Realize Your Product Promise®

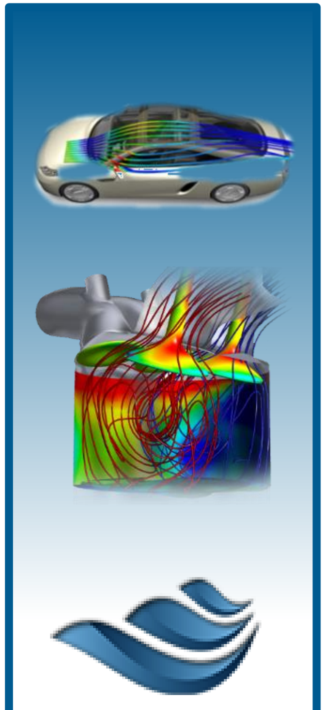
ANSYS仿真平台在电驱动系统中的应用和案例解析

庄百兴
ANSYS China

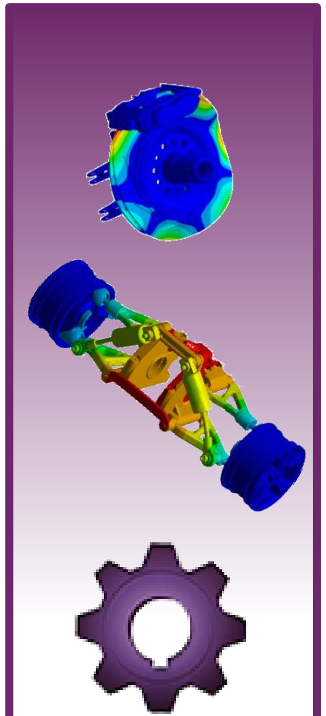
ANSYS

- ANSYS 成立于1970年
- ANSYS 致力于工程仿真软件的开发、销售和技术支持，通过仿真预测产品在真实环境下的行为模式和制造过程
- 世界领先的电磁、结构、流体、芯片和嵌入式系统仿真软件供应商

