

# Bearingless Motors in SyMSpace



SyMSpace Days

September 18-19, 2024

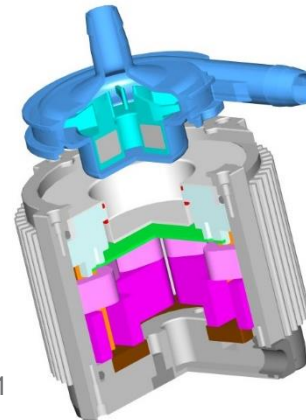
# Agenda

## 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

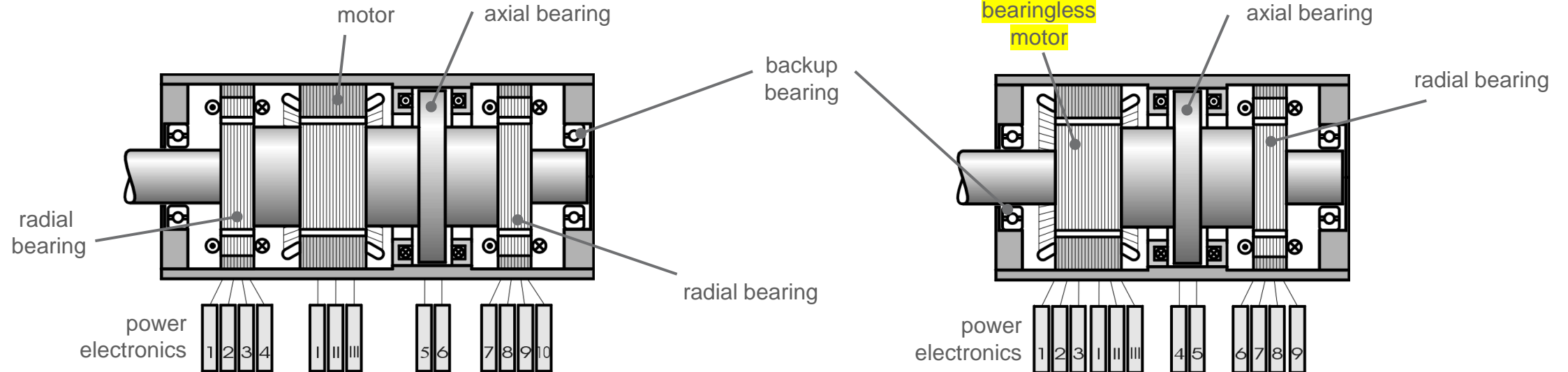


Levitronix BPS-1



# 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)

Bearingless Induction Machines



TIT, A. Chiba

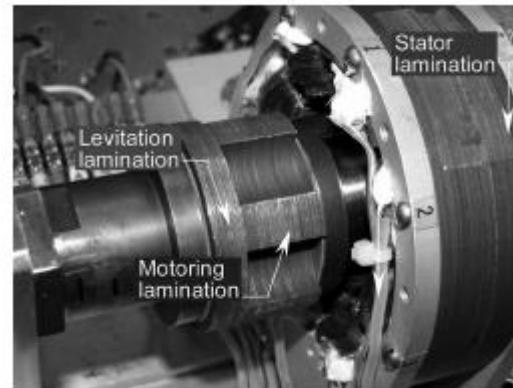
PMSM



TU Darmstadt, A. Binder

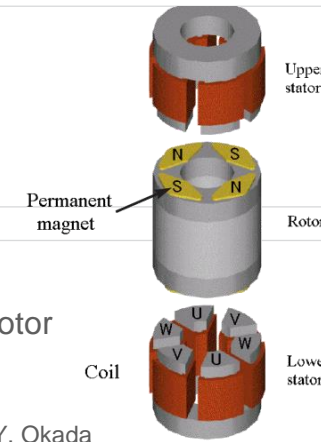
