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Jiling Guo, Loïc Quéval, Bastien Roucaries, Vido Lionel, Frédéric Trillaud, et al.. Semi-analytical nonlinear model of slotless electrical machines. COMPUMAG, Jul 2019, Paris, France. hal-02464672

**HAL Id: hal-02464672**

**<https://hal.science/hal-02464672>**

Submitted on 3 Feb 2020

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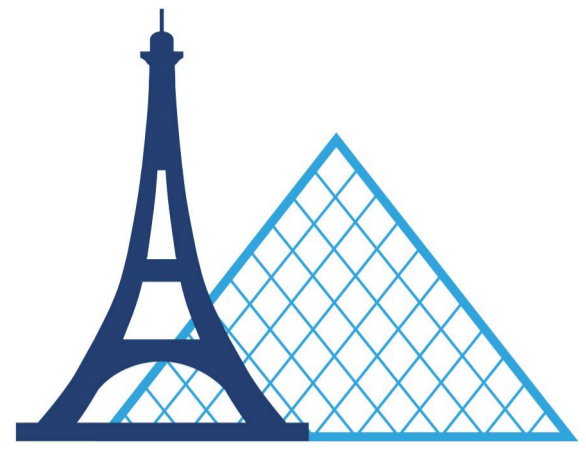


# Semi-Analytical Nonlinear Model of Slotless Electrical Machines

Jiling Guo<sup>1</sup>, Loïc Quéval<sup>2</sup>, Bastien Roucaries<sup>3</sup>, Lionel Vido<sup>3</sup>, Li Liu<sup>1</sup>, Christophe Berriaud<sup>4</sup>, Frederic Trillaud<sup>5</sup>

<sup>1</sup>School of Electrical Engineering, Southwest Jiaotong University, Chengdu 610031, China  
<sup>2</sup>GeePs, UMR CNRS 8507, CentraleSupélec, Univ. Paris-Sud, Univ. Paris-Saclay, Sorbonne Univ., 91192 Gif-sur-Yvette CEDEX, France  
<sup>3</sup>SATIE, CNRS UMR 8029, Univ. of Cergy Pontoise, 95000 Cergy-Pontoise, France  
<sup>4</sup>DRF/IRFU/DACM, CEA Saclay, Univ. Paris-Saclay, 91191 Gif-sur-Yvette, France  
<sup>5</sup>Instituto de Ingeniería, Universidad Nacional Autónoma de México, 04510, CDMX, Mexico

