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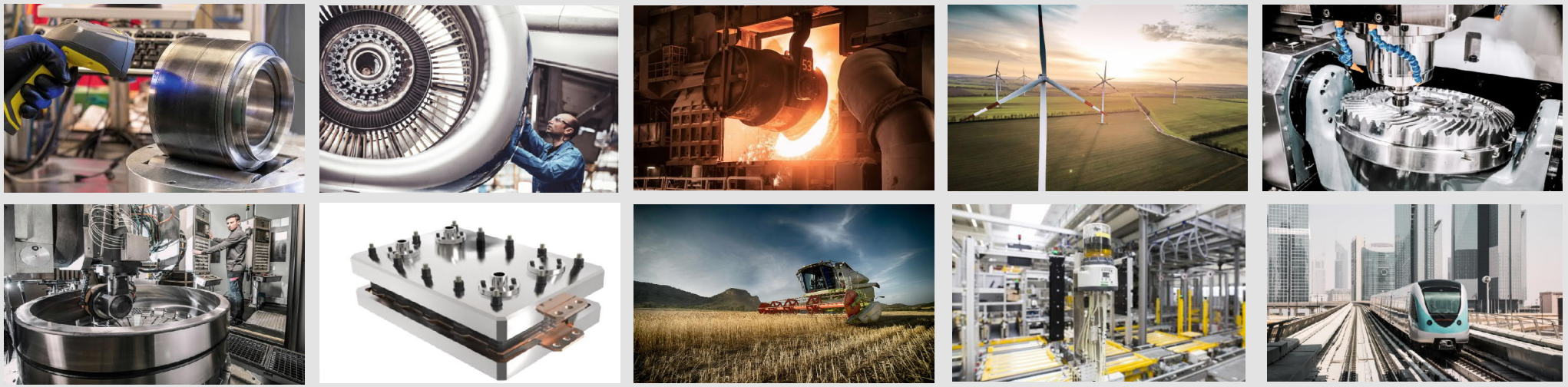

Product Development for Industry 4.0

Robotics - from Business Case to Product and Innovation Opportunities!

Prof. Dr.-Ing. Tomas Smetana

Senior Vice President Advanced Innovation Schaeffler Group

27.10.2022

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Tomas Smetana

Personal data

- Born in Czech Republic
- 48 years, married, 2 children
- Hobbies: technology, history, arts, languages, traveling, endurance sport

Academic career

• 1992-1998	TU Prague, mechanical engineering and advanced engineering
• 1998-2001	PhD in mechanical engineering at the TU Chemnitz in Germany
• June 2022	Professor at Shanghai University

Professional career

• Since 2001	Schaeffler AG, Herzogenaurach
• 2001-2005	Simulation engineer in the Central R&D
• 2005-2009	Advanced development, BD transmission applications
• 2009-2013	Product group eAxles, Systems Division eMobility
• 2013-2016	Product line Chassis Actuators, BD Chassis
• 2016-2019	CTO Asia Pacific, Yokohama
• 2019-2022	Global CTO Division Industrial, Shanghai
• Since 01.09.2022	Senior Vice President Advanced Innovation, Herzogenaurach

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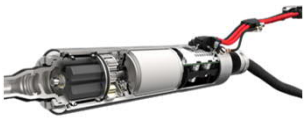
My important product development milestones ...

~ 2005

One-way clutches

~ 2010

Light weight differentials



~ 2015

- Electric axles
- active role control

~ 2020

- Robotics
- Service solutions
- Digital twins and AI

~ 2022

- Hydrogen electrolyze

2030

?

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Schaeffler facts and figures – One of the world's largest family-owned companies

approx. **83,000** employees worldwide

approx. **200** locations in over **50** countries

9.1% EBIT margin in 2021[1]

75 plants and **20** R&D centers

over **1,800** patents registered in 2021

sales of approx. **€ 13.9 billion** in 2021

As of December 31, 2021 | [1] Before special items

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Diversified customer base – Serving ten customer sectors