Magnetic Bearing SR-Motor

NASA, C. R. Morrison

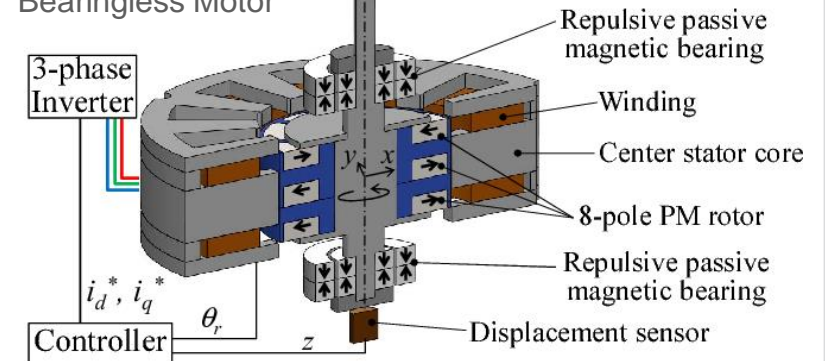


Axial Self-Bearing Motor

Ibaraki Univ. Y. Okada



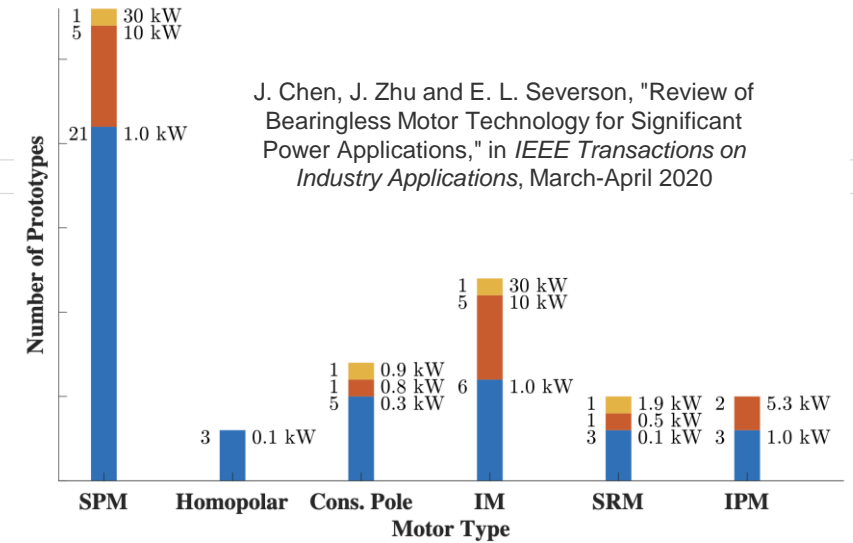
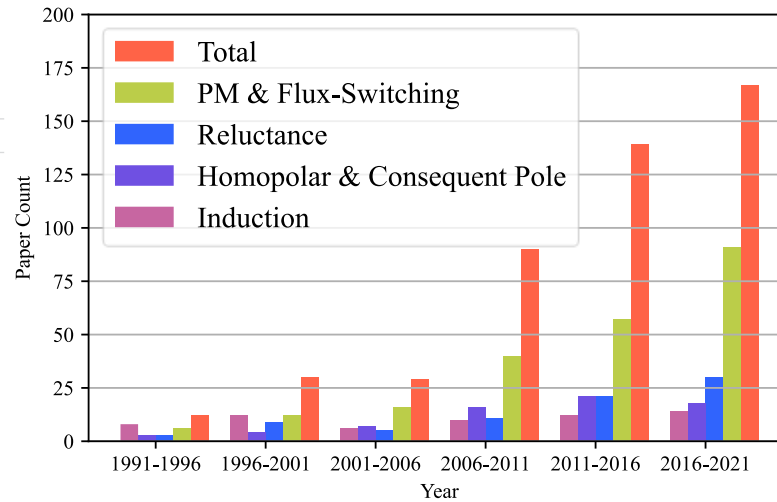
Single-Drive Bearingless Motor



TDU, H. Sugimoto

# Introduction

## Bearingless Motor



BPS-1



BFS-i10



SKF



Amber Kinetics



HeartMate 3

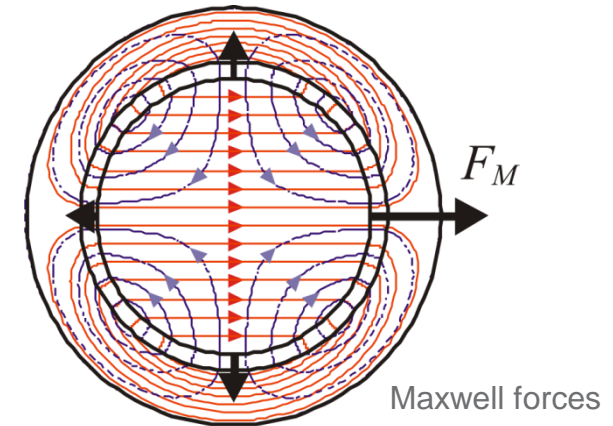
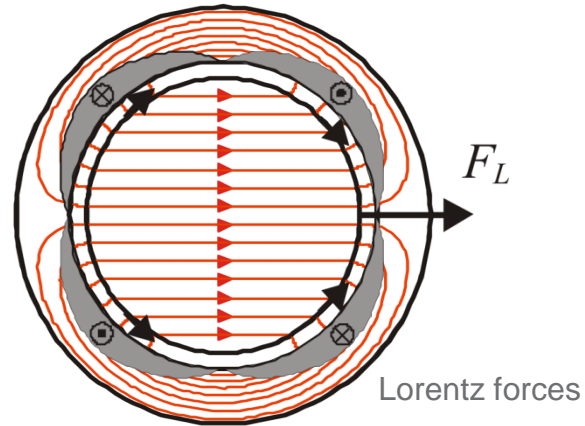


