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Bearingless Motors in SyMSpace

JKU Institute for Electrical Drives and Power Electronics

SyMSpace Days

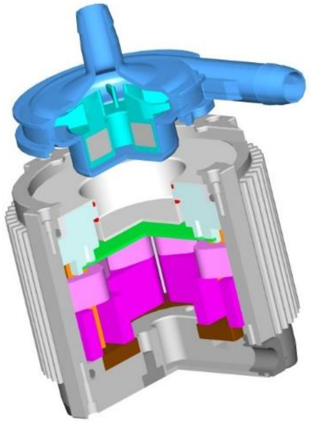
September 18-19, 2024

Agenda

Content

- Introduction
  - What is a bearingless motor?
  - Some research projects
- Model and Control
  - How to stabilize the rotor?
- SyMSpace Bearingless Motor Component
- Future Aspects
  - Link X2C and SyMSpace

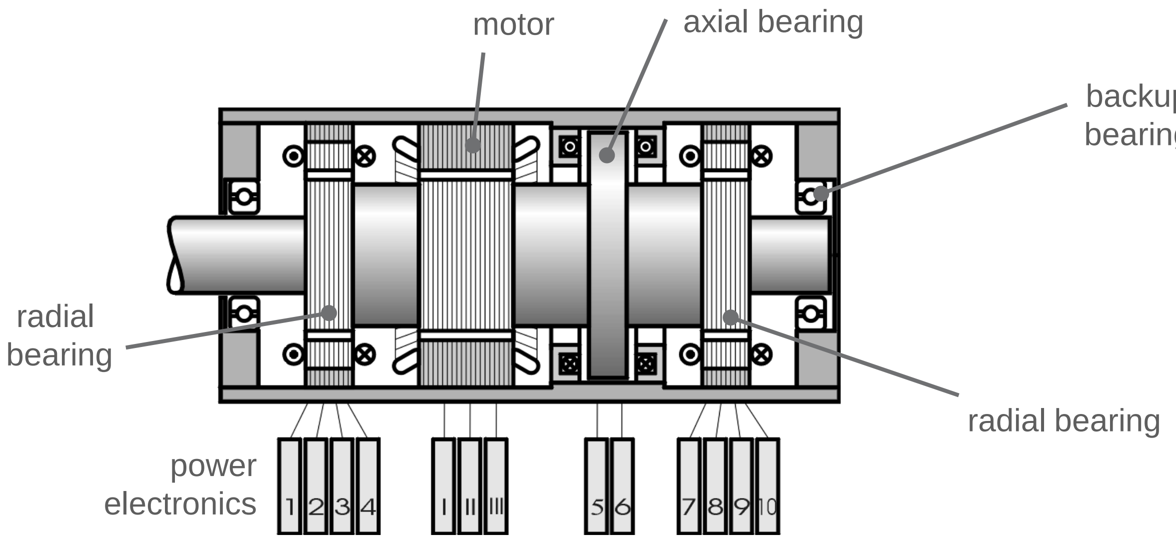
HeartMate 3

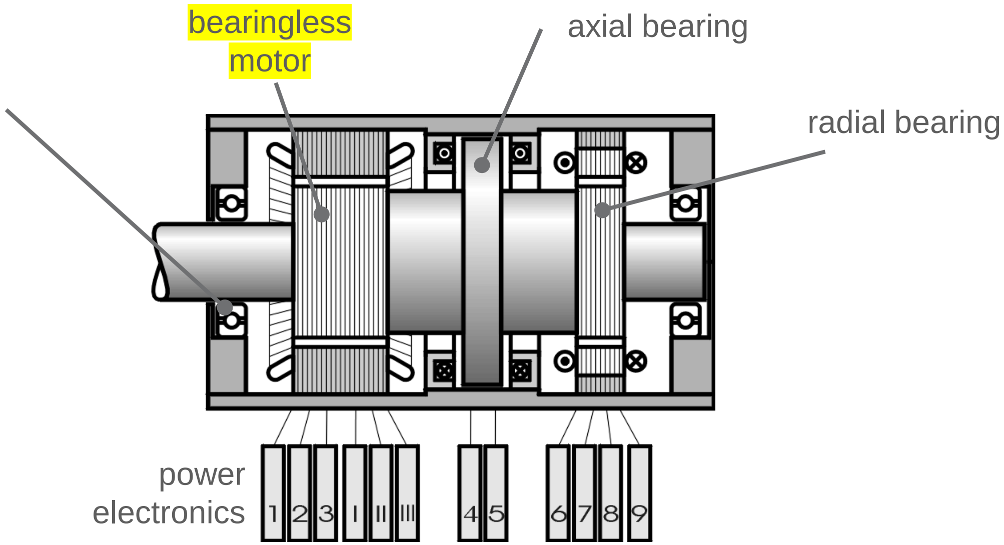


Levitronix BPS-1

Introduction

Bearingless Motor





Magnetically suspended drive

- drive and suspension is decoupled
- separated design of drive and suspension is possible
- typically larger and higher electric and mechanical demand

Bearingless motor

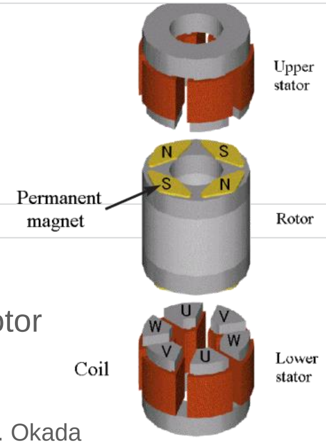
- very cost-effective setup for smaller systems
- drive and suspension are often on a common lamination stack
- more complex control structure

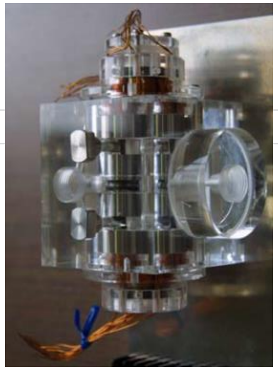
Introduction

Bearingless Motor

- Torque and **radial** forces (often used)
- Torque and **axial** forces (seldom)