Cars & Light Commercial Vehicles

Truck & Bus

Industrial Automation

Wind

Two-wheelers

Off-road

We pioneer motion

Rail

Aerospace

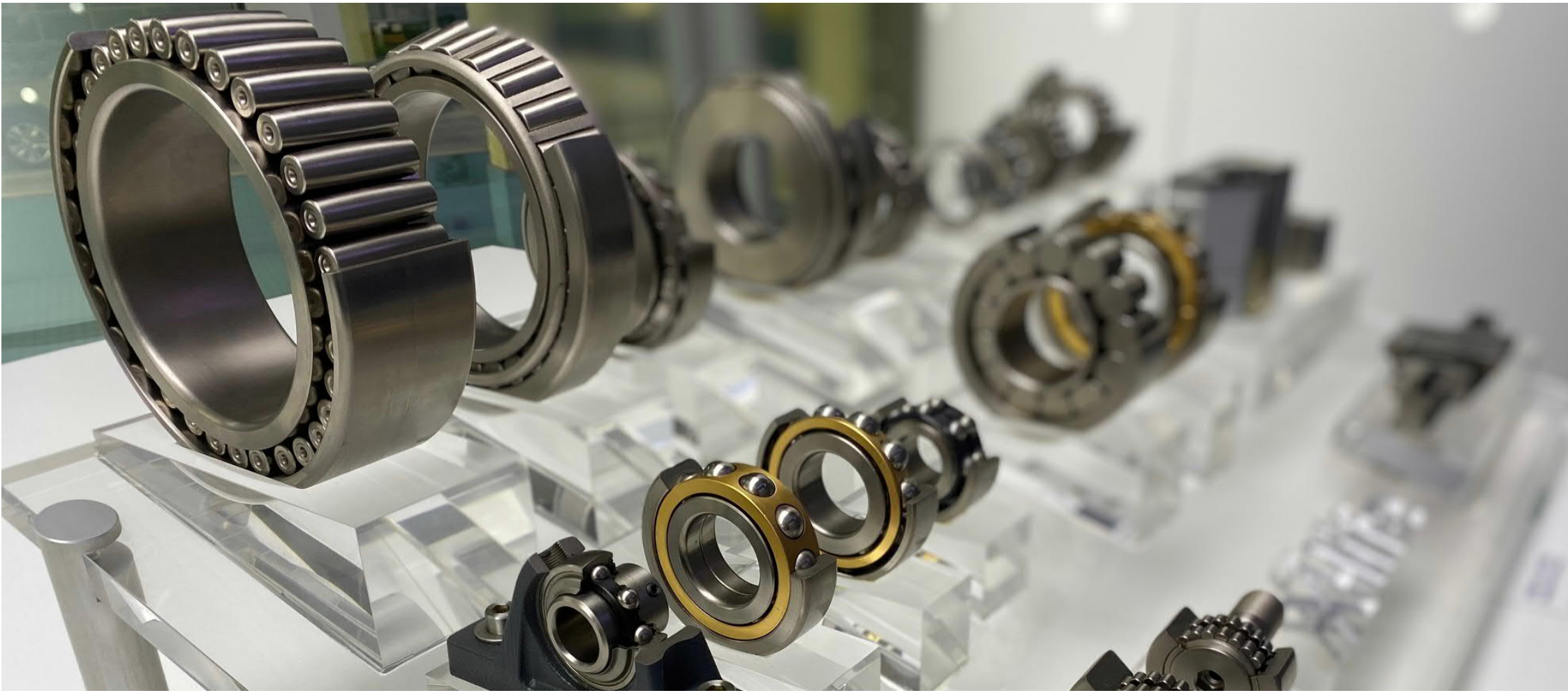
Raw Materials

Power Transmission

Mobility

Motion

Industrial Bearings



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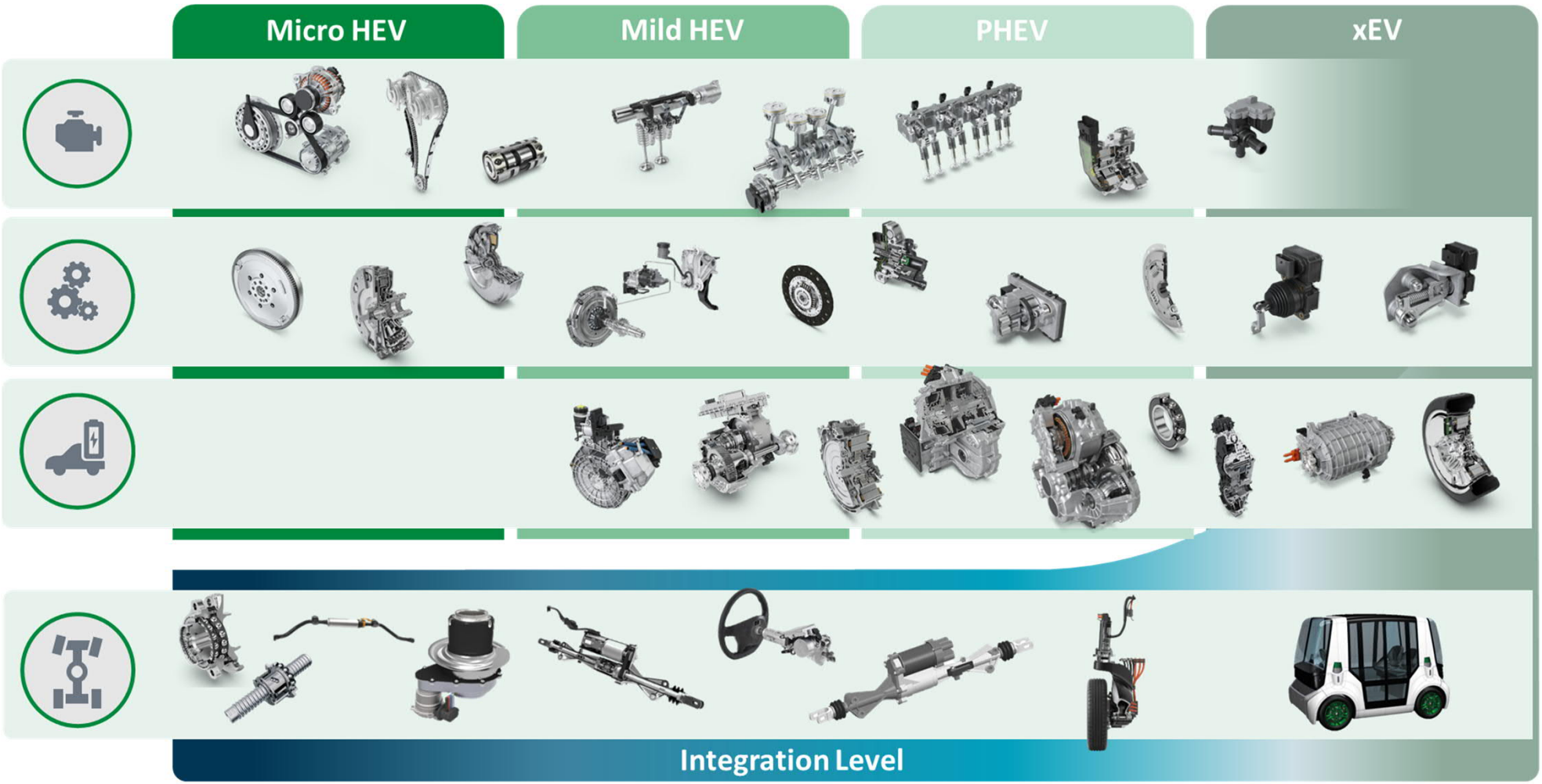
Automotive Products



Robot - Definition

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Josef Capek, 1890-1938
Czech writer

Introduction of the word Robot in the book R.U.R in 1920
“Robota”, means “difficult work” in the Czech language

Different type of Robots