# Introduction

## Bearingless Motor

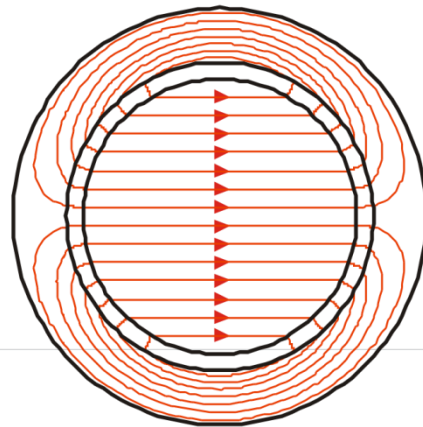
Force generation

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



Torque generation

$$P_{stator} = P_{rotor}$$

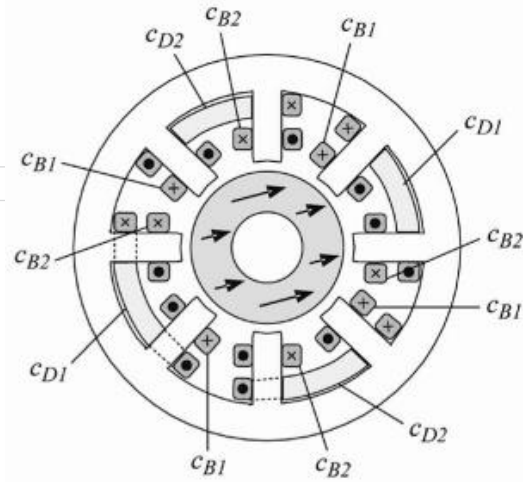


Maxwell forces do not create any torque here!

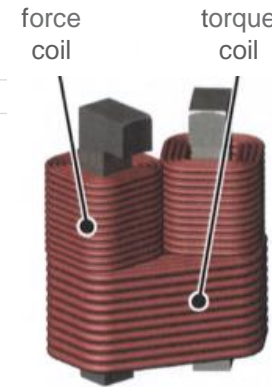
# Introduction

## Bearingless Motor

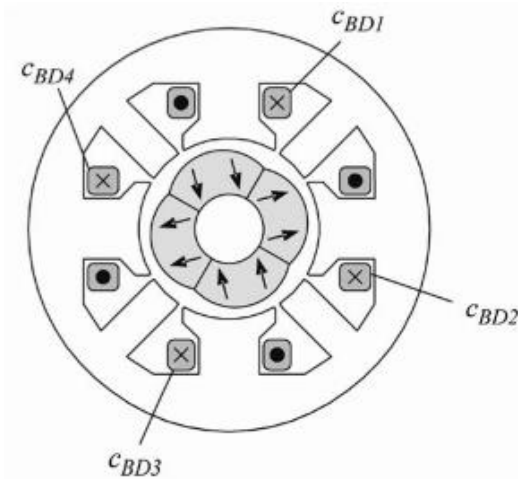
### Winding systems



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

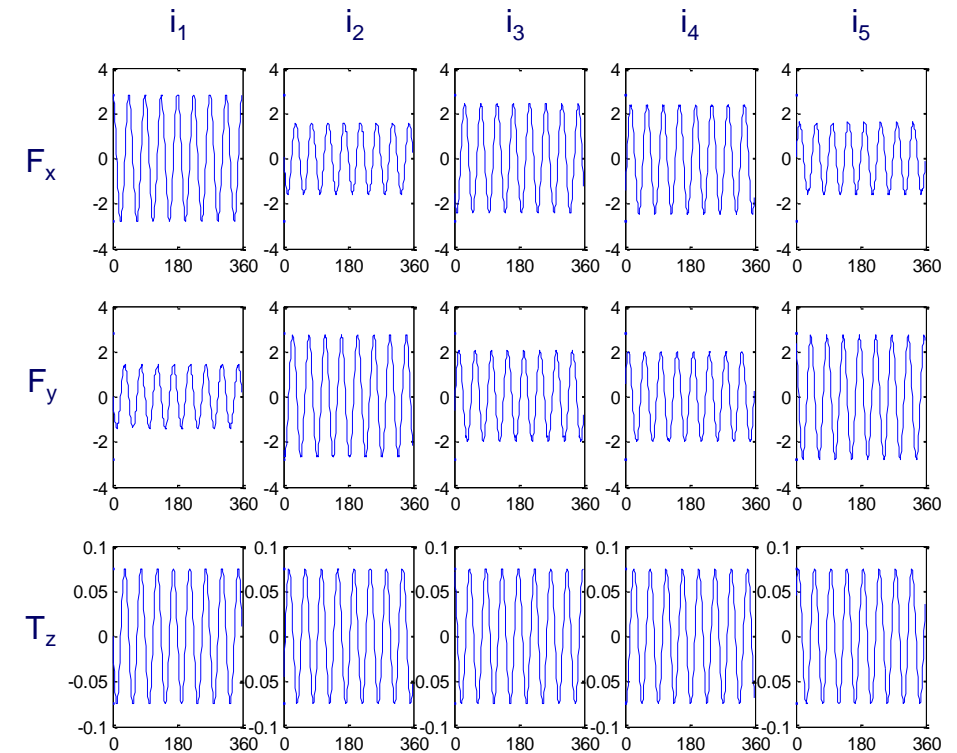
current-force-matrix  $\mathbf{T}_m(\varphi)$

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

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

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  $\mathbf{i}_S^T \mathbf{i}_S \rightarrow \min$