Axial Self-Bearing Motor





Ibaraki Univ. Y. Okada

Bearingless Induction Machines

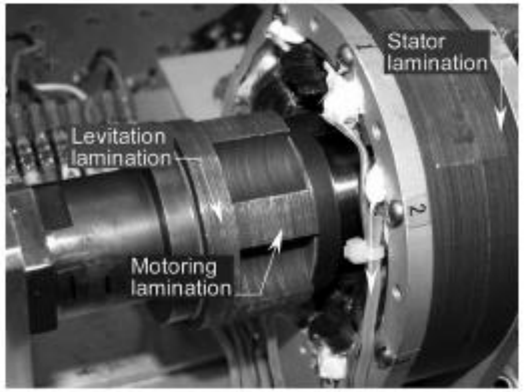
TIT, A. Chiba

PMSM

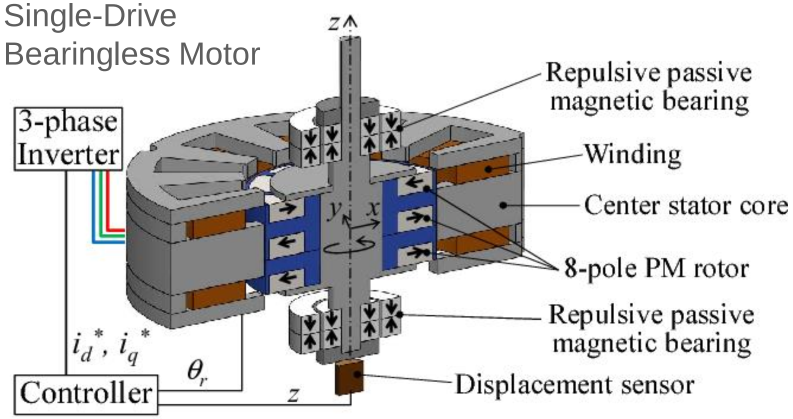
TU Darmstadt, A. Binder

Magnetic Bearing SR-Motor

NASA, C. R. Morrison



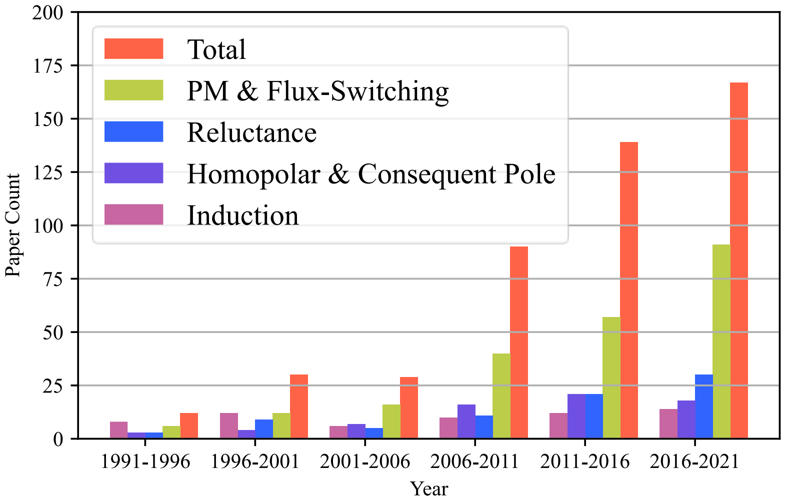
Single-Drive Bearingless Motor

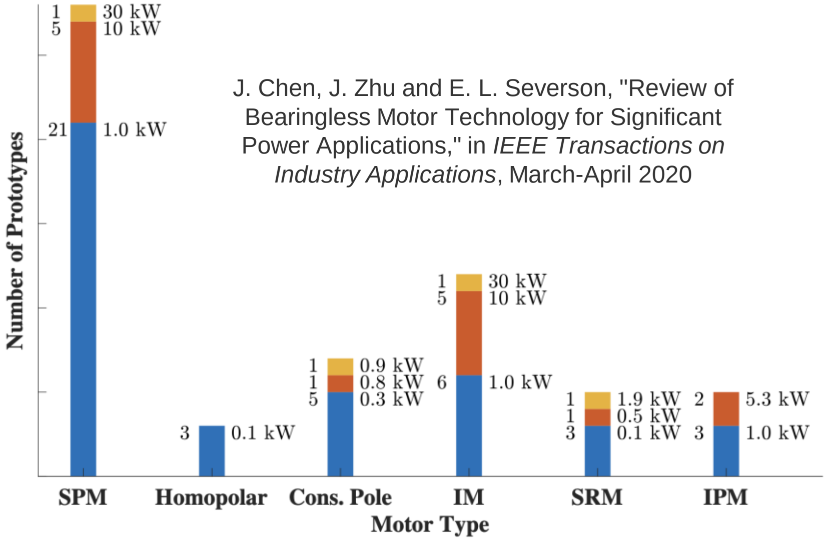


TDU, H. Sugimoto

Introduction

Bearingless Motor





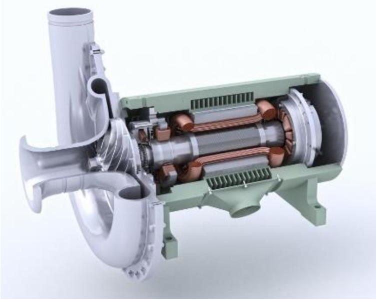
J. Chen, J. Zhu and E. L. Severson, "Review of Bearingless Motor Technology for Significant Power Applications," in *IEEE Transactions on Industry Applications*, March-April 2020