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Understanding of market and customer requirements are necessary to realize new business growth with robotics!

Robot markets

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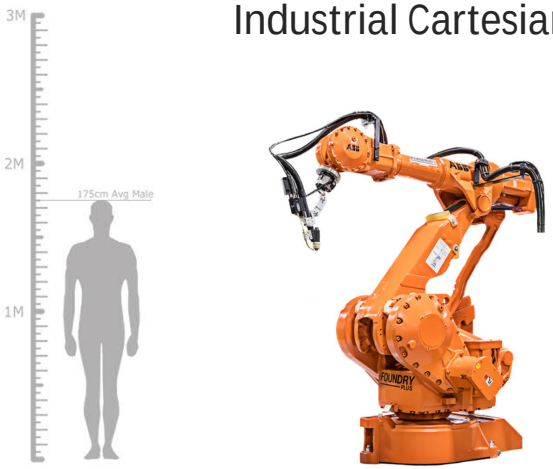
Industrial Cartesian robots



- "Behind the fence", no interaction with people
- Payload up to 300 kg (1000 kg)
- Repeatable periodic tasks
- Operating only by experts
- High product maturity
- Established market, CAGR ca. +6%

Target: Expand business with components

Cobots = Collaborative robots

- "Out-of-fence", collaborating with people
- Payload < 15 kg (20 kg)
- Frequently changing tasks
- Easy to operate by blue collars (AI)
- Lower product maturity
- Rapidly growing market, CAGR > +50%