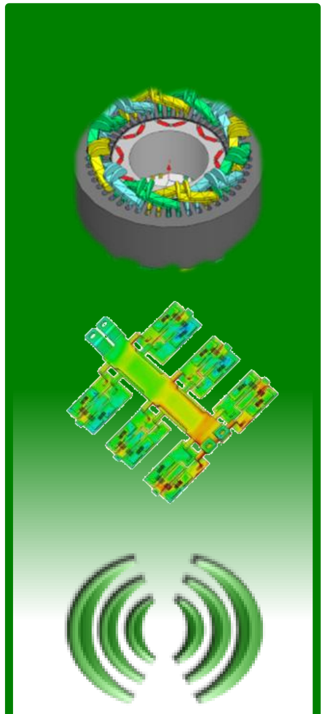
ANSYS 多物理域仿真



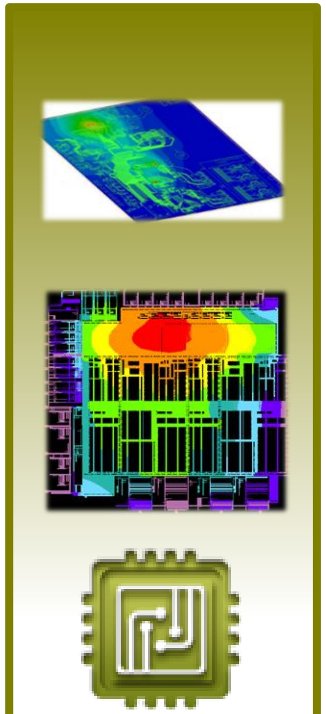
流体



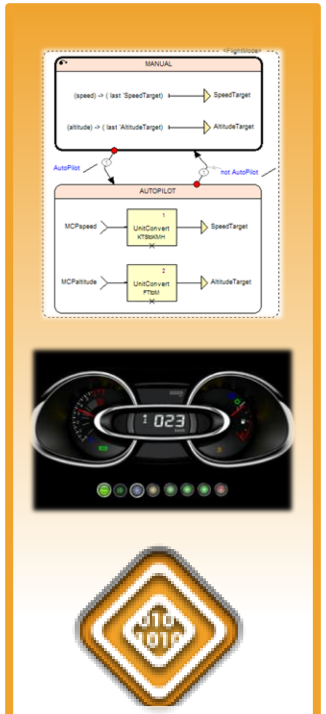
结构



电磁



半导体



系统

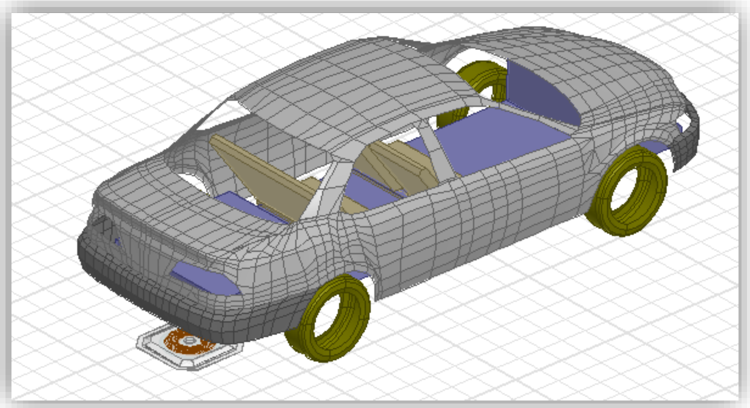
电驱动系统的关键技术

动力电池

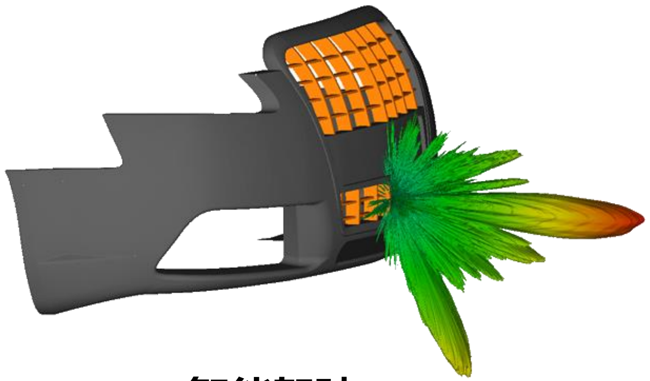
控制器

软件

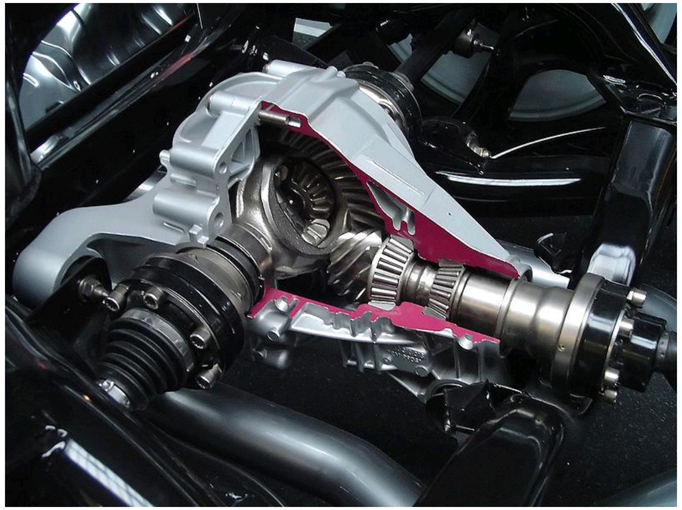