HeartMate 3

BPS-1

BFS-i10

SKF



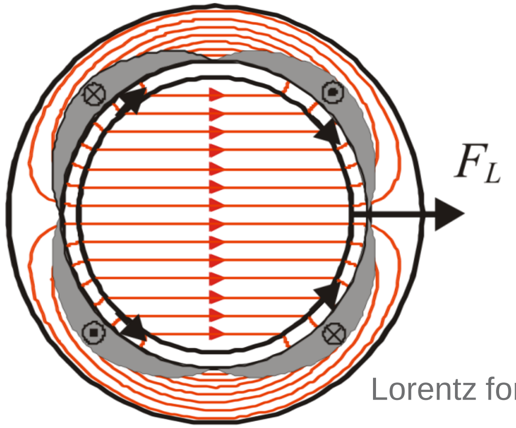
Amber Kinetics

Introduction

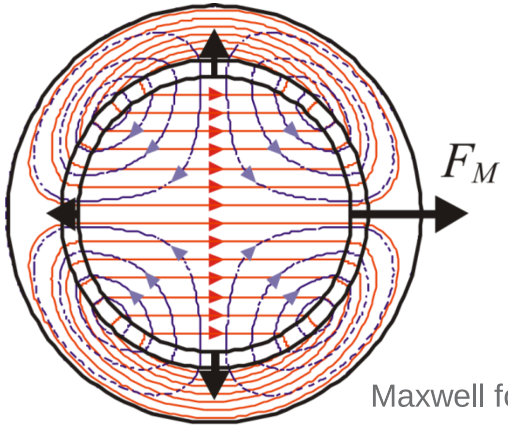
Bearingless Motor

Force generation

$p_{stator} = p_{rotor} \pm 1$



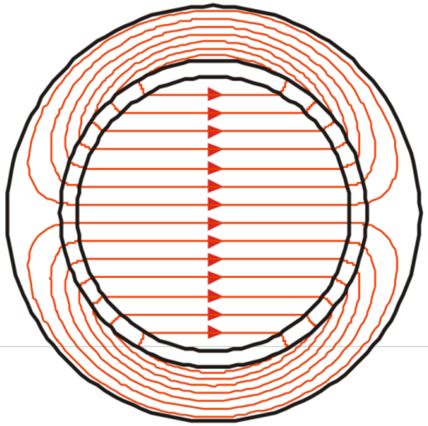
Lorentz forces



Maxwell forces

Torque generation

$p_{stator} = p_{rotor}$

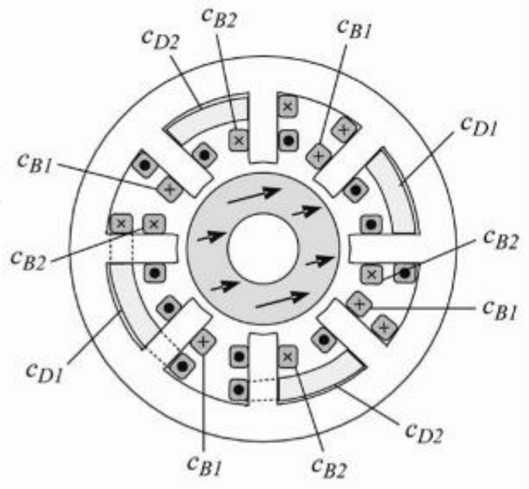


Maxwell forces do not create any torque here!

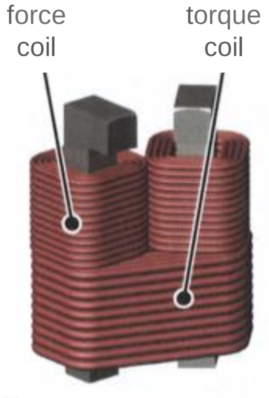
Introduction

Bearingless Motor

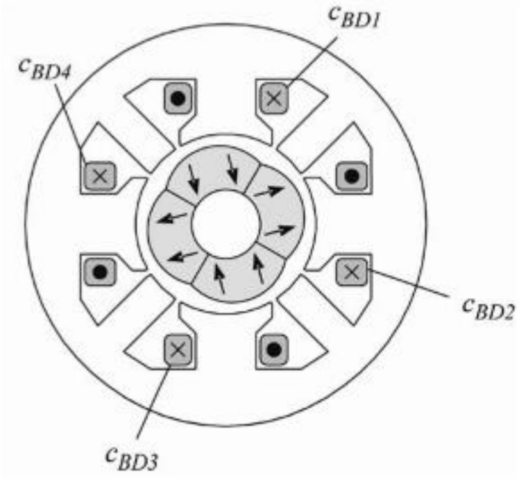
Winding systems



separated windings



- more complicated to manufacture
- decoupled force and torque generation
- design of force and torque is decoupled



combined windings

- simple to manufacture concentric coils
- coupled force and torque generation
- design of forces and torque is not independent

Model and Control

Force/Torque Model

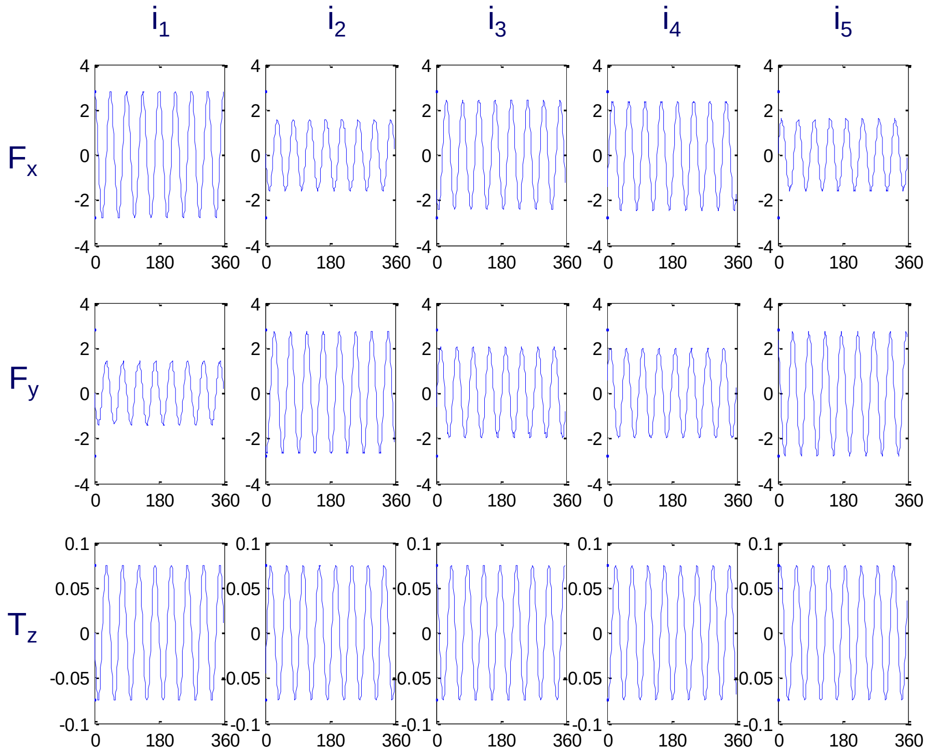
current-force-matrix $\mathbf{T_m}(\varphi)$