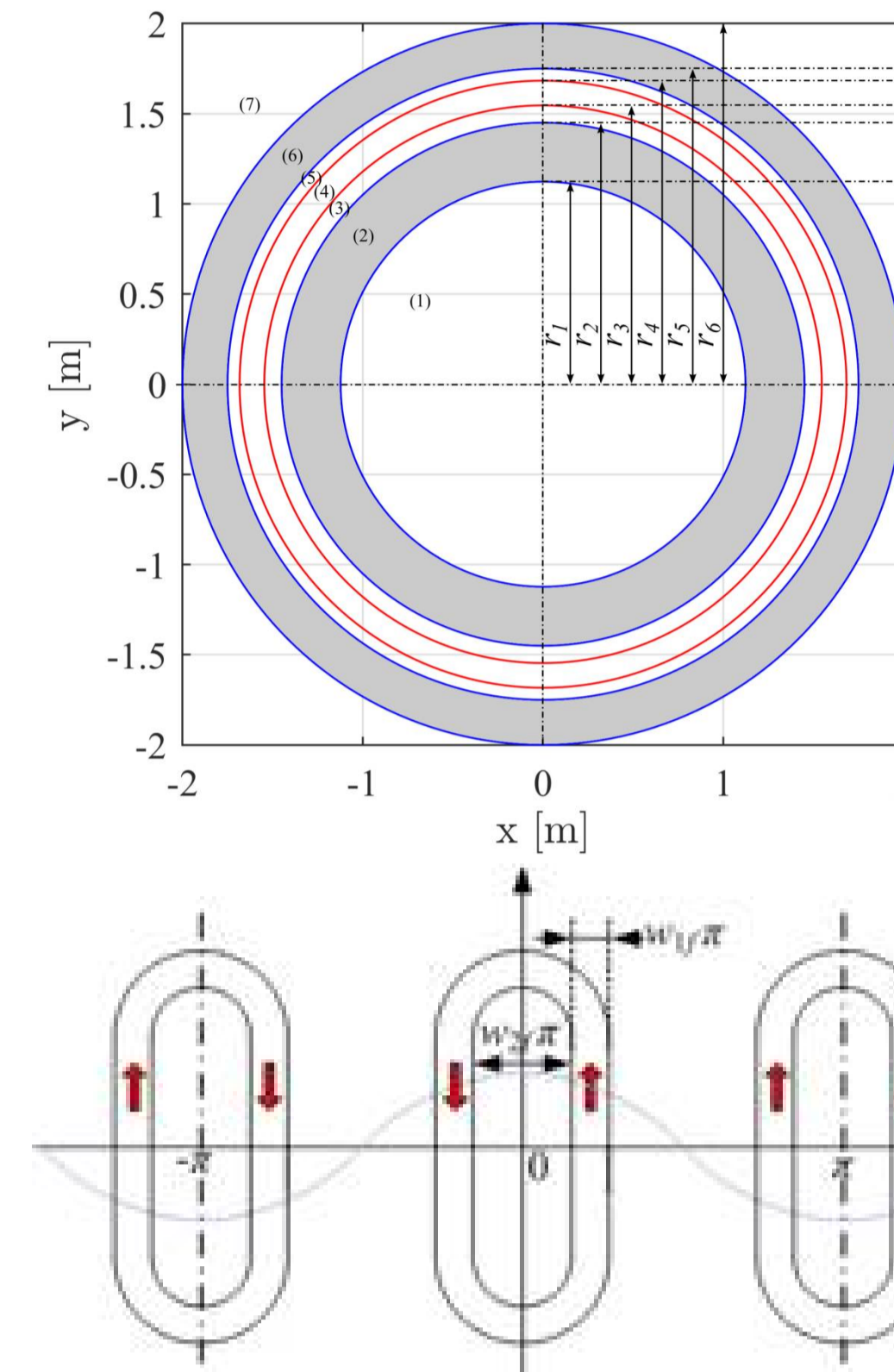
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## Introduction

The following incremental improvement of the current sheet model of slotless wound rotor electrical machines allows simultaneously to model both the rotation of the rotor field winding and the time-dependent stator armature windings currents. Additionally, an iterative scheme is introduced to take into account the magnetization of rotor and stator iron cores. The results are compared with those of a 2-D nonlinear finite element model.