电机



无线充电

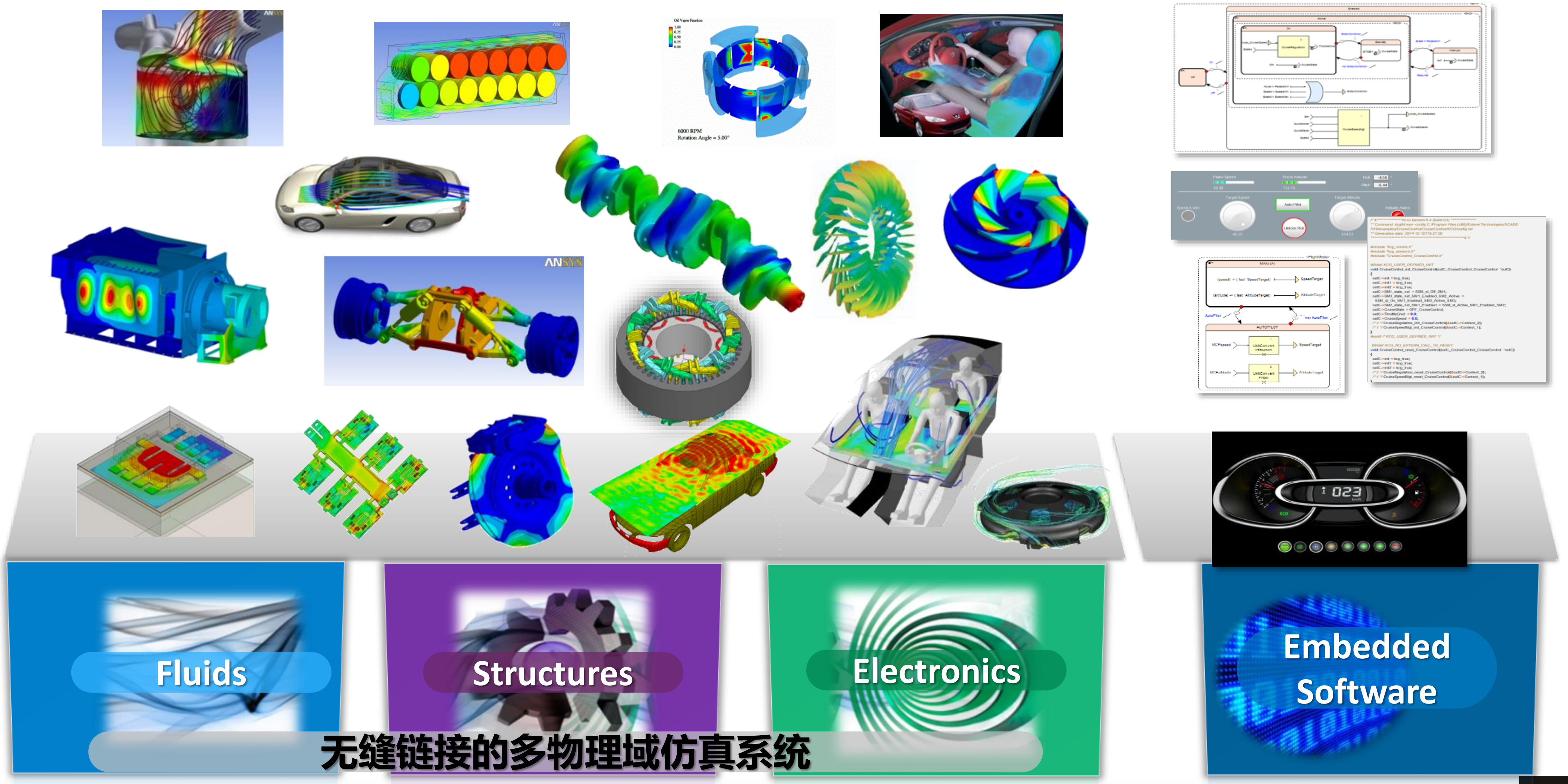


智能驾驶

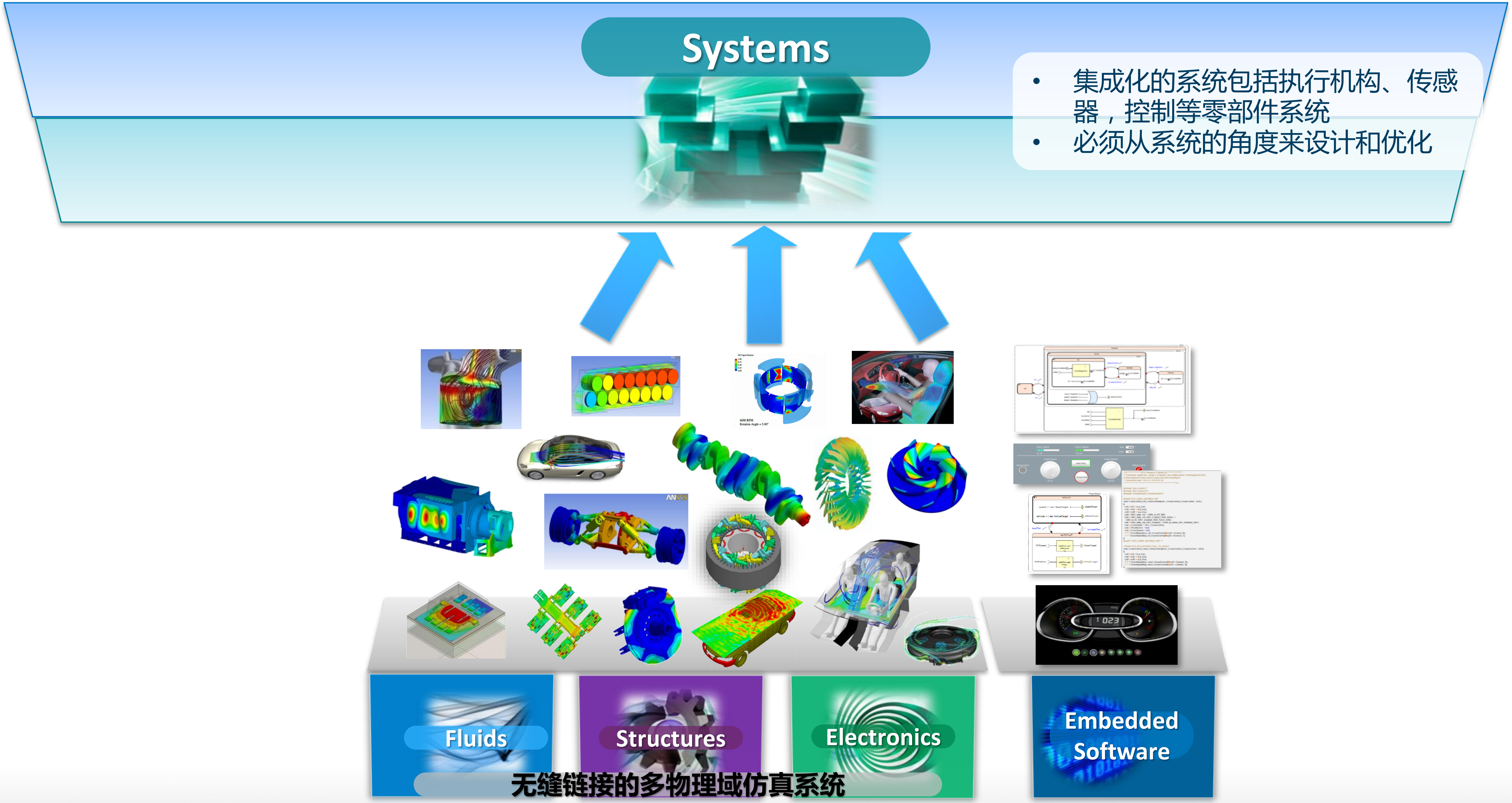


传动机构

ANSYS 集成化的零部件仿真系统

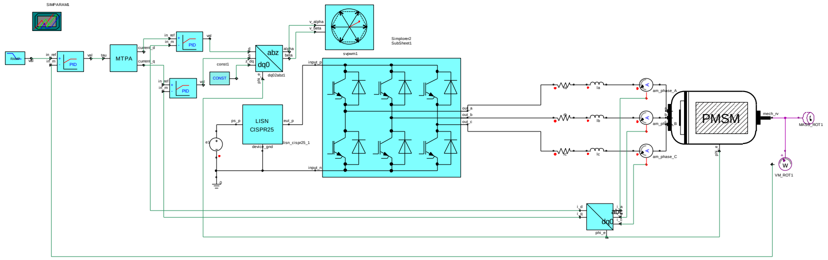


发展趋势：系统级仿真

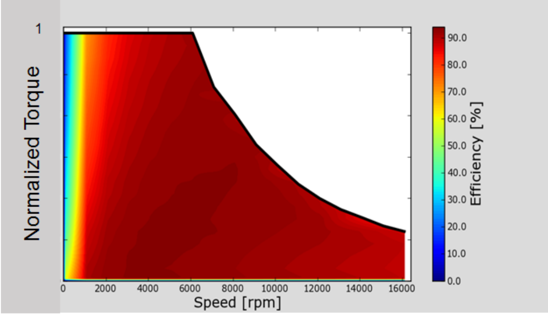


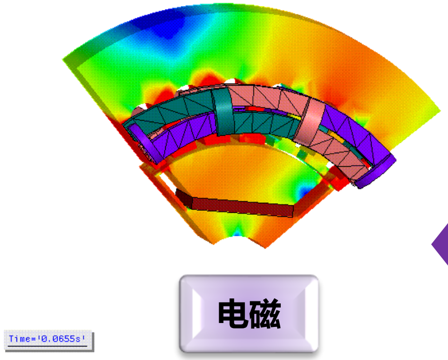
- 集成化的系统包括执行机构、传感器，控制等零部件系统
- 必须从系统的角度来设计和优化