- possibility to influence the plant
- generally fully occupied
- determined by FE-simulations or analytical model

$$\begin{bmatrix} F_x \\ F_y \\ T_z \end{bmatrix} = \mathbf{T}_m(\varphi)\,\mathbf{i}_S \qquad \mathbf{i}_S = \mathbf{K}_m(\varphi) \begin{bmatrix} F_x \\ F_y \\ T_z \end{bmatrix}$$

force-current-matrix $\mathbf{K_m}(\varphi)$

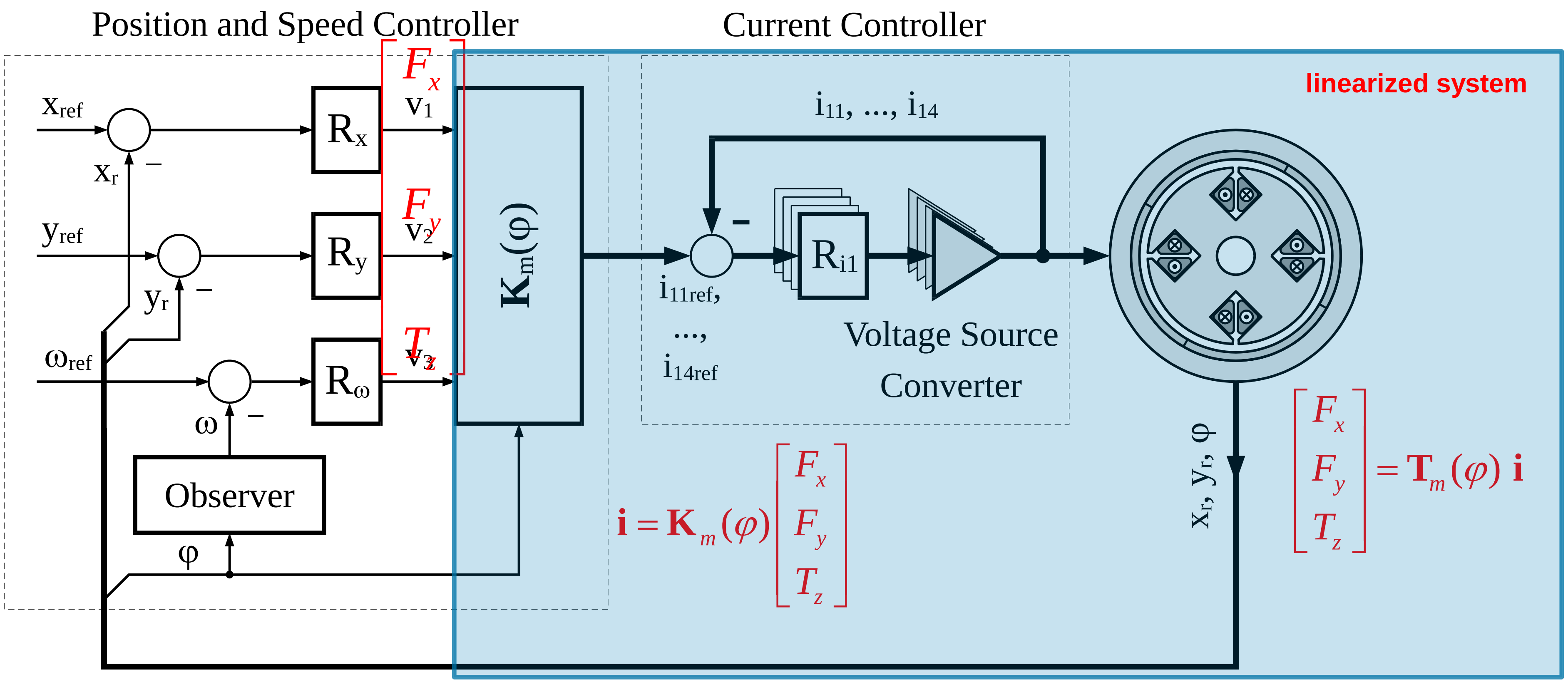
- to be computed for control
- simple to calculate for dimension 3 $\mathbf{T}_m(\varphi)\mathbf{K}_m(\varphi) = \mathbf{E}$
- with higher dimensions: additional constraint $\mathbf{i}_S^T\,\mathbf{i}_S \rightarrow \min$



$$\mathbf{K}_m(\varphi) = \mathbf{T}_m^{\mathrm{T}}(\varphi)\,\left(\mathbf{T}_m(\varphi)\mathbf{T}_m^{\mathrm{T}}(\varphi)\right)^{-1}$$