## Machine model (10 MW)



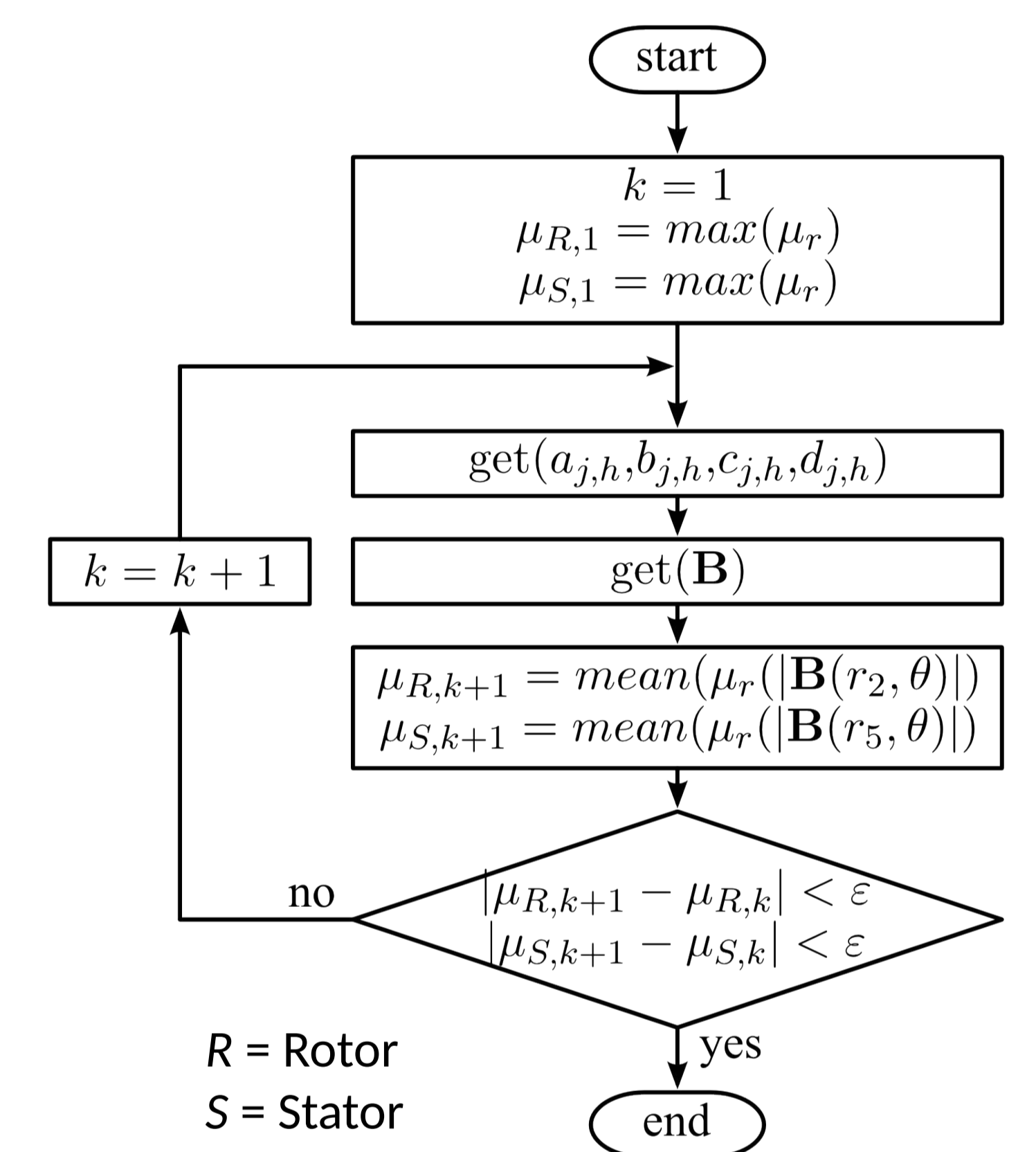
PARAMETERS OF THE 12-POLE 3-PHASE SYNCHRONOUS MACHINE

Symbol	Parameter	Value
$r_1$	rotor core inner radius	1.123 m
$r_2$	rotor core outer radius	1.450 m
$r_3$	field winding radius	1.546 m
$r_4$	armature windings radius	1.683 m
$r_5$	stator core inner radius	1.750 m
$r_6$	stator core outer radius	2.000 m
$h_f$	field coil height	0.057 m
$w_f$	field coil width	0.042 m
$\theta_{1f}$	field coil width elec. angle	0.163 rad
$\theta_{2f}$	field coil aperture elec. angle	2.703 rad
$h_a$	armature coil height	0.041 m
$w_a$	armature coil width	0.194 m
$\theta_{1a}$	armature coil width elec. angle	0.692 rad
$\theta_{2a}$	armature coil aperture elec. angle	0.664 rad
$P$	number of pole pairs	6
$L_{eff}$	effective length	1.54 m
$N$	armature windings nb of turns	120
$N_f$	field winding nb of turns	1
$r_{Te}$	radius for evaluation of field and torque	1.619 m

## Semi-analytical model: overview

The machine is divided into annular concentric air/iron subdomains. The windings are modeled by current sheets between two subdomains. Using the distribution of current via its Fourier series  $K$ , the magnetostatic vector potential  $\mathbf{A}$  can be inferred.