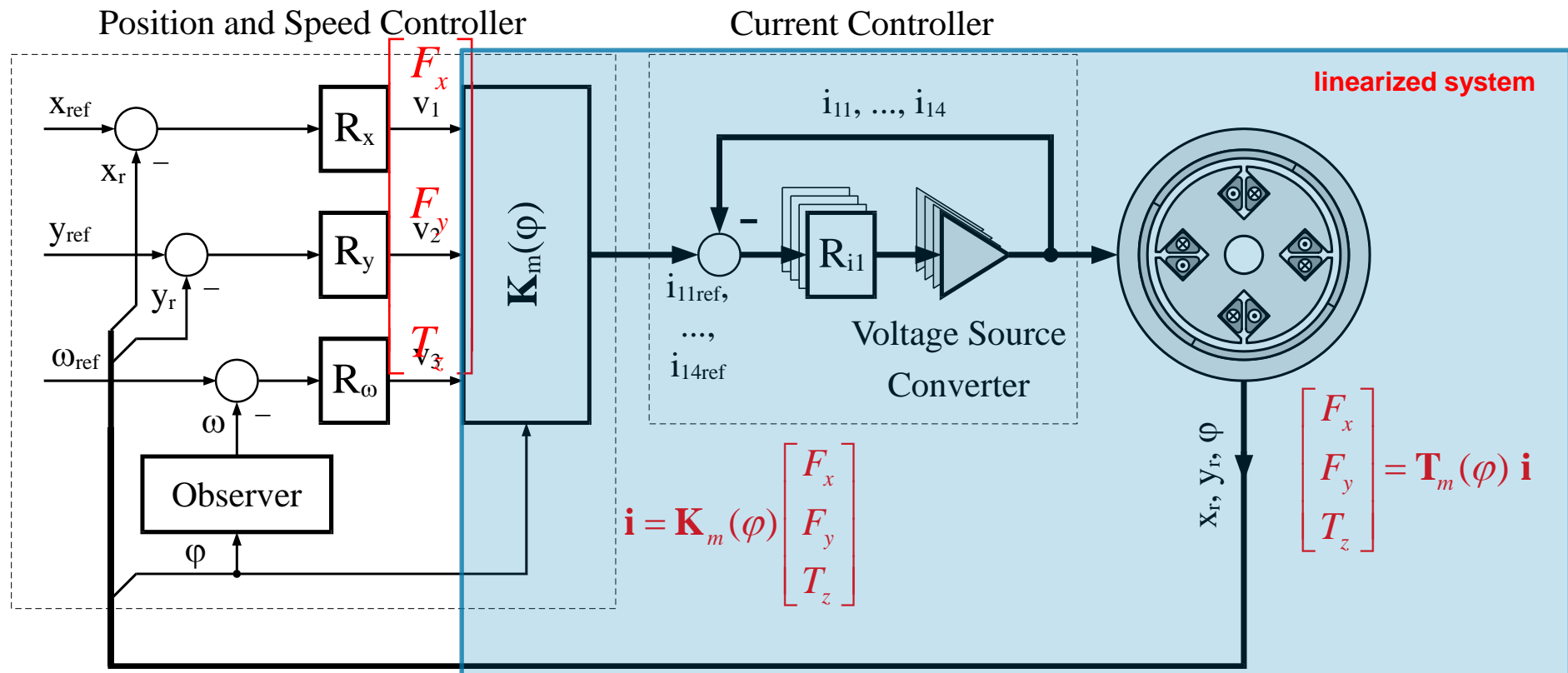


$$\mathbf{K}_m(\varphi) = \mathbf{T}_m^T(\varphi) \left( \mathbf{T}_m(\varphi) \mathbf{T}_m^T(\varphi) \right)^{-1}$$



