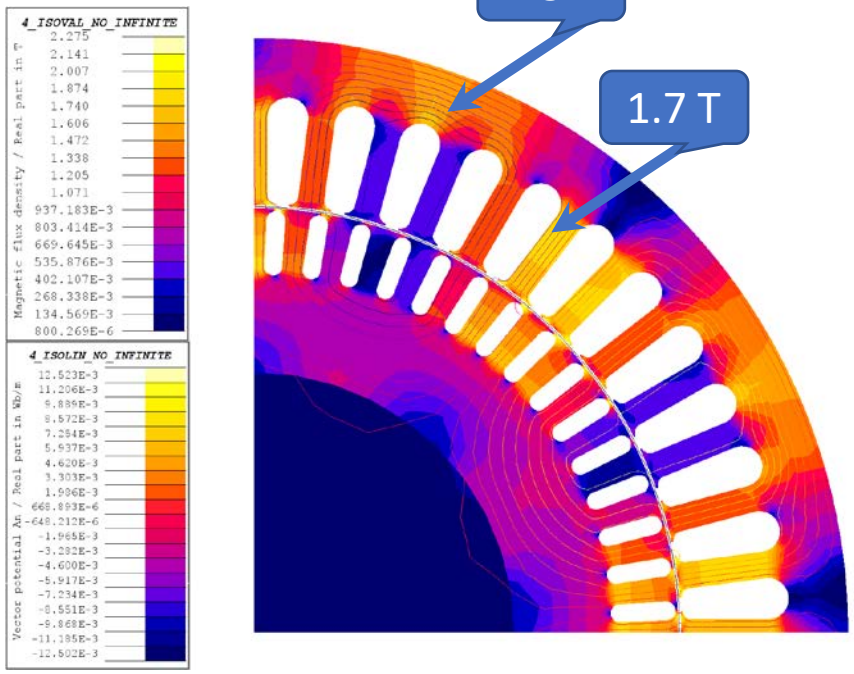
De	[mm]	114.2
Di	[mm]	80
Nslot	[-]	60
Lstk	[mm]	220

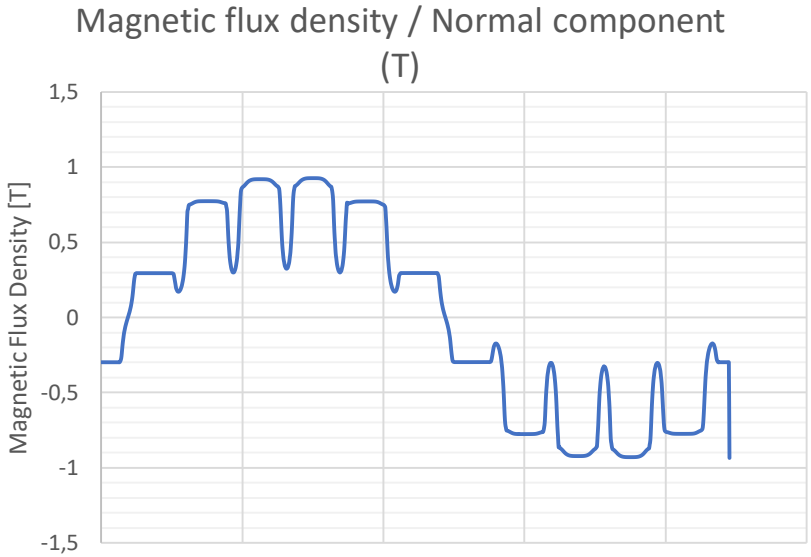
- 18000 rpm → periph. Speed 107 m/s
- Rotor will require strengthening ring