电机本体仿真



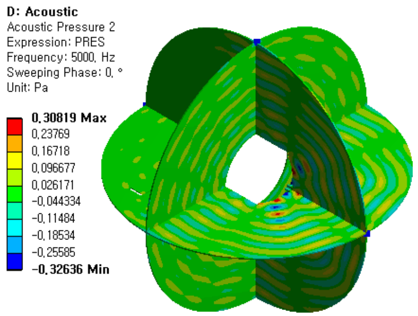
驱动

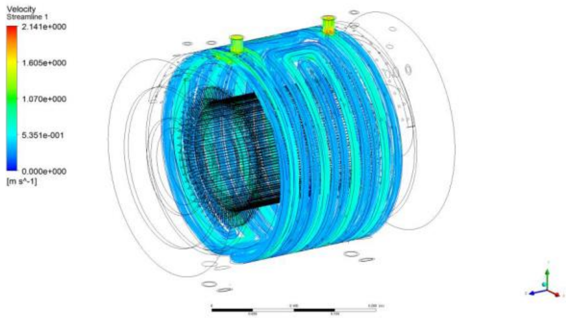




电磁

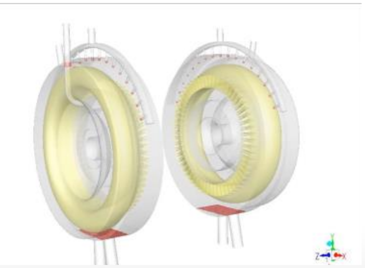
噪声

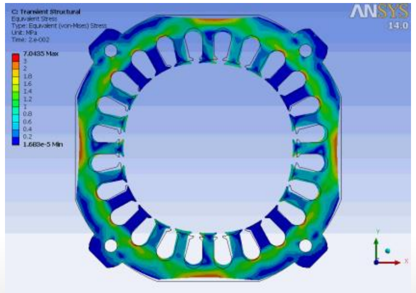




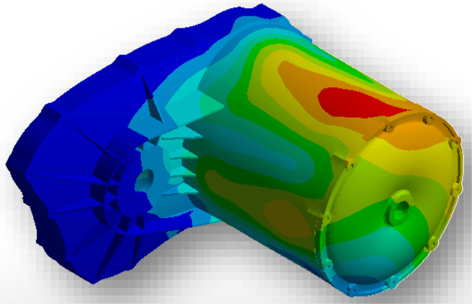
流体

振动

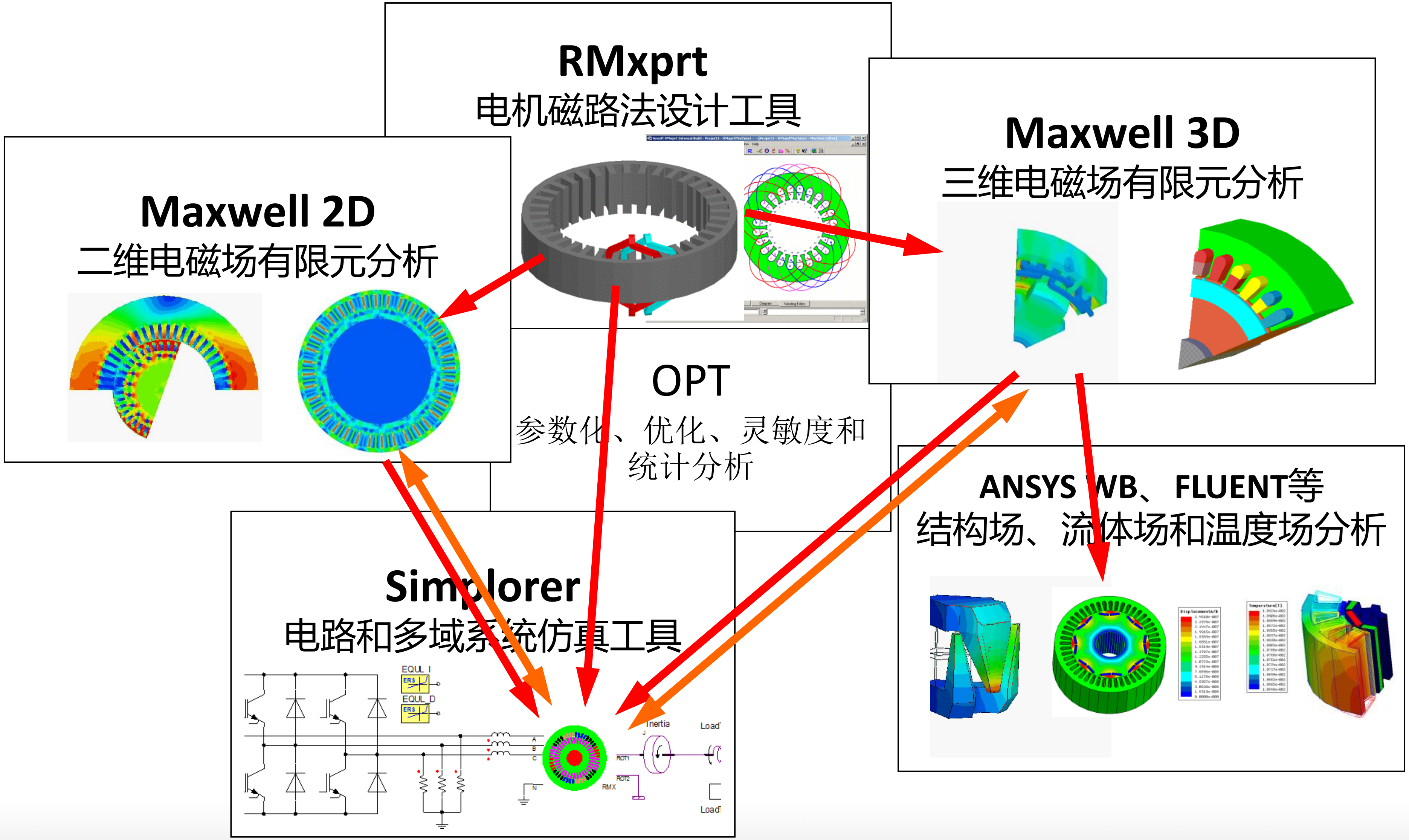




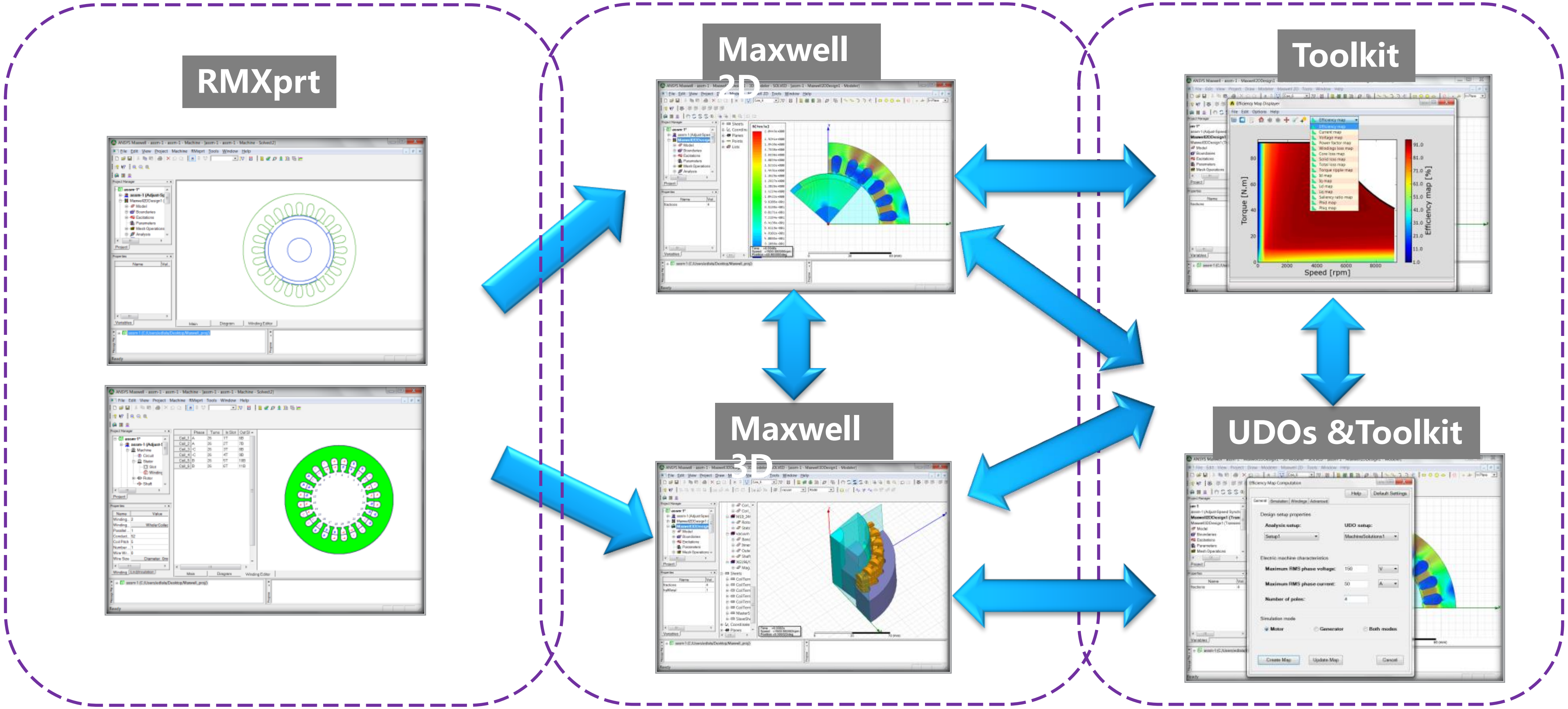
应力和形变



ANSYS电机设计流程



高效的电机电磁自动化设计流程

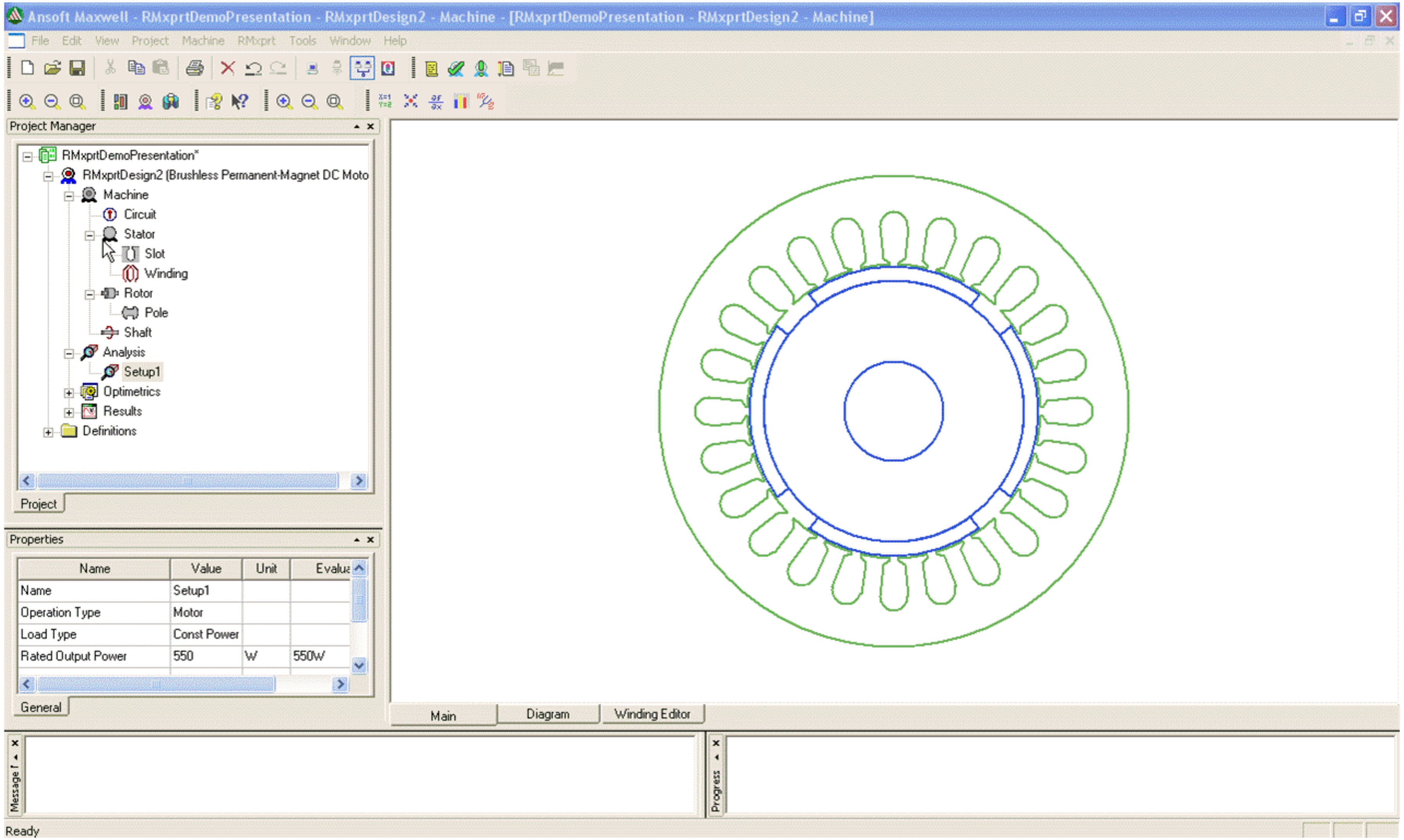


初始设计与建模