Target: New businesses with mechatronic solutions

Industrial Robot Arm - Core Components and Value Add

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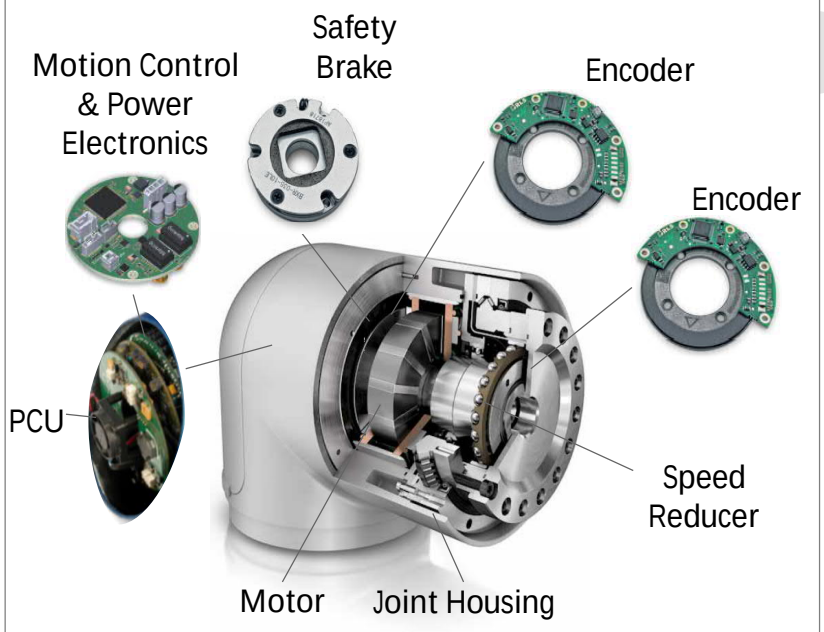
6 Joints (67%[1)])



*(1 = share of Cobot product cost

Controller (11%[1)])

Robot Body (22%[1)])

Periphery

Range Extender

End-effectors

Robot arm joints represents more 60% of industrial robot arm value add

Cobots at Schaeffler Production Plants

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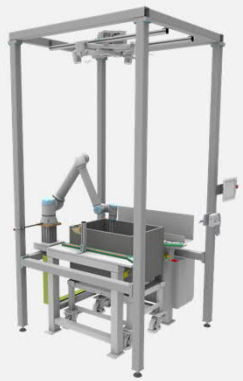
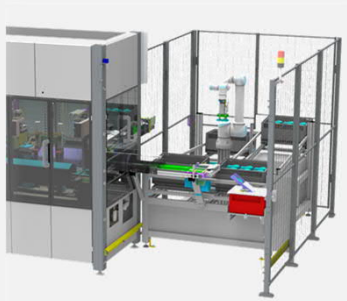
Automatic cell



- Roller bearings
- Loading rings via Bin-Picking
- Plant Schweinfurt

Coexistence

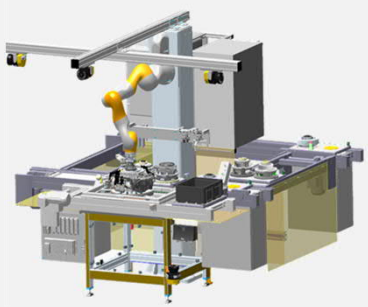


- TMM components
- Unloading sensor covers into carrier
- Plant Svitavy

Cooperation

- ASEH GEH
- Sample Inspection Outer diameter
- Plant Homburg

Collaboration



- E-axle components
- Assembly several gear boxes in housings
- Plant Herzogenaurach