Model and Control

Control Scheme

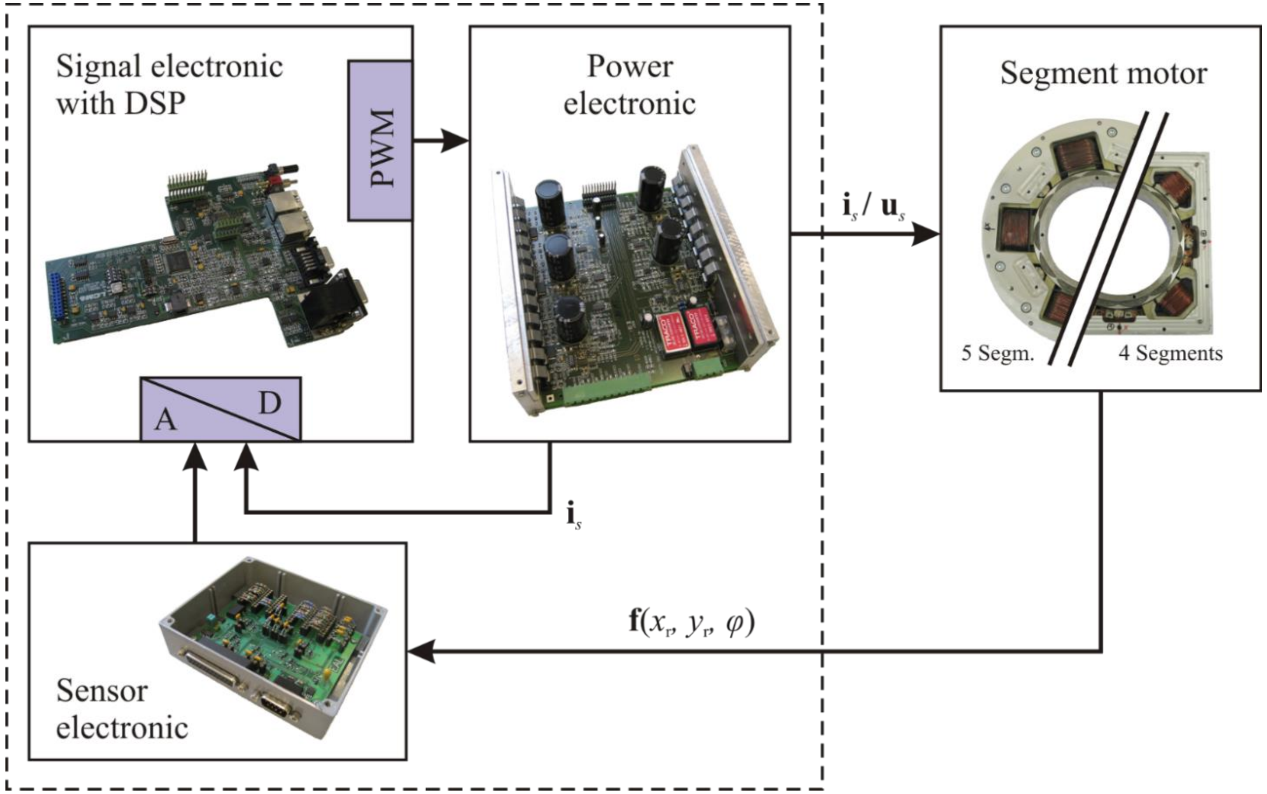


Model and Control

Overall System

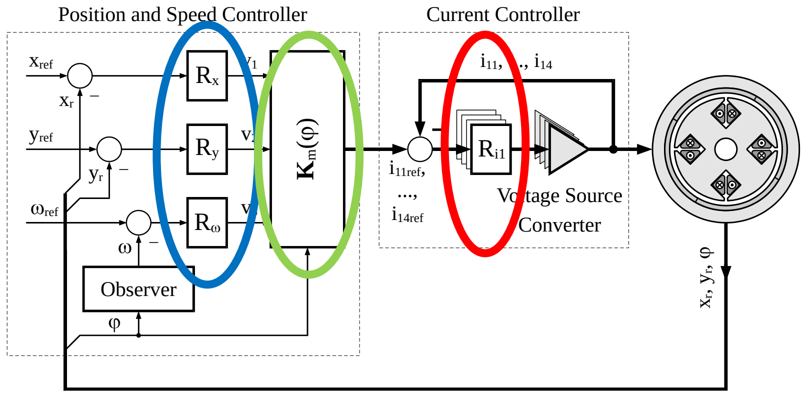
Components

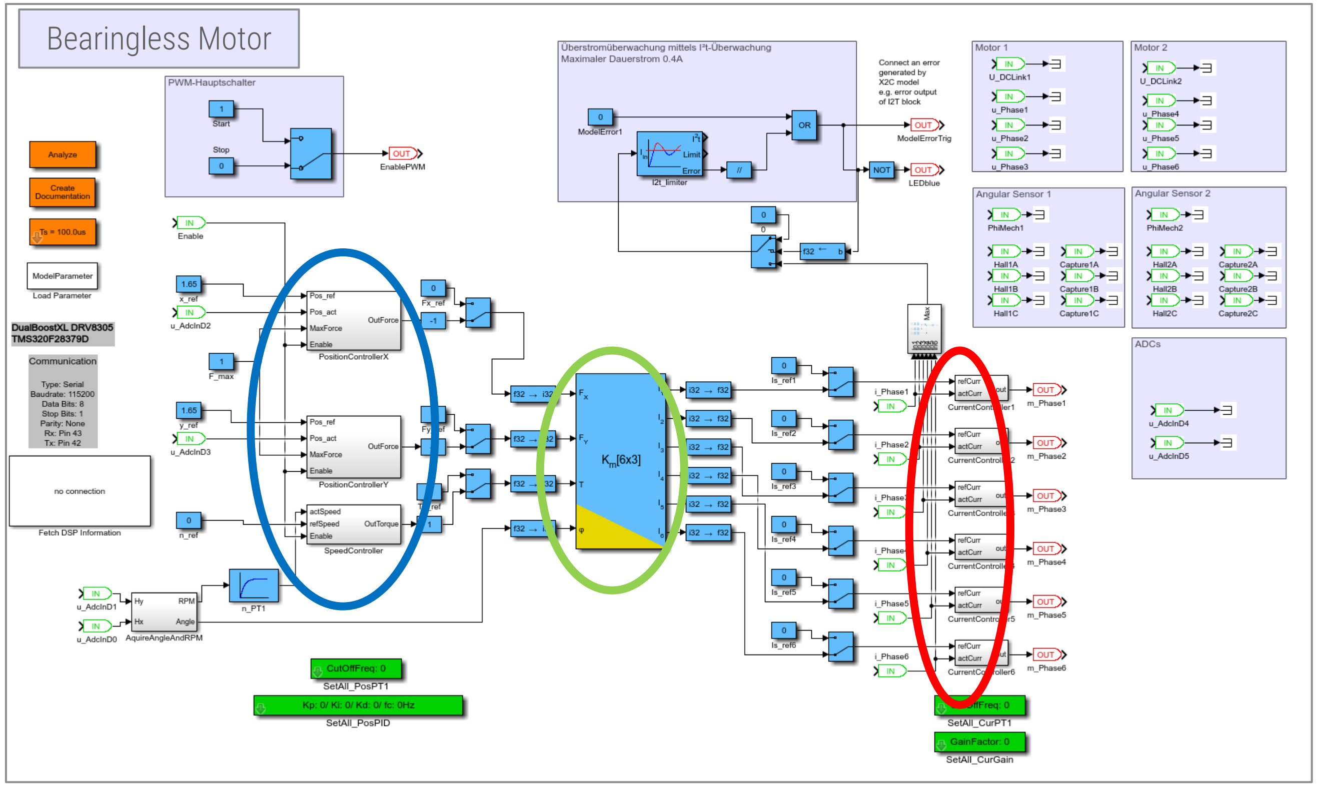
- Power electronics
- Signal electronics (DSP)
- Sensor electronics