有限元求解
DSO和HPC

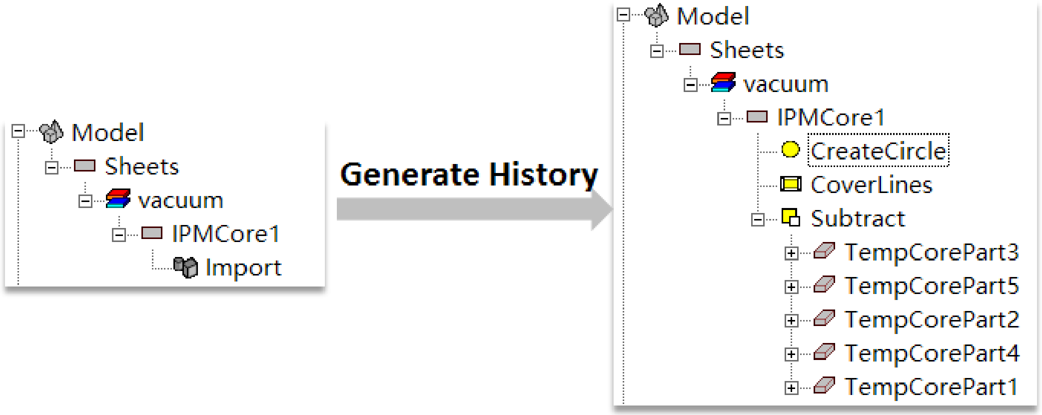
后处理、优化
定制化流程

RMxprt 一键有限元

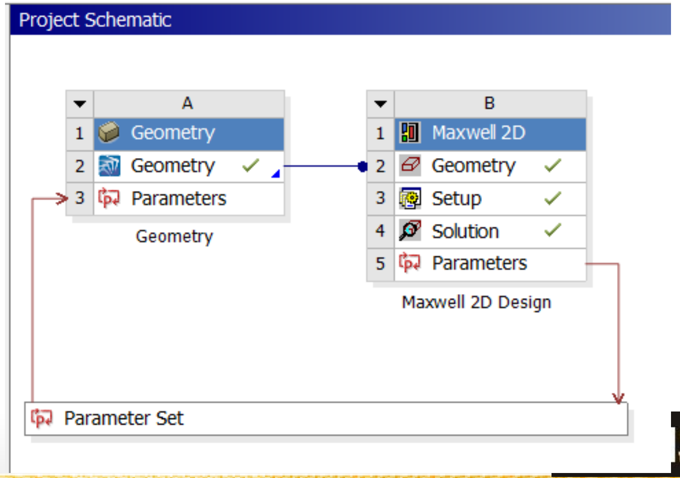


丰富的参数化建模手段

- **Maxwell常规参数化建模方法**
  - 参数化变量
  - Maxwell自建模参数化
  - Maxwell模型修改参数化，导入模型参数化
  - RMxprt、UDP参数化模型
  - 3D Component
  - 外电路、材料、温度等变量参数化
- **Maxwell与DM、SpaceClaim、DX协同参数化分析介绍**
  - DM与MCAD的连接与参数传递
  - DM与Maxwell的链接与参数传递
  - SpaceClaim与Maxwell的链接与参数传递

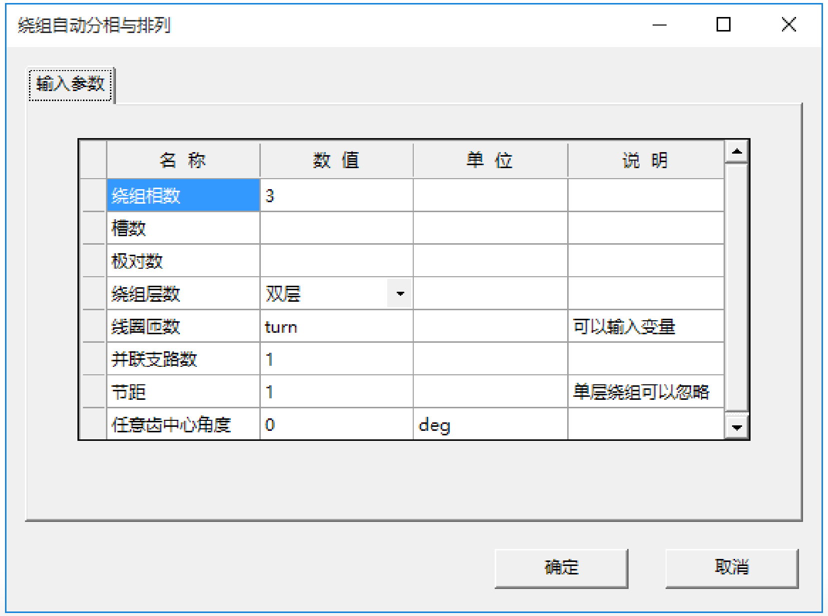


CoilR	5	mm	5mm
CoilOR	10	mm	10mm
CoilHeight	15	mm	15mm
AWG	30		30
C	1.15		1.15
Sigma	58000000		58000000
WireDia	0.0082*0.8931^AWG		0.000275...
Xsection...	CoilHeight*(CoilOR-CoilR)/1000mm^2		7.5e-005
Turns	int(C*XsectionCoilArea/WireDia^2)		1132
MeanTur...	pi*(CoilR+CoilOR)/1000mm		0.047123...
WireCros...	pi*WireDia^2/4		5.980299...
CoilResis...	Turns*MeanTurnLength/Sigma/BareWireCrossSection		18.08818...