# Model and Control

## Control Scheme

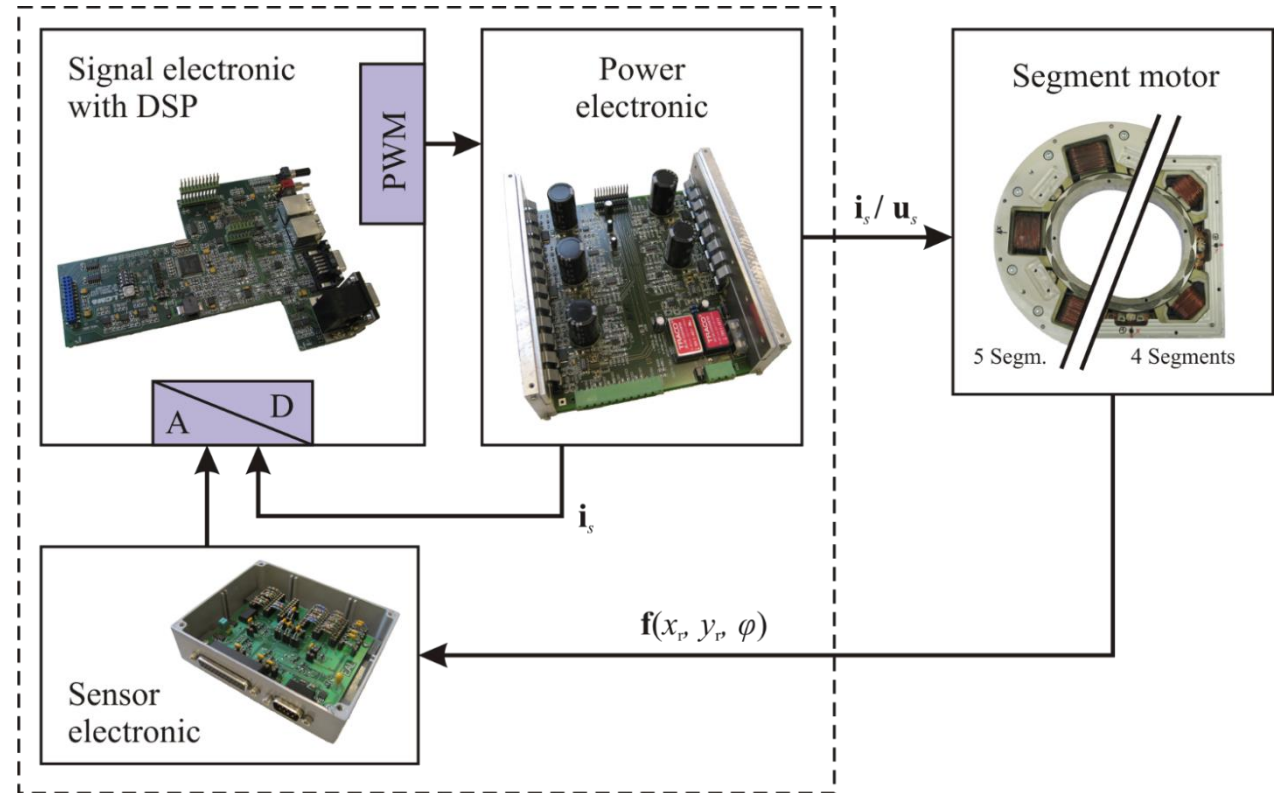


# Model and Control

## Overall System

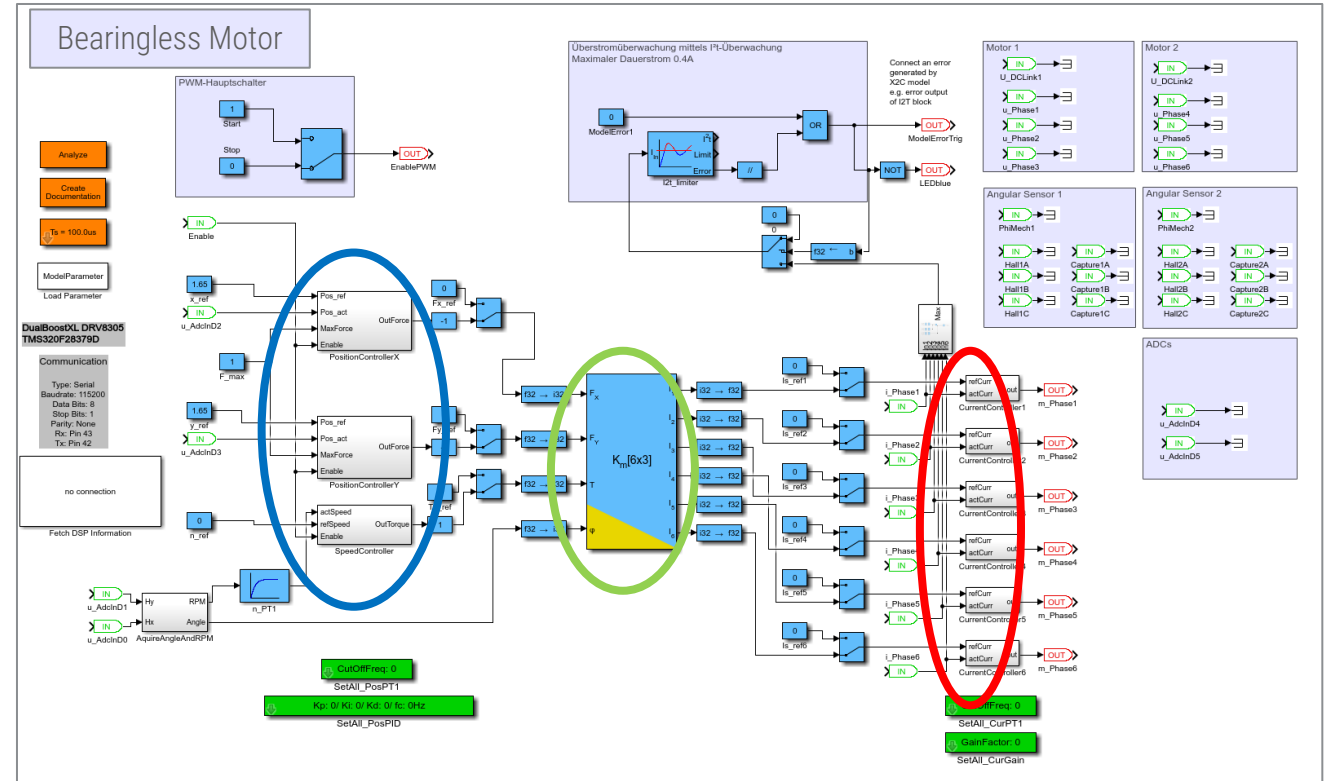
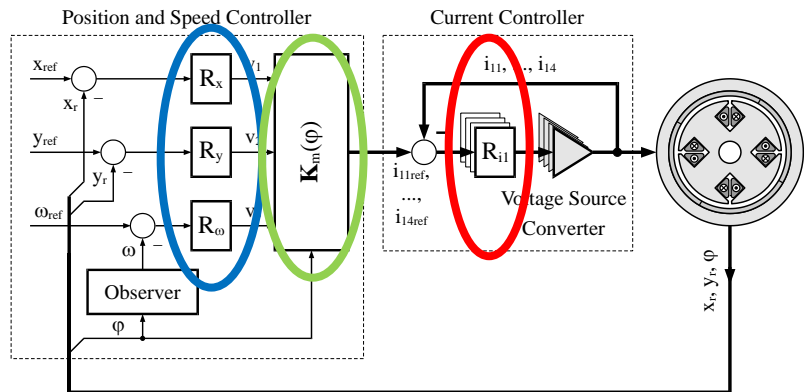
### Components