Model and Control

X2C Control Scheme

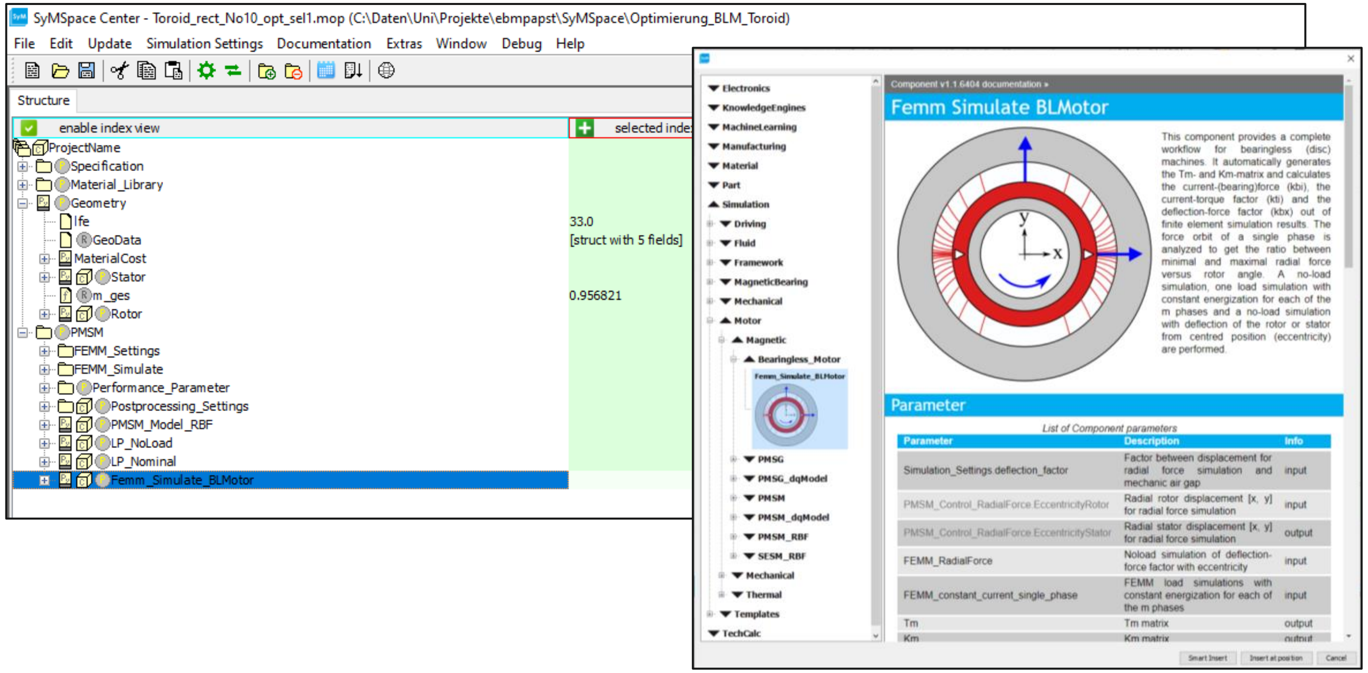




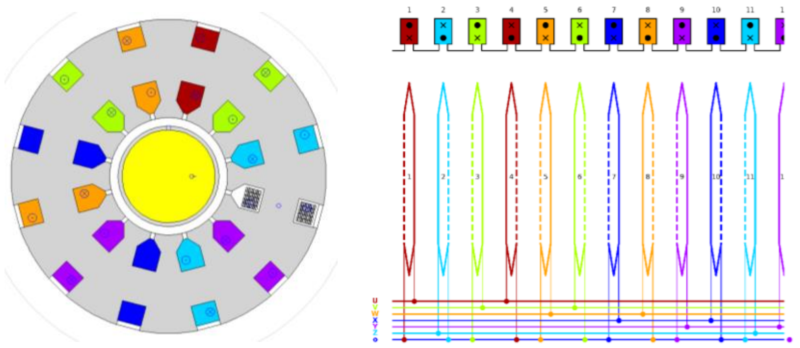
SyMSpace Bearingless Motor Component

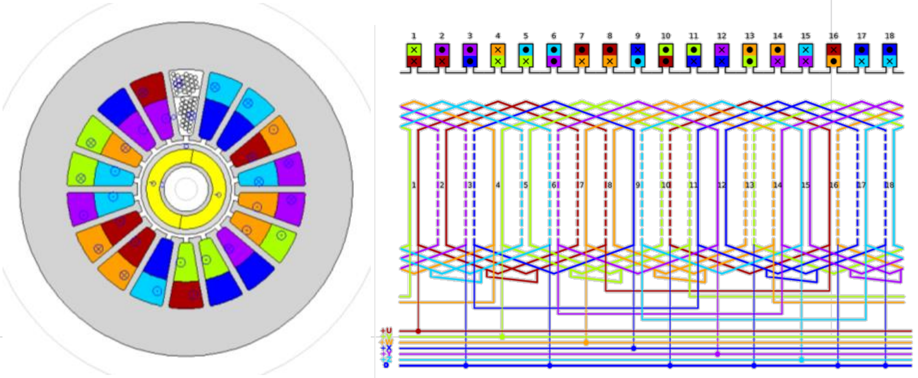
Overview

- Integrated in PMSM->FEMM Simulate_BLMotor



Toroidmotor





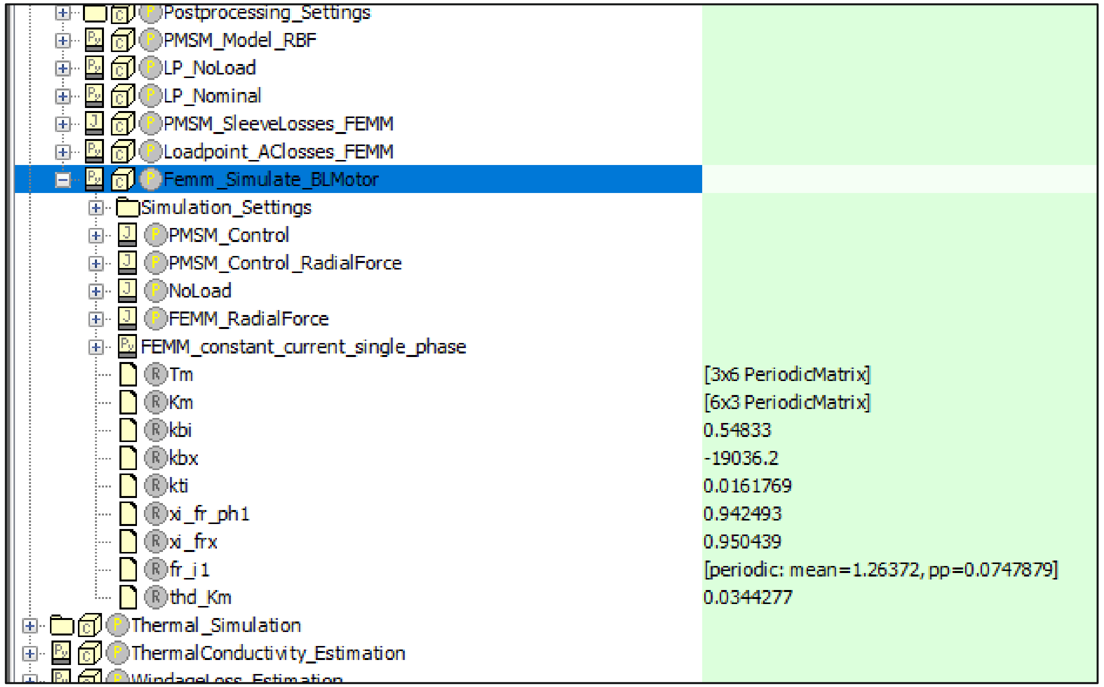
Zahnspulenmotor

- Multiphase system with proper winding scheme is needed!

SyMSpace Bearingless Motor Component

Content

- All phases are energized with constant current one after the other