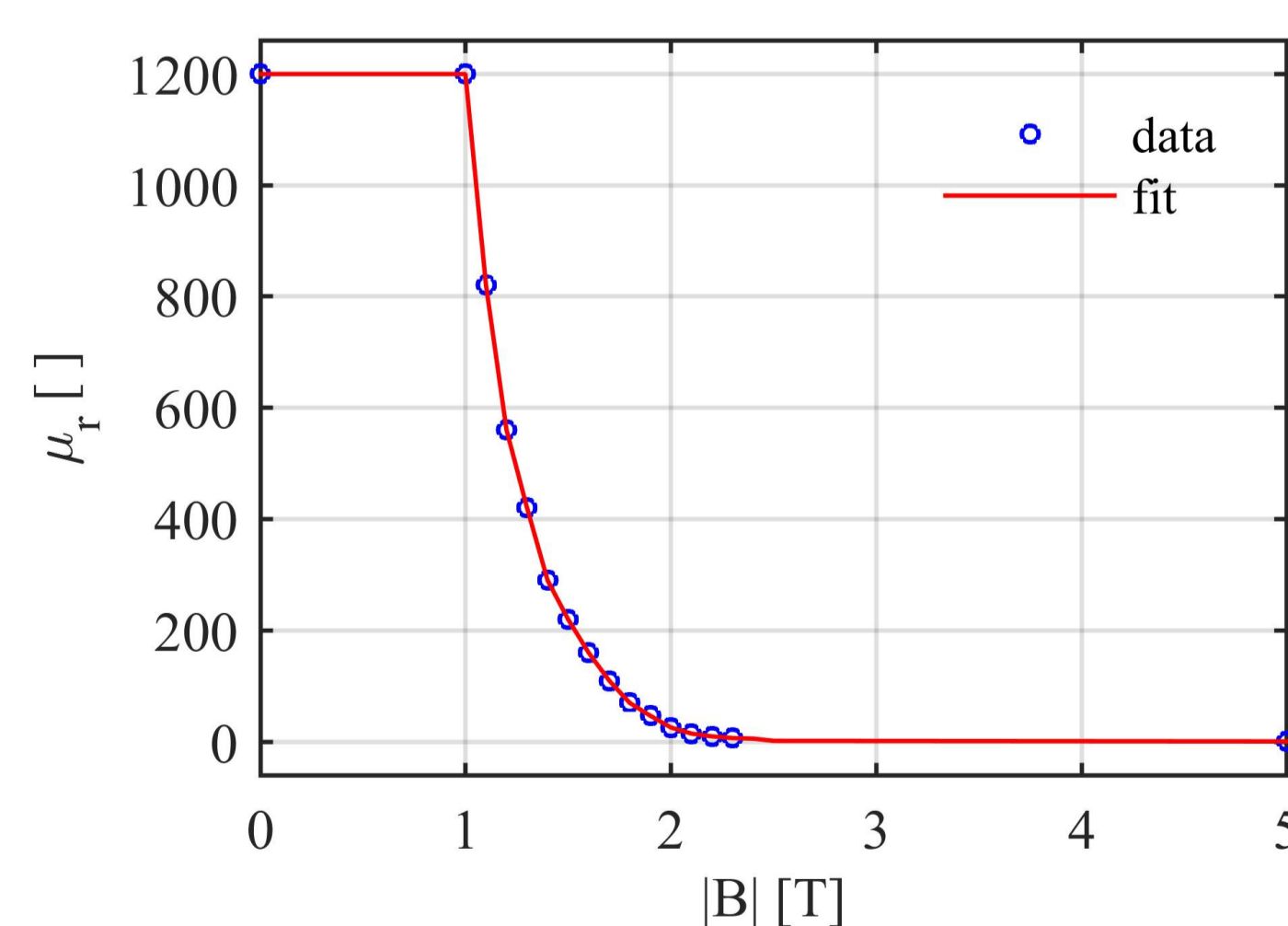
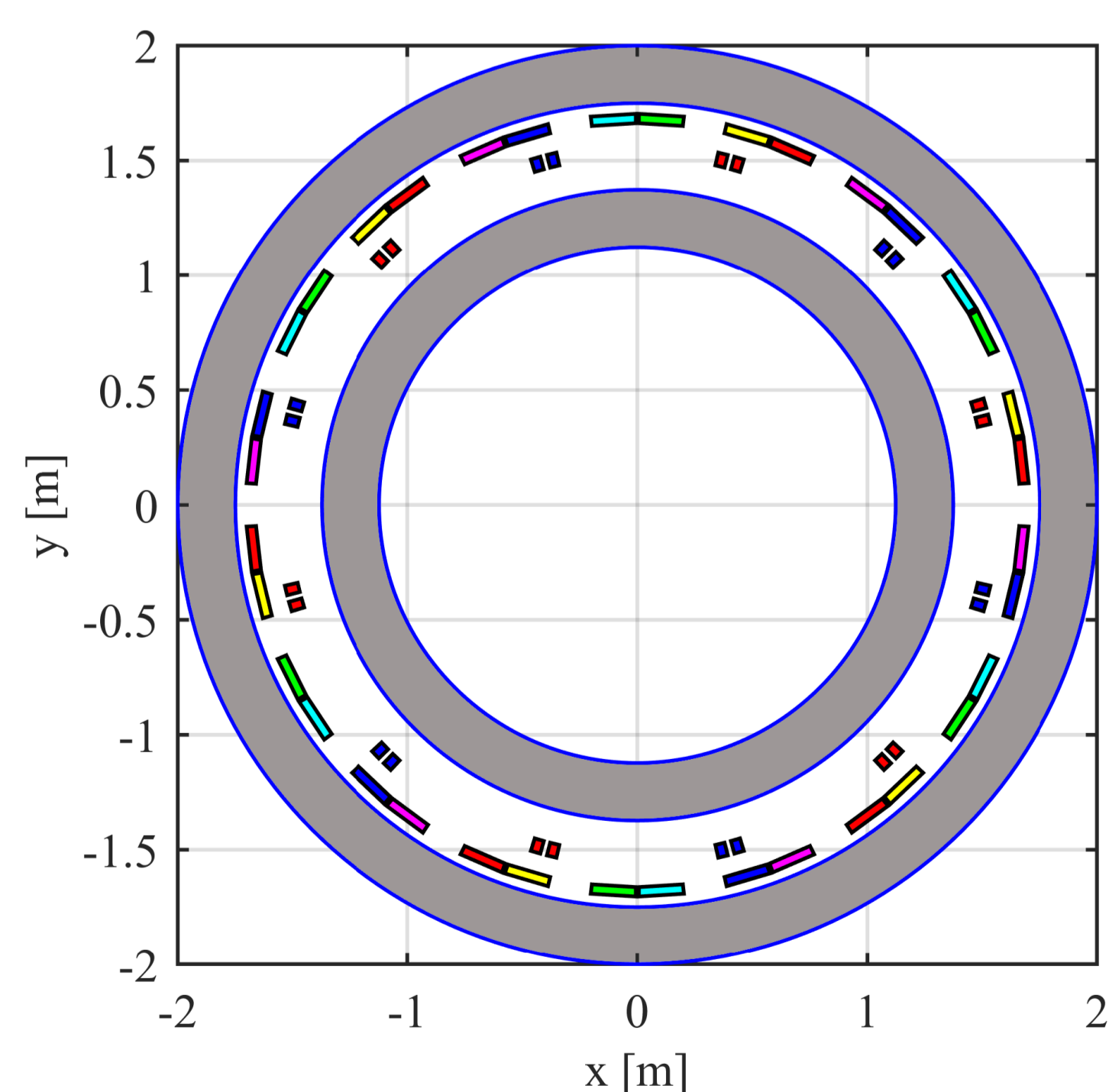
- Concentric current sheets (input):
- Nonlinear  $B-H$  curve:  $\mathbf{B} = \mu(\mathbf{B}) \mathbf{H}$
- Magnetic vector potential (from Maxwell-Ampère: find  $a, b, c, d$  via separation of variables):