Customer Expectations & Product Portfolio

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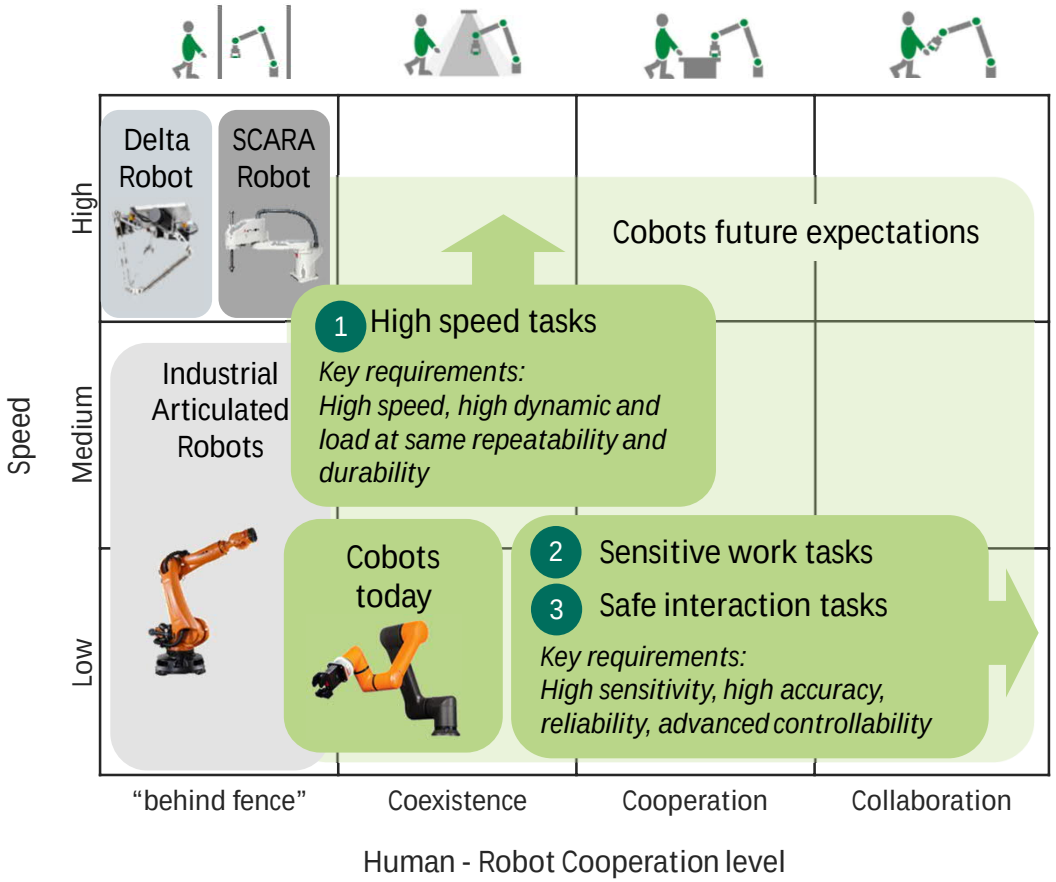

1 High speed tasks

- High stiffness bearings XZU
- Precise wave type speed reducers
- High performance PCB motors

2 Sensitive work tasks

3 Safe interaction tasks

- Integrated torque sensor
- Robot arm joint and new functions

Product portfolio requirements derived from future expectations of end-users in production!

Innovation Levels, Risks and Challanges

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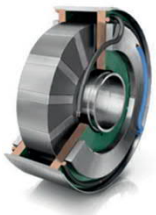
- Technology transfer from auto
- Less USPs, provide availability
- High product variance required!

- Tech. enablers: Sensotec and AI
- USP: Fully integrated sensor
- New cobots markets!

- Schaeffler core business
- Value add for speed reducer
- No direct sales to competitors!



- Tech. enablers: PCB, SMC
- USP: Power density, no cogging
- Price sensitive replacement market!

Increasing innovation level requires transformation of the whole organization, increases USPs but also risks

Main Bearing for Speed Reducers

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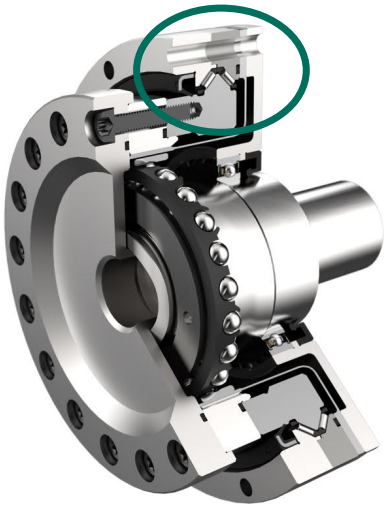
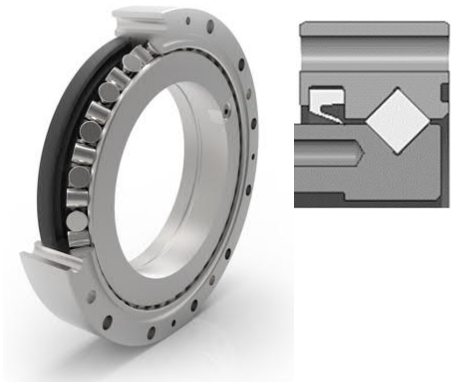
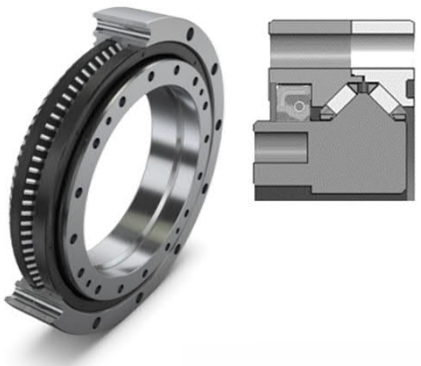


State of art:
Cross Roller Bearings (XRB)