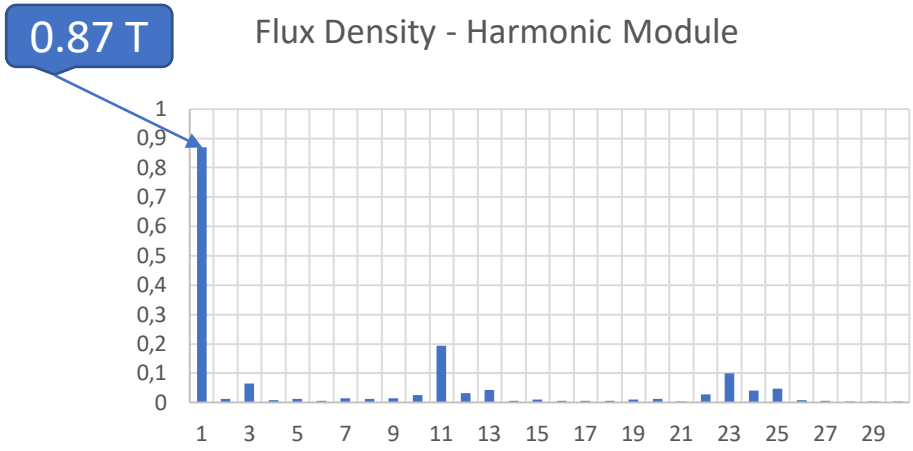


No Load Simulation: FLUX 2D

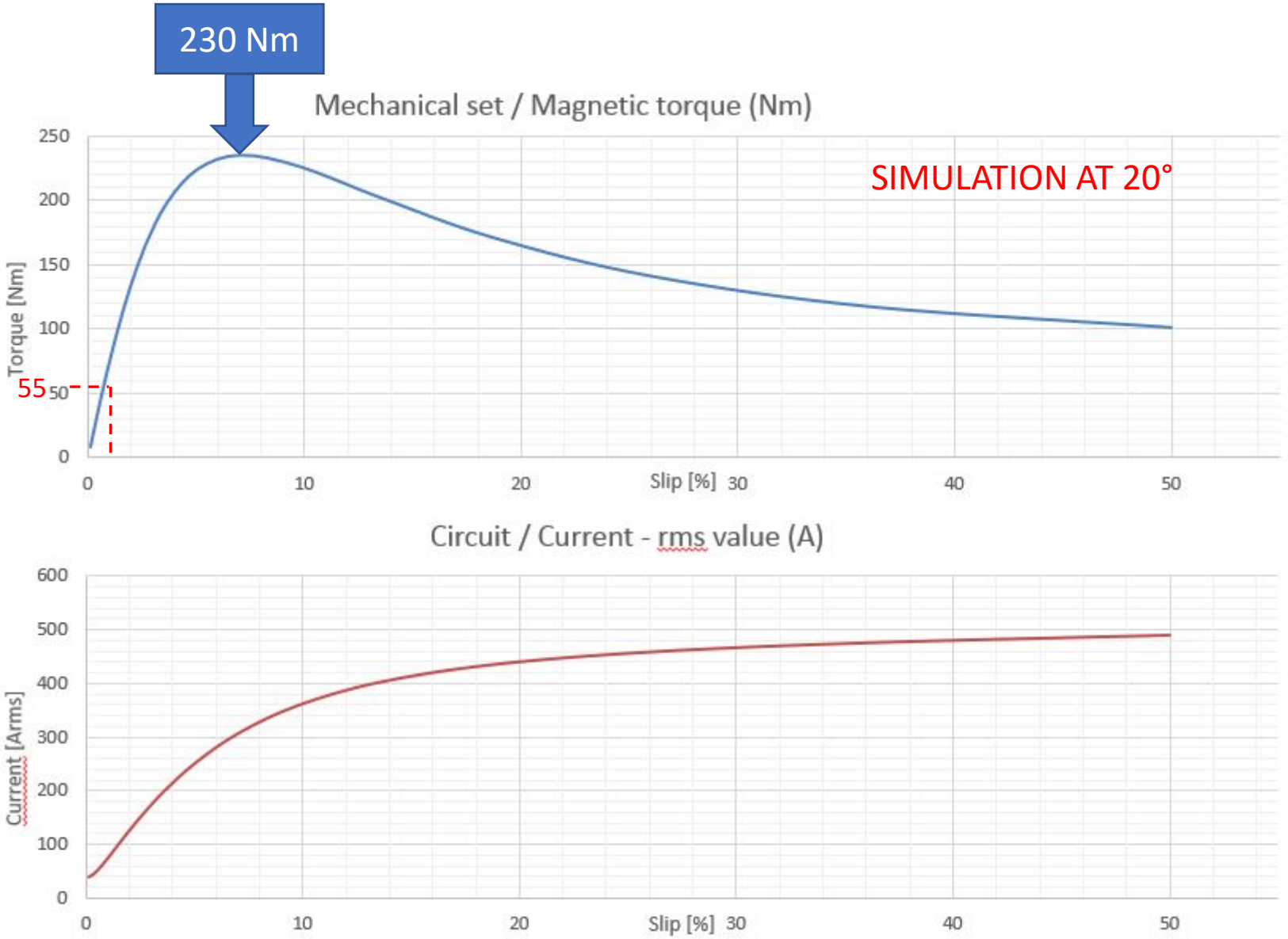
Supply Voltage	[Vrms]	380
Frequency	[Hz]	300
Current	[Arms]	42
Iron Losses	[W]	1485
Lamination	[-]	M330-35A