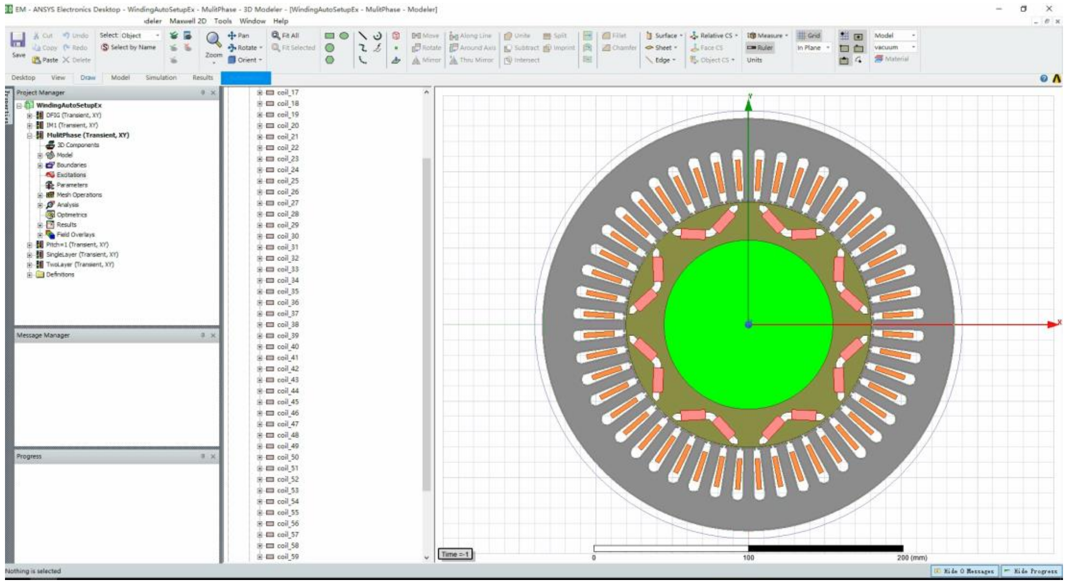


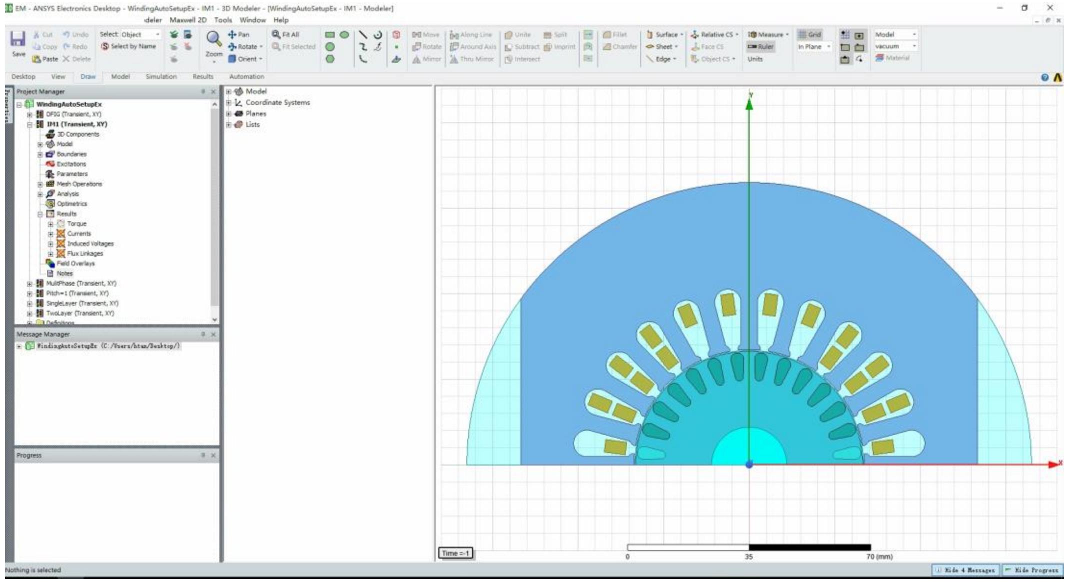
便捷的有限元前处理工具

- Maxwell中绕组自动分相和设置
- 设置激励和计算A相轴线位置
- 适用于2D/3D
- 适用于单相、三相或多相电机
- 适用于旋变等匝数不等绕组

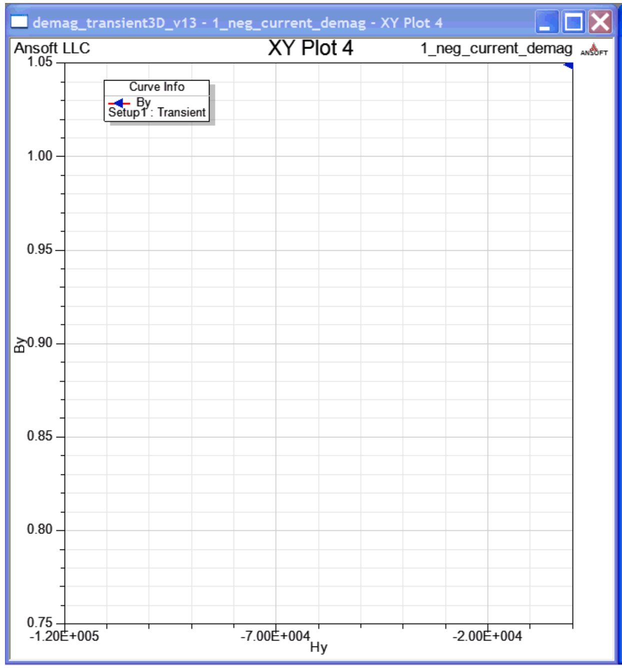


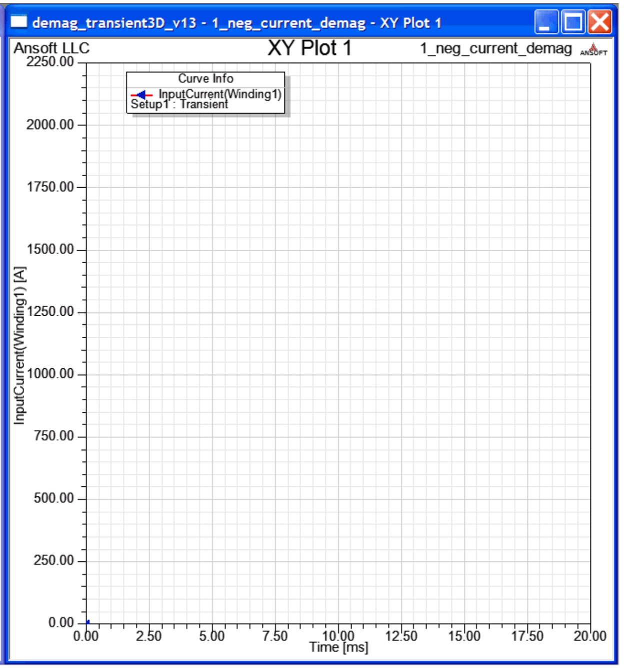
名 称	数 值	单 位	说 明
绕组相数	3		
槽数			
极对数			
绕组层数	双层		
线圈匝数	turn		可以输入变量
并联支路数	1		
节距	1		单层绕组可以忽略
任意齿中心角度	0	deg	