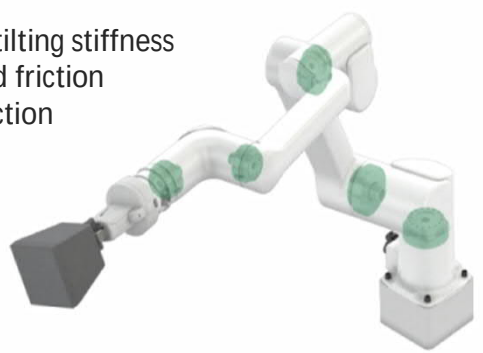


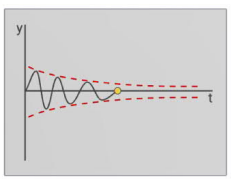
- High cost, difficult to assemble
- High and variable friction

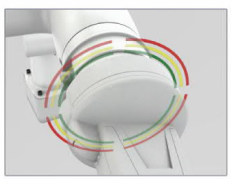
Schaeffler:
Cross Needle Bearings (XZU)



- 30% higher tilting stiffness
- 20% reduced friction
- Constant friction







Innovative cross-needle bearing results into significant system improvements regarding precision and speed!

Interaction between Robots and Humans

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High safety & sensitivity!

- Torque control in robot arms
- Force feedback in end-effectors
- Vision systems for object recognition
- Self-learning capabilities
- Easy to teach & communicate

Speed reducer with integrated Torque Sensor

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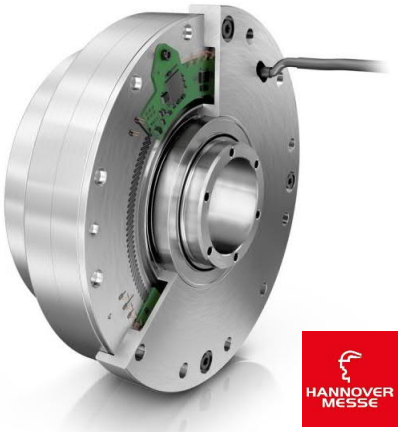

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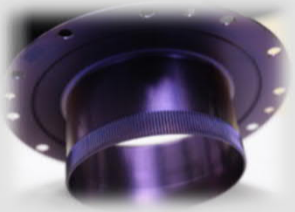
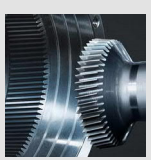
Advanced Manufacturing





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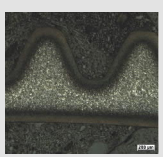
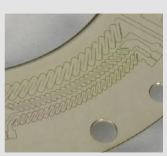
Material & Surface technologies





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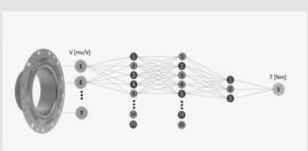
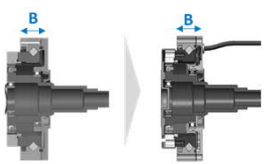
Mechatronics & Artificial Intelligence





- USP: integrated torque sensor
- High sensitivity and safety
- High stiffness and precision
- No additional space and weight

Functional competences: Simulation, Validation, Industrialization

Schaeffler core competences: System know how, materials & surface technology and industrialization capabilities!

Speed reducer with integrated Torque Sensor

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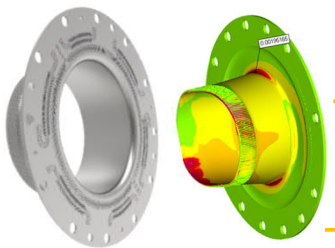
External forces on robot

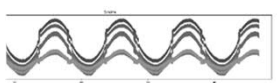
Speed reducer

Flex spline with Sensotect®



1x DMS V1 [mV/V]

6x DMS V2 [mV/V]



Signal Status

Torque [Nm]

Microelectronics

low level SW

input signal processing

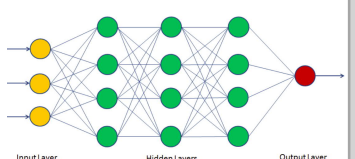
output signal processing

application SW

mode management start up and shutdown

torque estimation

machine learning (AI)



diagnostics

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Innovation: fully integrated torque measurement based on Sensotect & embedded AI (machine learning)