Load Simulation 300 Hz: FLUX 2D



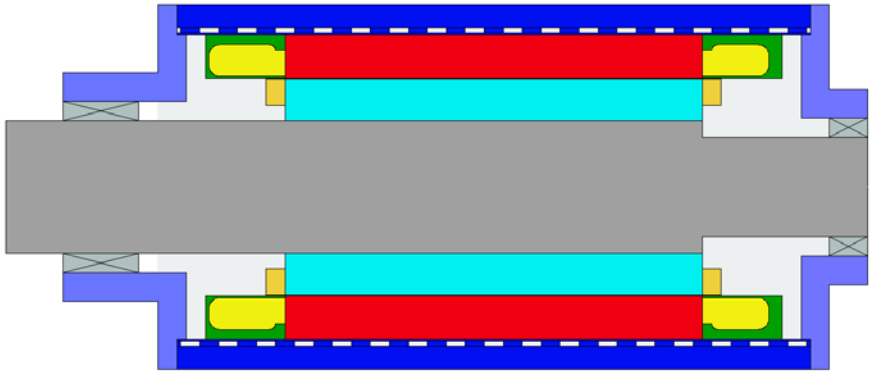
Motor-CAD Simulation

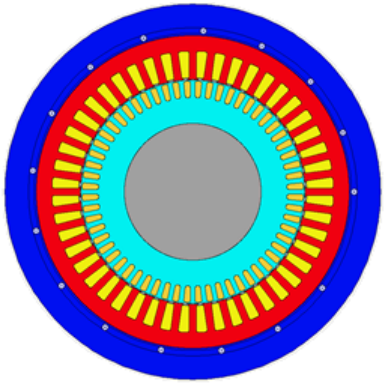
➢ Power loss under load (4500 rpm) by FLUX

Ambient Temperature		
Pj stator	[W]	641
Pj rotor	[W]	138
P iron stator	[W]	1467
P iron rotor	[W]	16
Total loss	**[W]**	**2262**