- Displaced rotor is simulated at no load
- Resulting analysis
  - Tm and Km matrix
  - Torque factor kti (in Nm/A)
  - Force factor kbi (in N/A)
  - Max. to min. force xi_fx (in %)
  - Radial stiffness kbx (in N/mm)



SyMSpace Bearingless Motor Component

Content

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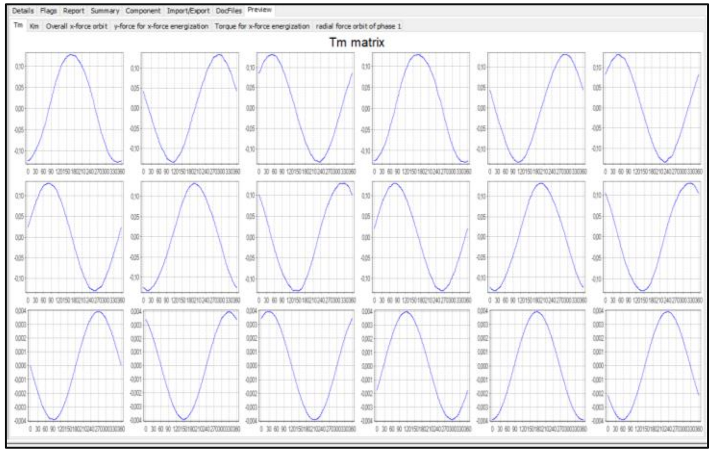
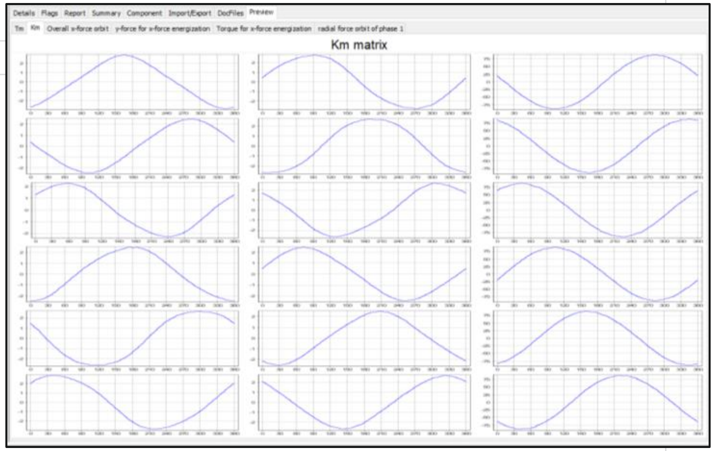
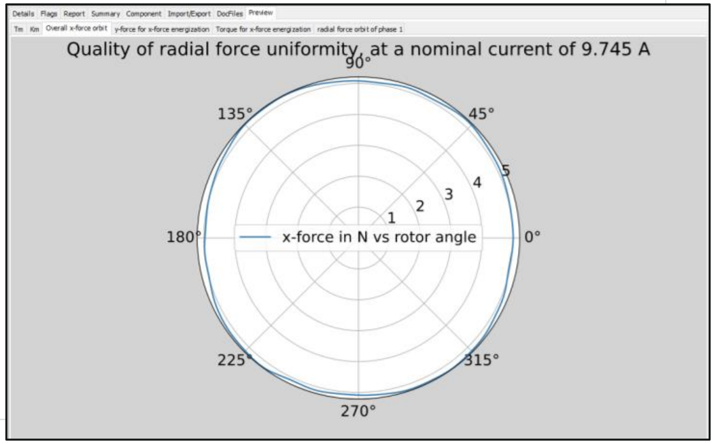