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



# Model and Control

## X2C Control Scheme



# SyMSpace Bearingless Motor Component

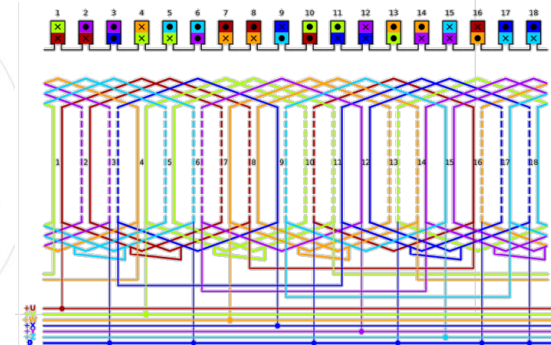
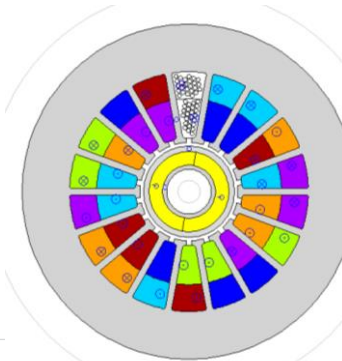
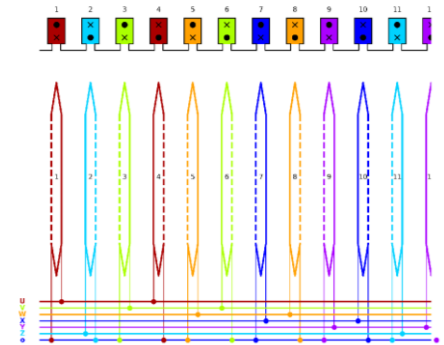
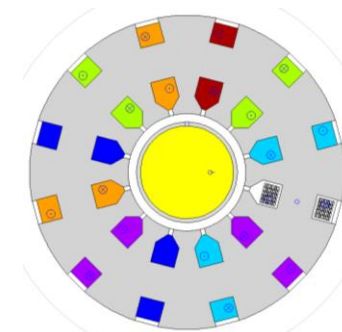
## Overview

- Integrated in PMSM->FEMM Simulate\_BLMotor

The screenshot shows the SyMSpace Center software interface. The left pane displays the project structure for 'Toroid\_rect\_No10\_opt\_sel1.mop'. The right pane shows the 'FemM Simulate\_BLMotor' component documentation, which includes a diagram of the motor's cross-section and a table of parameters.

Parameter	Description	Info
Simulation_Settings deflection_factor	Factor between displacement for radial force simulation and input mechanic air gap	input
PMSM_Control_RadialForce EccentricityRotor	Radial rotor displacement [x, y] for radial force simulation	input
PMSM_Control_RadialForce EccentricityStator	Radial stator displacement [x, y] for radial force simulation	output
FEMM_RadialForce	Noload simulation of deflection-force factor with eccentricity	input
FEMM_constant_current_single_phase	FEMM load simulations with constant energization for each of the m phases	input
Tm	Tm matrix	output
Km	Km matrix	output