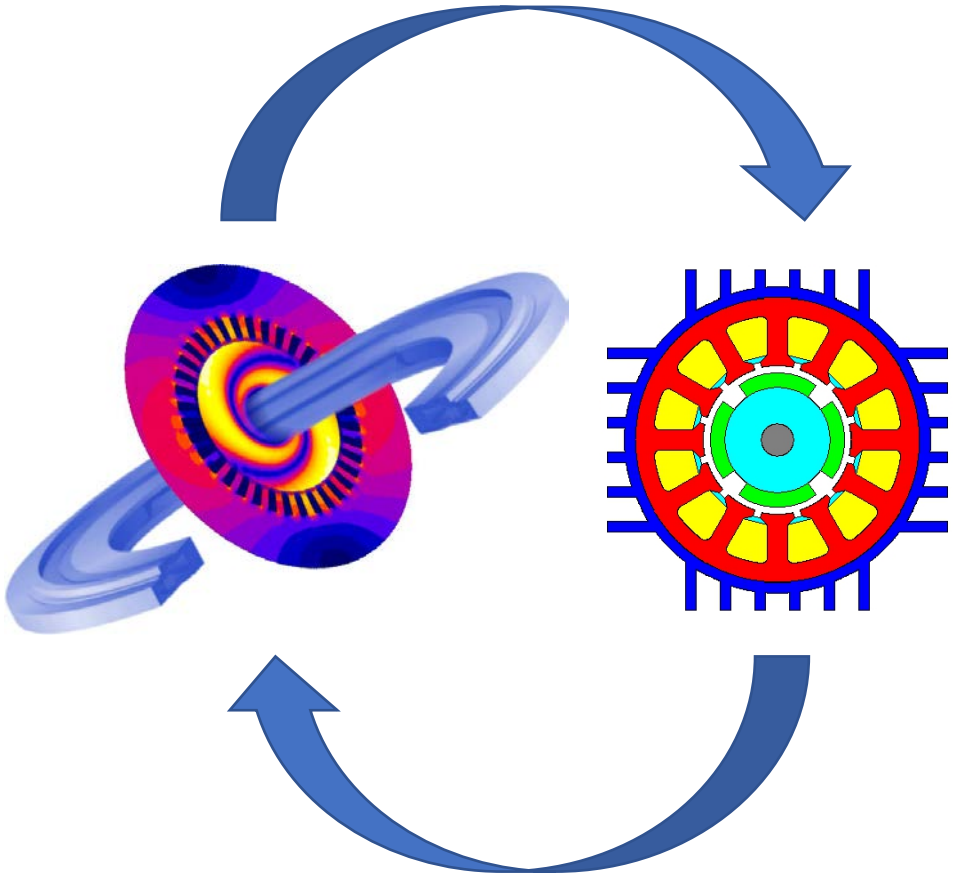
Calculated at 20°C

➢ Estimation operating temperature by Motor-CAD





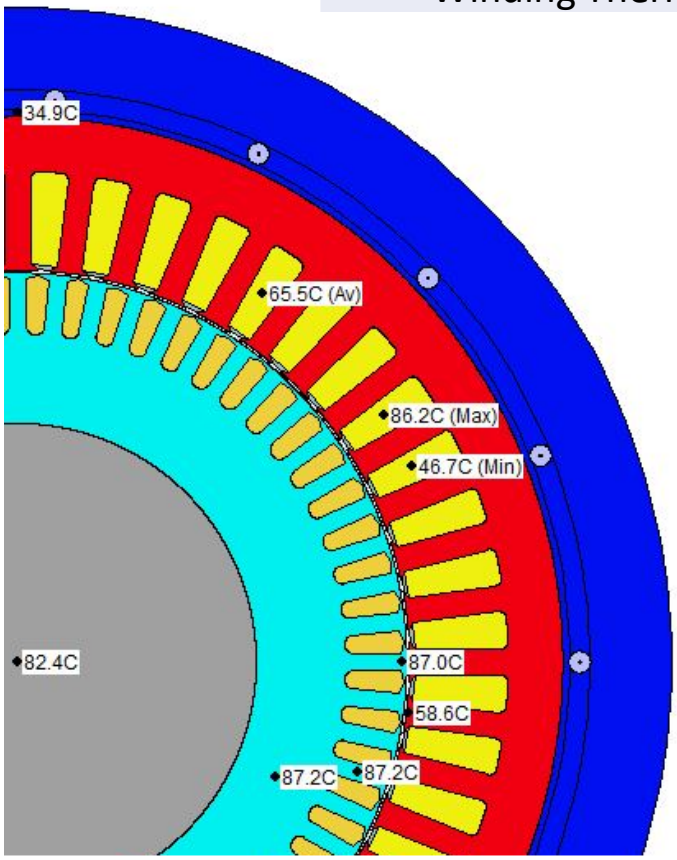
FLUX/MOTORCAD iteration: results