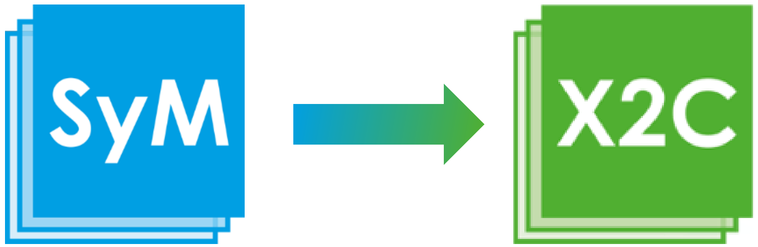


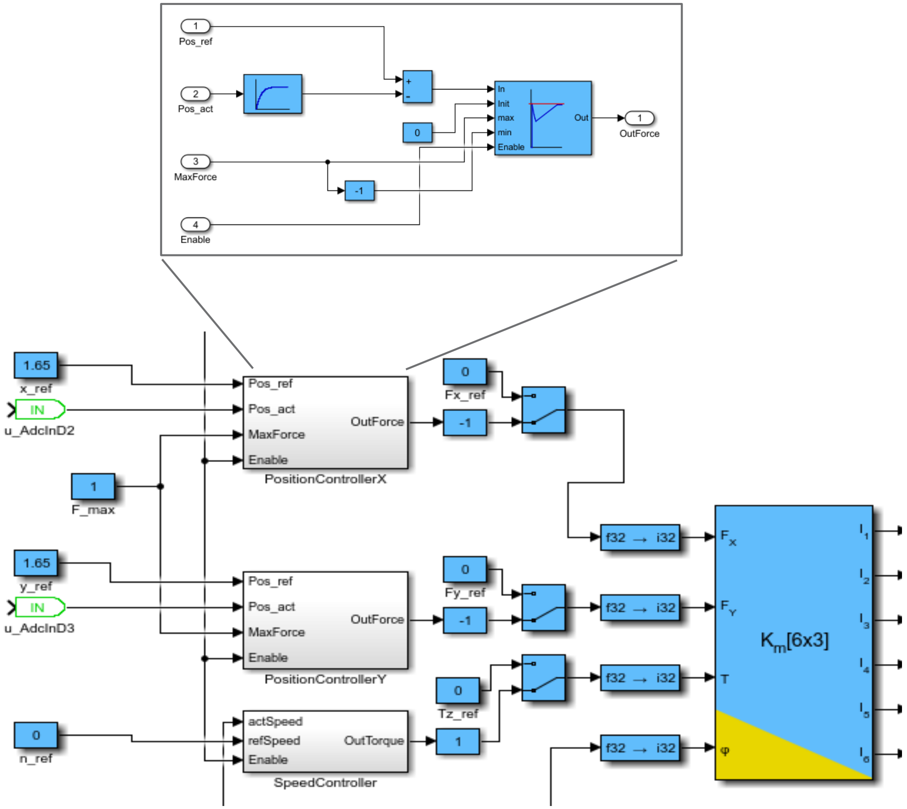


SyMSpace Bearingless Motor Component

Outlook

- Auto Commissioning with X2C
  - Position sensor characteristics
  - Current sensor characteristics
  - Determine X2C Control Parameter from SyMSpace

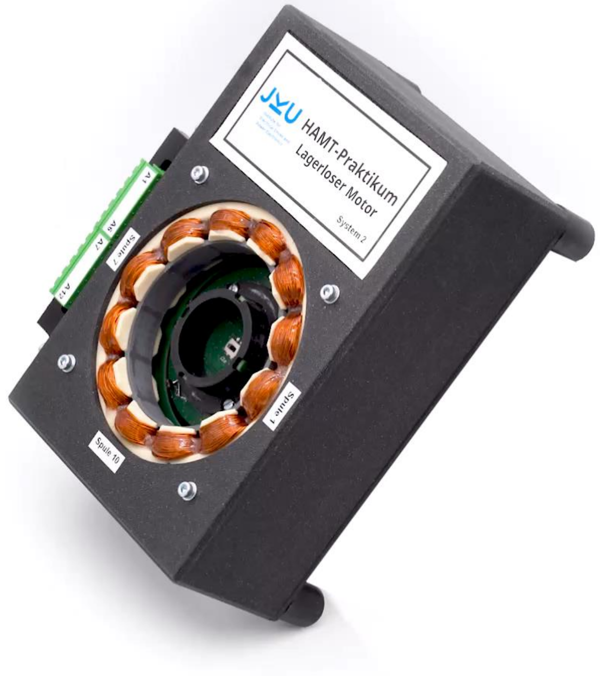


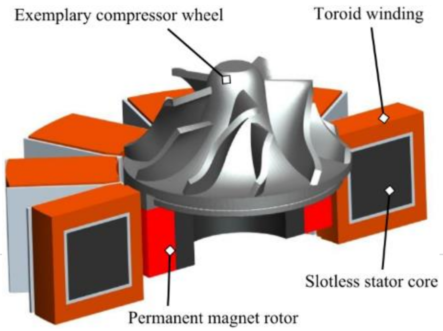


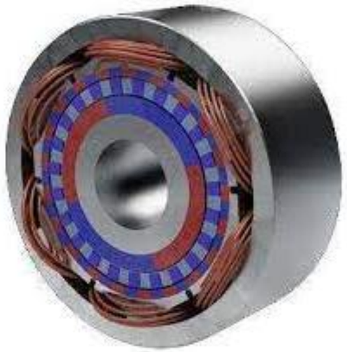
Bearingless Motor Projects

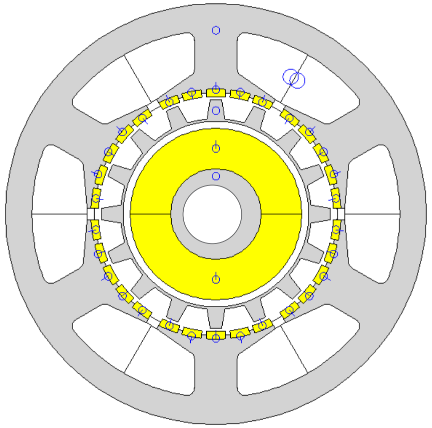
Examples

- Bearingless Motor Demonstrator Kit
  - Education and Training
- Bearingless High-Speed Motor
  - Compressors
- Bearingless Magnetic Gear Motor
  - High Torque Density
  - Direct Drive Applications









Science becomes

reality

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