Toroidmotor



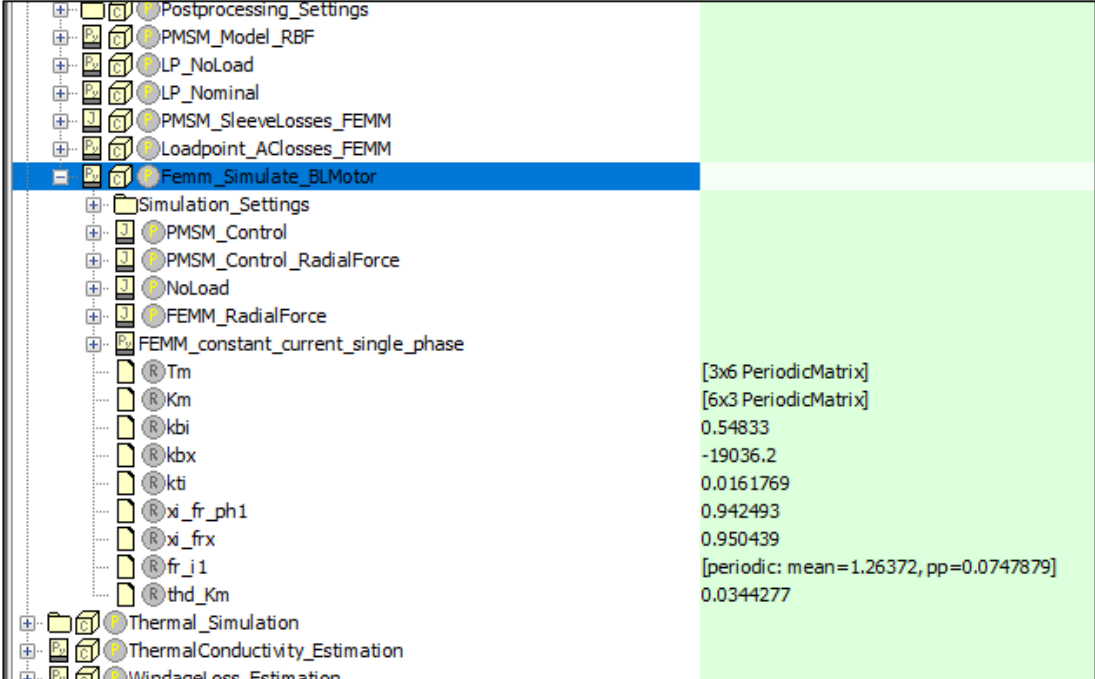
Zahnspulenmotor

- 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
  - $T_m$  and  $K_m$  matrix
  - Torque factor  $k_{ti}$  (in Nm/A)
  - Force factor  $k_{bi}$  (in N/A)
  - Max. to min. force  $\xi_{i\_fx}$  (in %)
  - Radial stiffness  $k_{bx}$  (in N/mm)

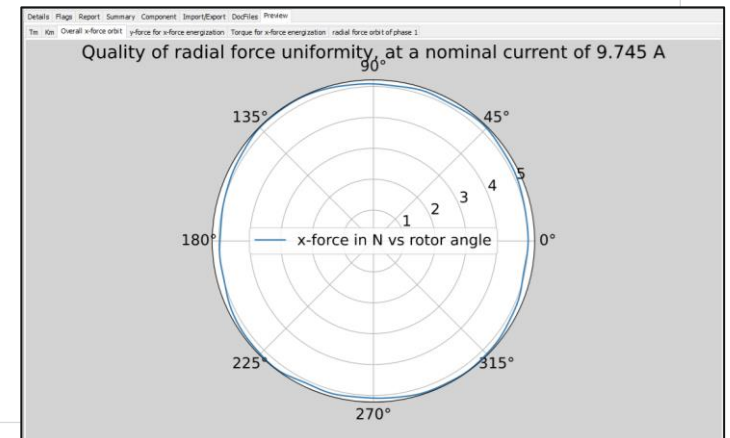
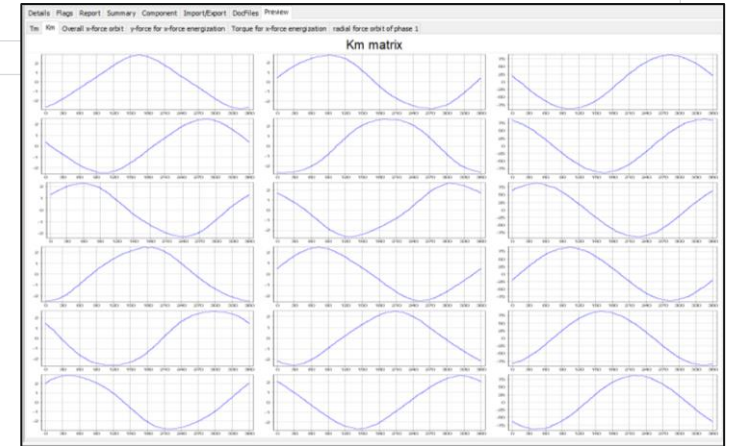
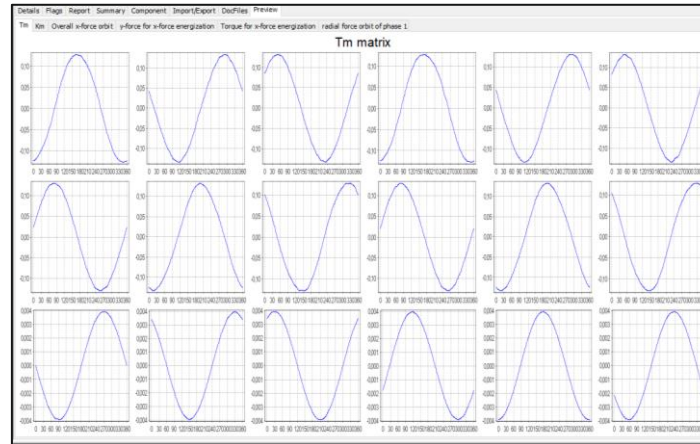


Postprocessing_Settings	
PMSM_Model_RBF	
LP_NoLoad	
LP_Nominal	
PMSM_SleeveLosses_FEMM	
Loadpoint_AClosses_FEMM	
Femm_Simulate_BLMotor	
Simulation_Settings	
PMSM_Control	
PMSM_Control_RadialForce	
NoLoad	
FEMM_RadialForce	
FEMM_constant_current_single_phase	
R_Tm	[3x6 PeriodicMatrix]
R_Km	[6x3 PeriodicMatrix]
R_kbi	0.54833
R_kbx	-19036.2
R_kti	0.0161769
R_xi_fr_ph1	0.942493
R_xi_frx	0.950439
R_fr_i1	[periodic: mean=1.26372, pp=0.0747879]
R_thd_Km	0.0344277
Thermal_Simulation	
ThermalConductivity_Estimation	
WindageLoss_Estimation	