Speed reducer with integrated Torque Sensor

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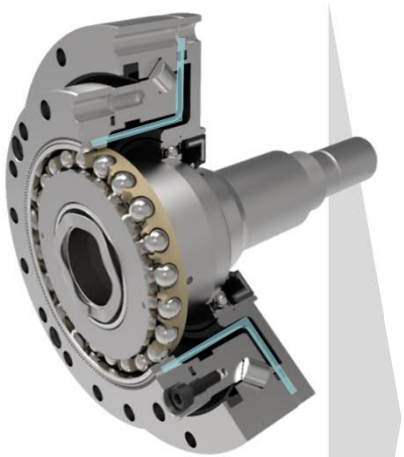
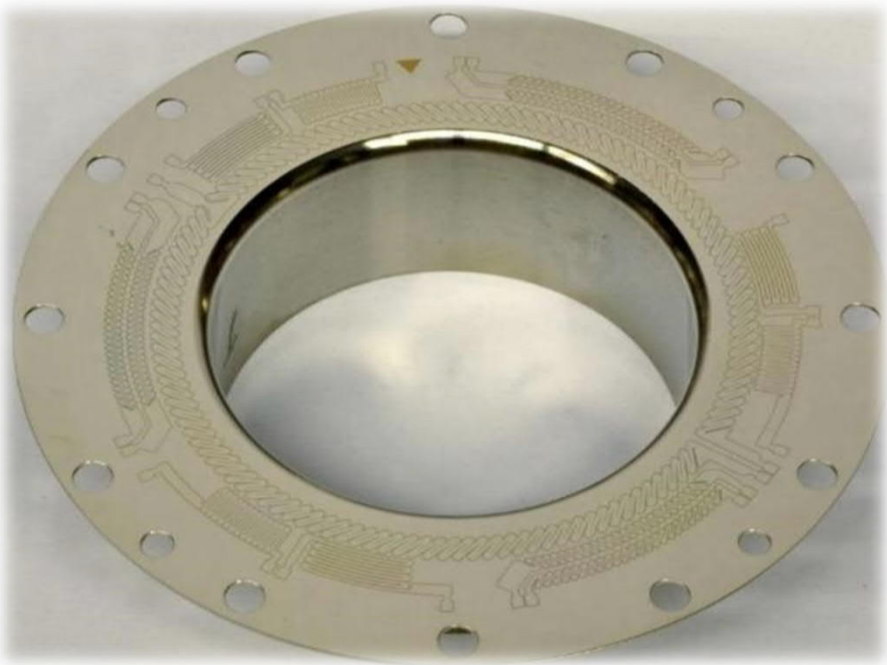
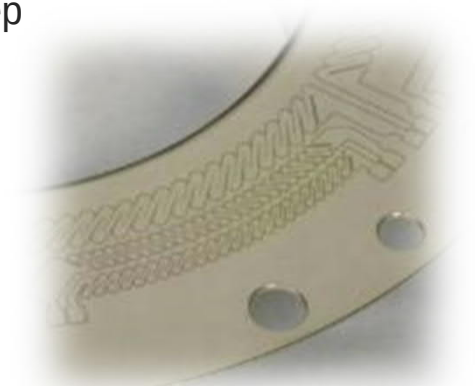
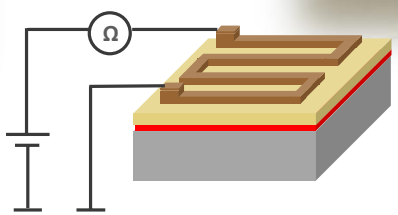




- Two layer nano-coating
- Laser structured straing gage patterns
- direct measurement of deformations
- high precision and durability
- no creep





Innovation: Sensotect® coating for measurement of surface deformations inside transmission

State of Art – “Full Bridge”

Input → Signal processing → Output

V [mv/V]

1

2

⋮

7

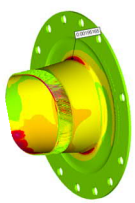
k x Σ i / 7

1

T [Nm]

1

ε > 7%



- Complex deformations
- Production tolerances
- Friction from bearings

k-factor
= 1 variable

- Imprecise measurement
- Insufficient compensation of real influences

Conclusion: Standard full bridge can‘t fullfil requirements of robot applications

Schaeffler embedded AI

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Input | **Signal processing** | **Output**

Basic layers | *Individual layer*

V [mv/V]

1 2 ⋮ 7

1 2 3 4 5 ⋮ 14 15

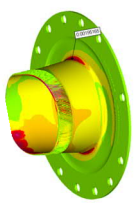
1 2 3 4 5 ⋮ 14 15

1 2 3

T [Nm]

1

$\varepsilon < 1\%$



- Complex deformations
- Production tolerances
- Friction from bearings

Neural network

7 x 15 x 15 x 3 = 4.725 variables

- High dynamic precision
- Real-Time, min. latency
- Production tolerances compensated

Conclusion: AI makes sense especially in combination with multiple sensors based on Sensotect