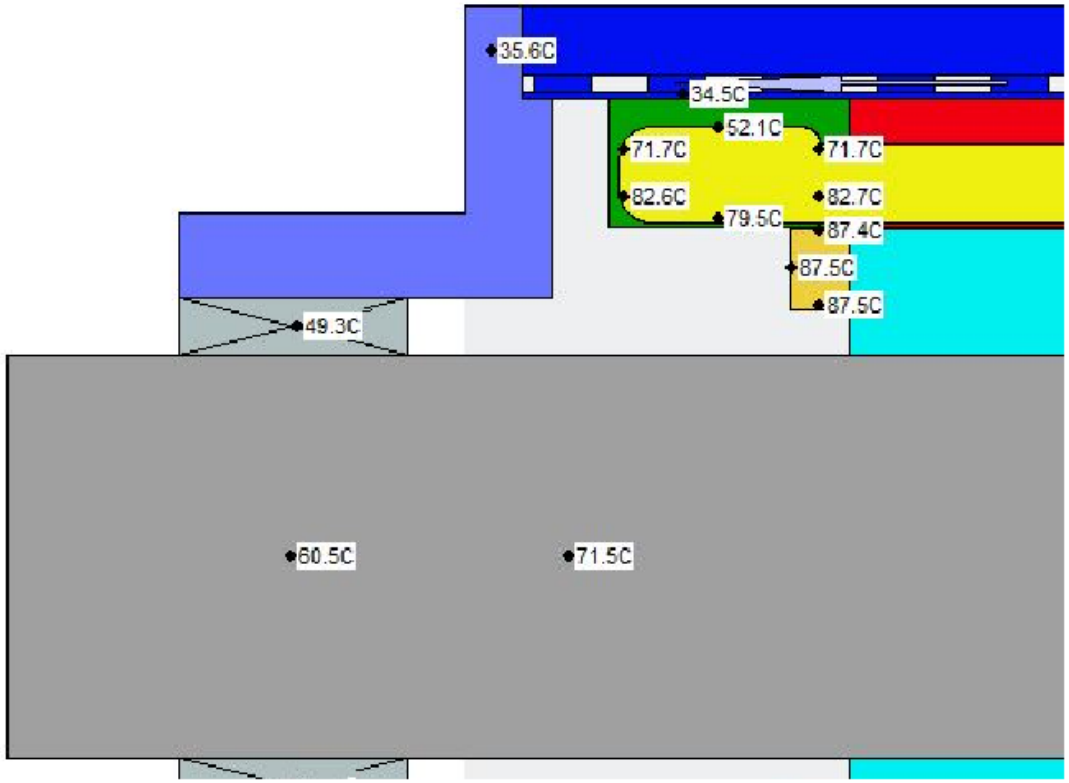


Nominal Power	**[kW]**	**26**
Nominal Torque	[Nm]	55.7
Peak Torque	[Nm]	225
Nominal Slip	[%]	0.98
Nominal Current	[Arms]	63
Total loss	**[W]**	**2698**
Efficiency	**[%]**	**90.6**