# SyMSpace Bearingless Motor Component

## Content

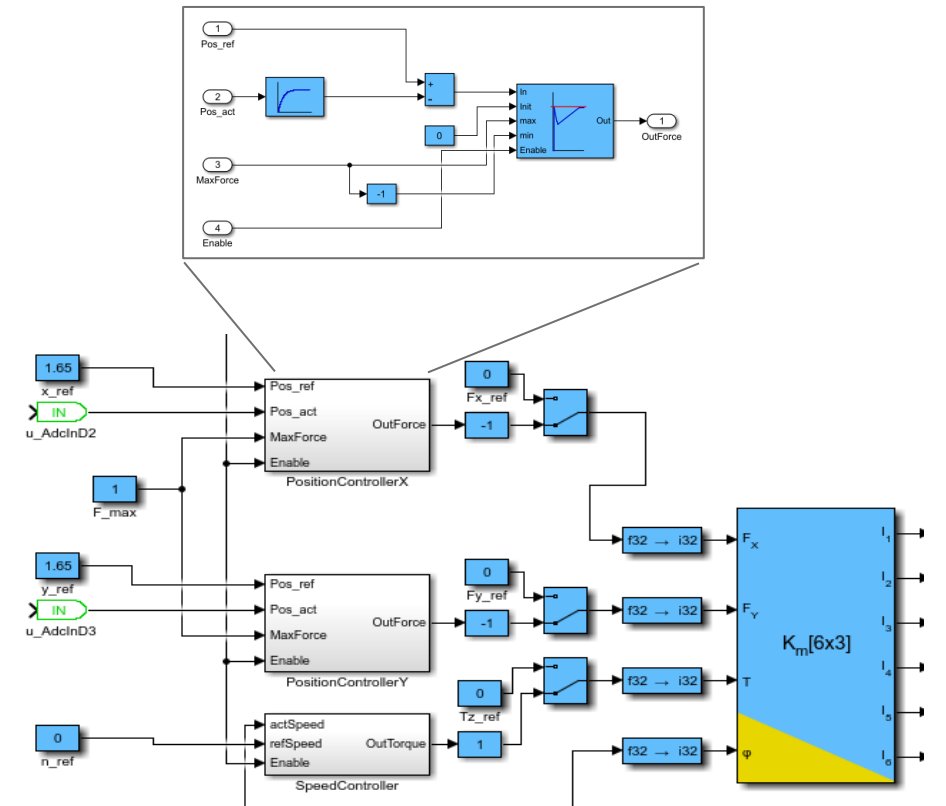
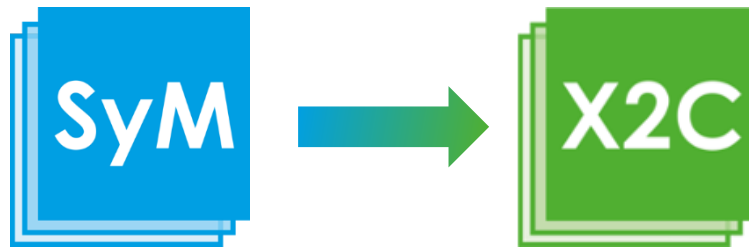
- All phases are energized with constant current one after the other
- Displaced rotor is simulated at no load
- Resulting analysis
  - Tm and Km matrix
  - Torque factor kti (in Nm/A)
  - Force factor kbi (in N/A)
  - Max. to min. force xi\_fx (in %)
  - Radial stiffness kbx (in N/mm)



# SyMSpace Bearingless Motor Component

## Outlook

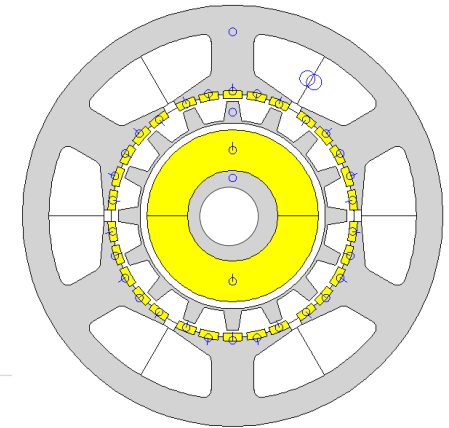
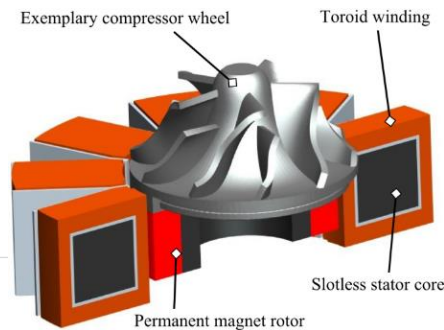
- Auto Commissioning with X2C
  - Position sensor characteristics
  - Current sensor characteristics
  - Determine X2C Control Parameter from SyMSpace



# 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**