Outlook: Advanced robots at Schaeffler

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

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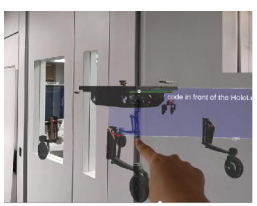
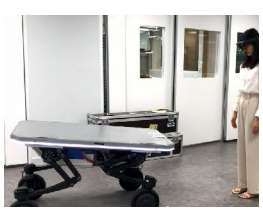
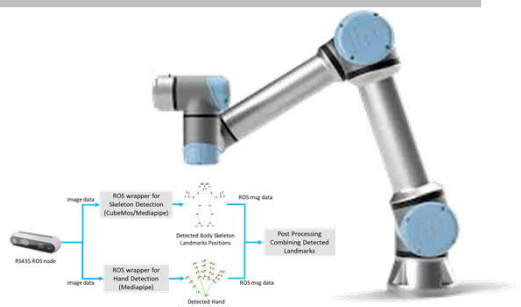
Autonomous movement

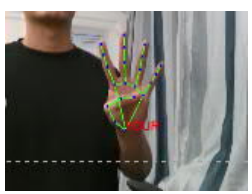


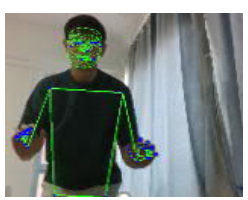


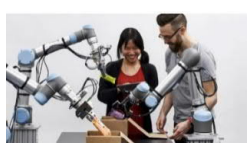
- Inspection systems
- Delivery services
- Professional services
- ...

Autonomous handling









HMI - Gesticulated and verbal communication

Target: fully autonomous delivery and handling systems for production or for professional services!

Future Application of Advanced Robotics …

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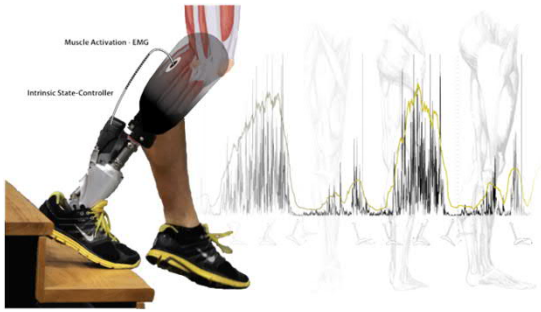
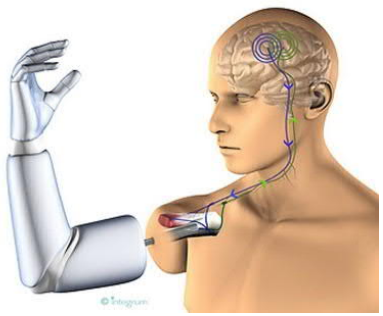
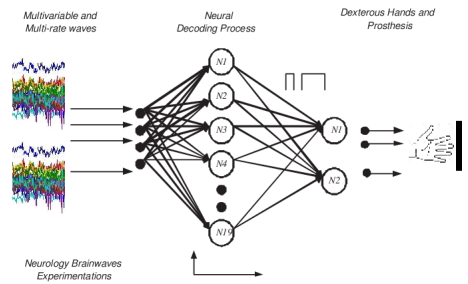
Protheses controlled by muscle contractions





Protheses controlled by mind/brain signals

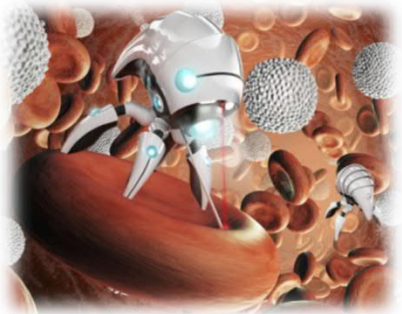


Insects remote controlled by chip

Exoskeletons

Humanoids

Nanorobotics



Schaeffler screen markets for future peaceful robot applications e.g. in healthcare!

Innovation-to-business …

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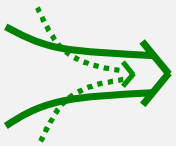
Strategy



- “Do less in order to achieve more”
  Focus on systematic efficient innovation instead of generating random manifold ideas!

Disruptiveness

- “As disruptive as necessary, as close to core as possible”
  Anticipate customer needs, understand future markets and own core values deeply before ideation!

Risks

- “Less risk, more fun”
  Make risks transparent and predictable as early as possible and mitigate them!

Efficiency

- “Fail fast with minimum costs”
  Allow idea diversity, support agility and failure culture, but efficiently and with lessons learned!