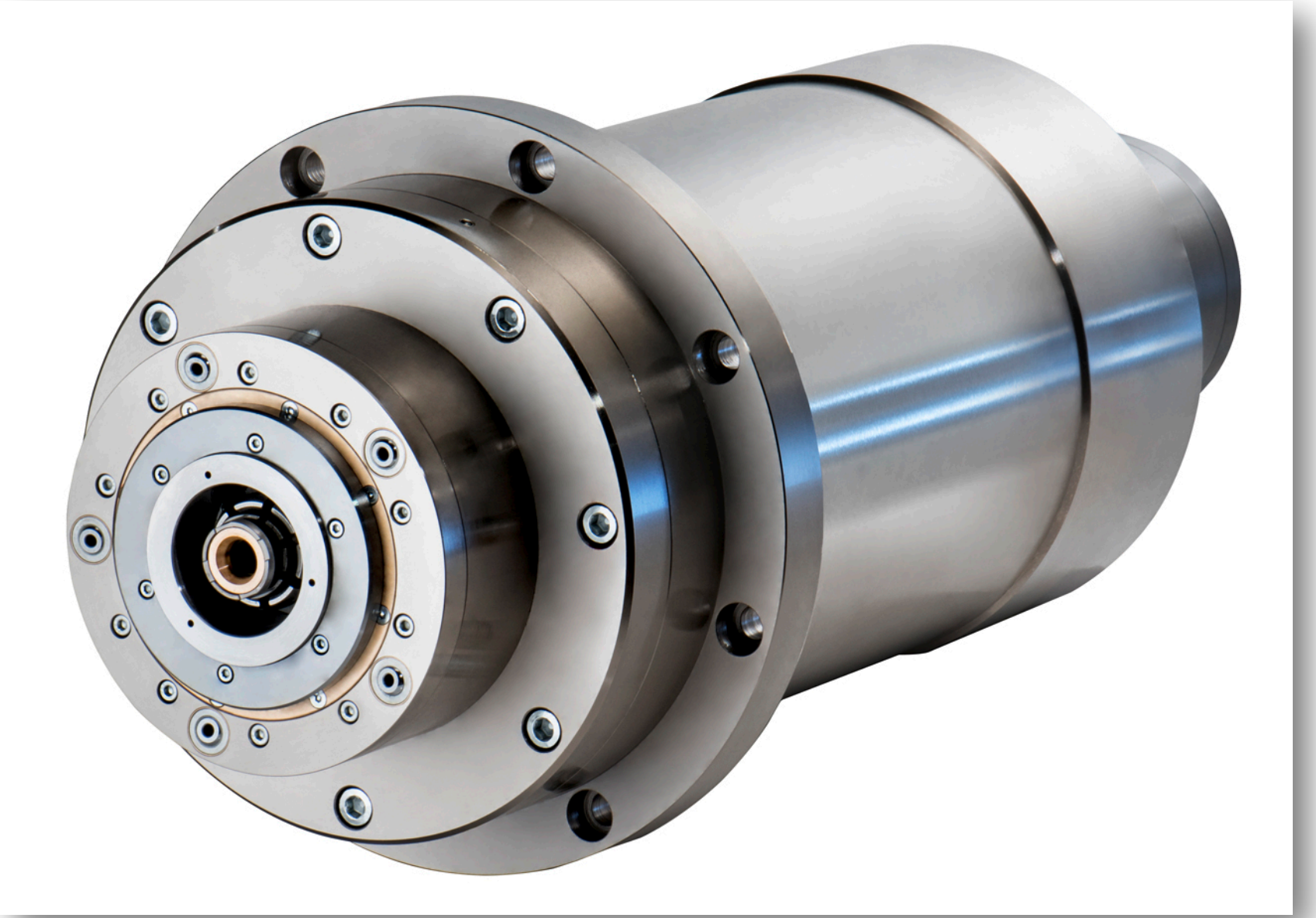
MOTORCAD results

Fluid Volume Rate	[l/min]	10
Inlet Temperature	[°C]	25
Outlet Temperature	[°C]	28.9
Winding Temperature	[°C]	66
Winding Time costant	[s]	100
Winding Thermal Resistance	[C/W]	0.015





The «real» Electrospindle



Thank you for your attention