## Numerical model (2D FEM)

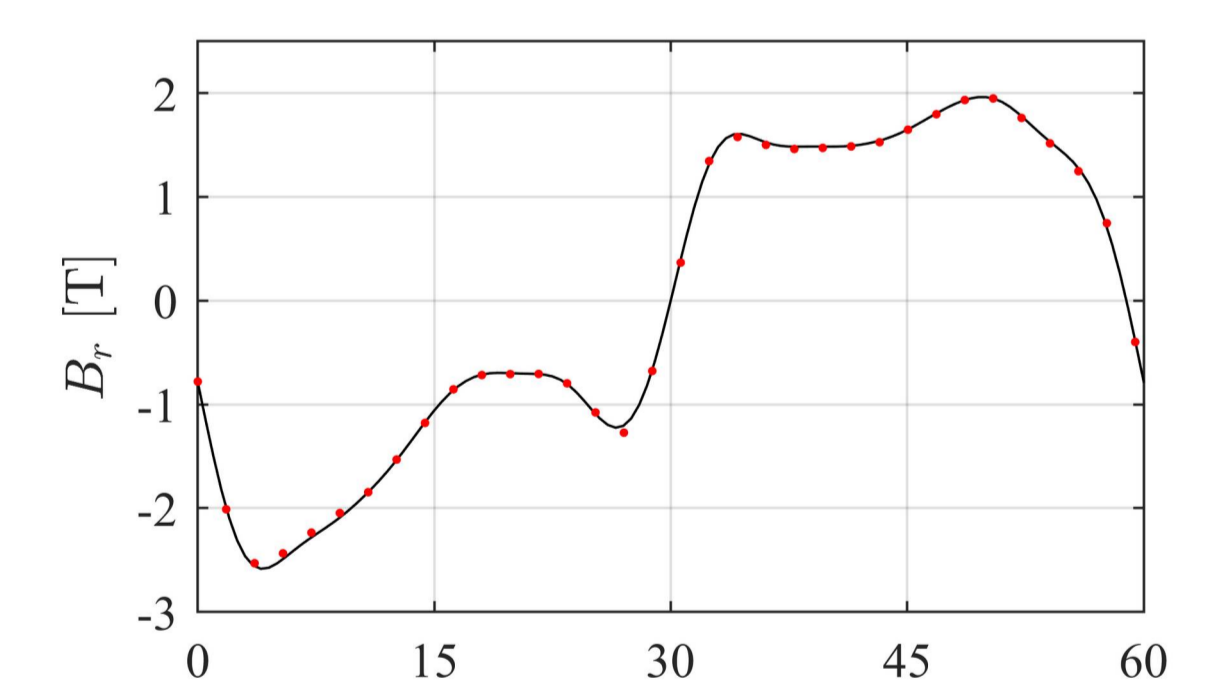
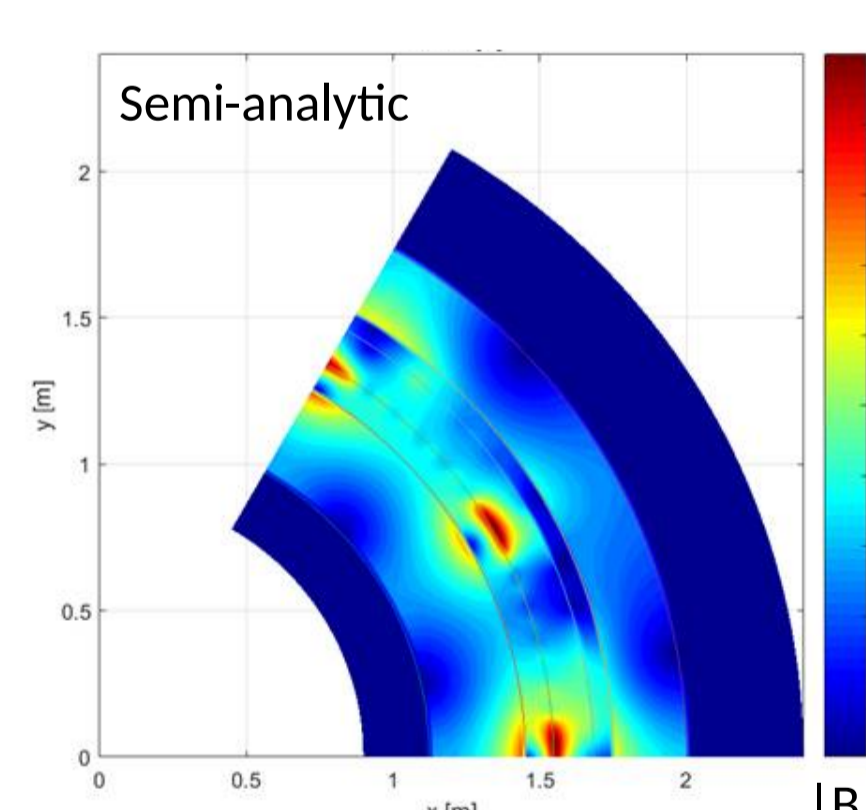
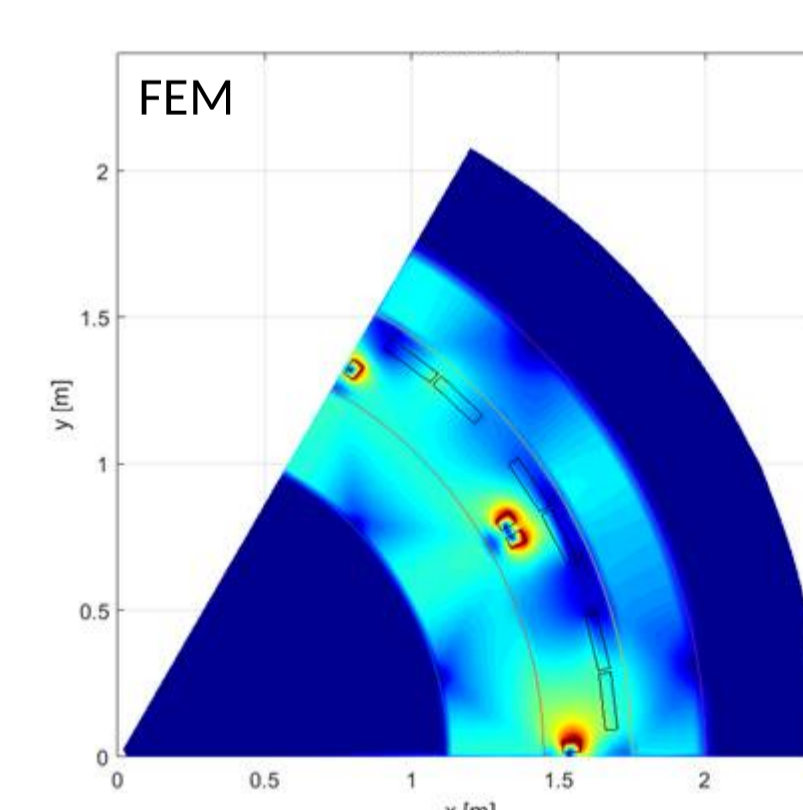
2D Finite Element Model built and solved in COMSOL Multiphysics using the AC/DC module with:

- A-formulation of Maxwell's equations
- Magnetostatic problem:
- In the ferromagnetic material:  $\mathbf{B} = \mu(\mathbf{B}) \mathbf{H}$
- Solid conductor

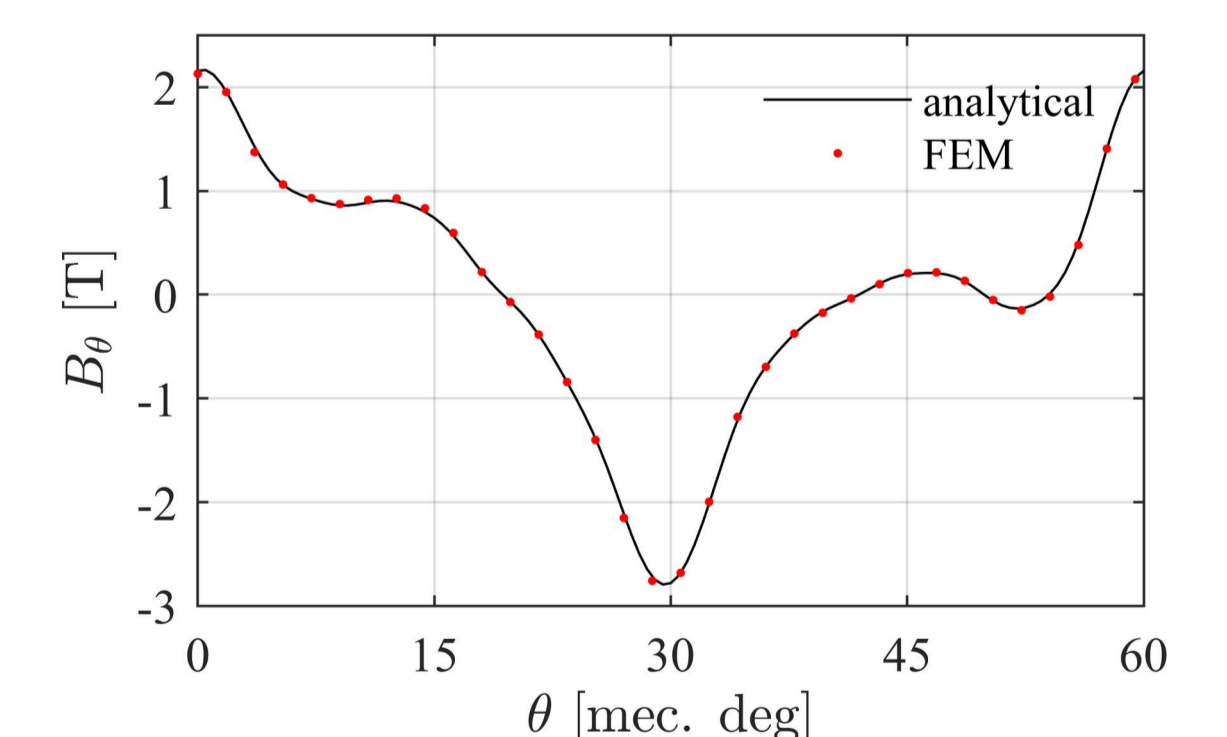


## Comparative results (10 MW, load example)

Load condition: 10 rpm,  $I_f$  (rotor) = 502.74 kA,  $I_d$  (stator) = -1.963 kA,  $I_q$  (stator) = -1.530 kA



The results of the nonlinear analytical and FEM models are in close agreements.



## Conclusion

The proposed model includes:

- simultaneously the rotor rotation and the 3-phase armature windings (new feature)
- an improved iterative scheme which resolves the iron nonlinear BH curve

This generic approach can be adapted to any slotless wound rotor machines including multiphase machines with multi-layer distributed or concentrated windings for rapid pre-design and optimization (6 times faster than FEM computation).

## Acknowledgments

This work was supported by the grants: EolSupra20 project ANR-10-LABX-0040-LaSIPS, the Chinese Scholarship Council, the Fundamental Research Funds for the Central Universities under Grants 2682018CX18, and DGAPA - UNAM PAPIIT-2019 IN107119.