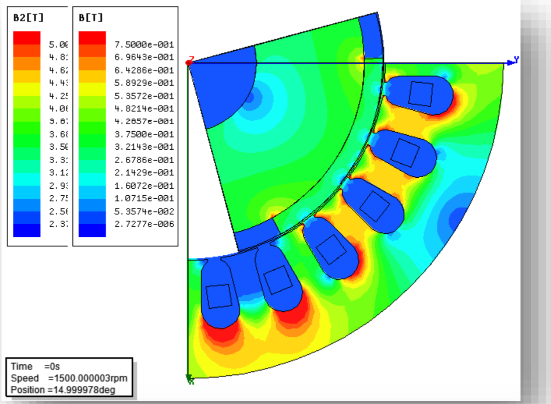


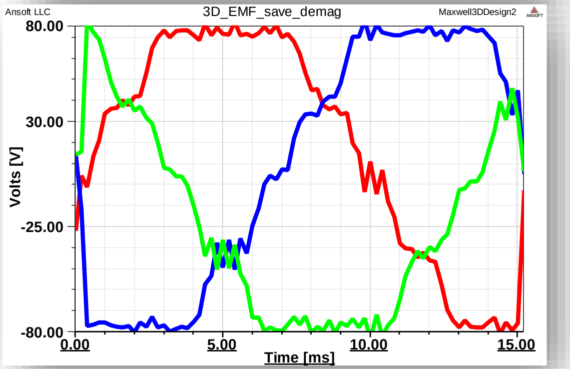
永磁电机退磁分析

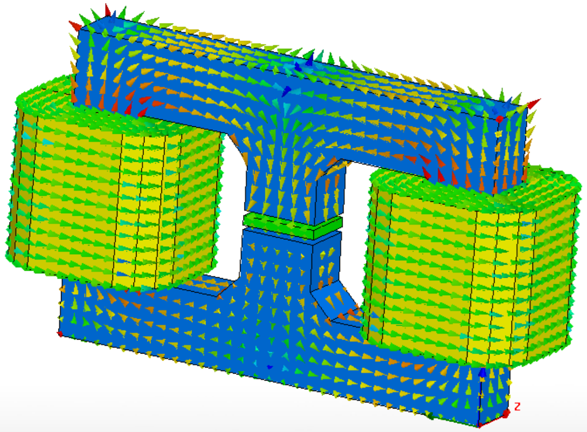


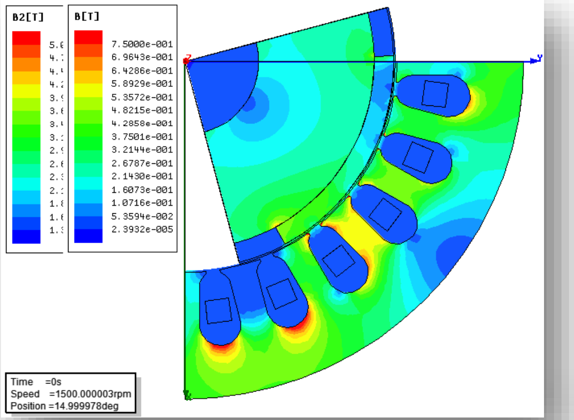


正常工况

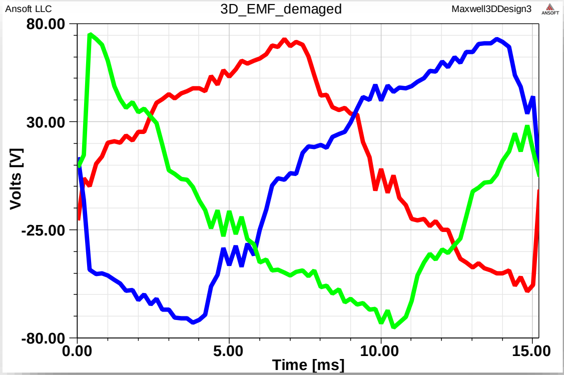




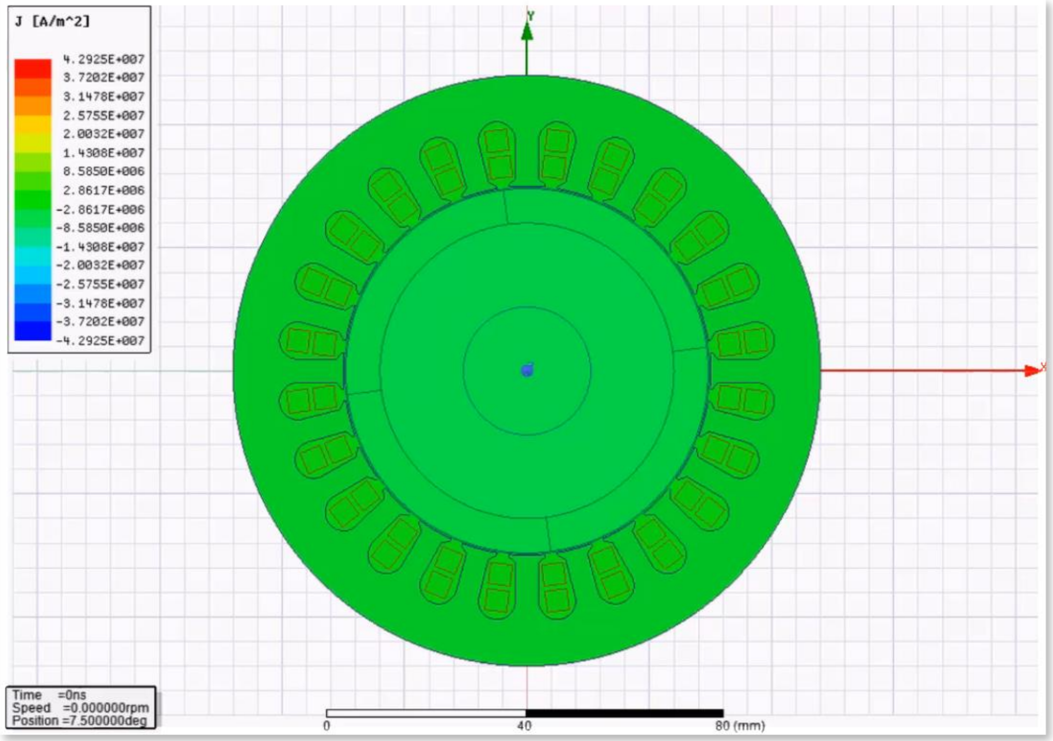


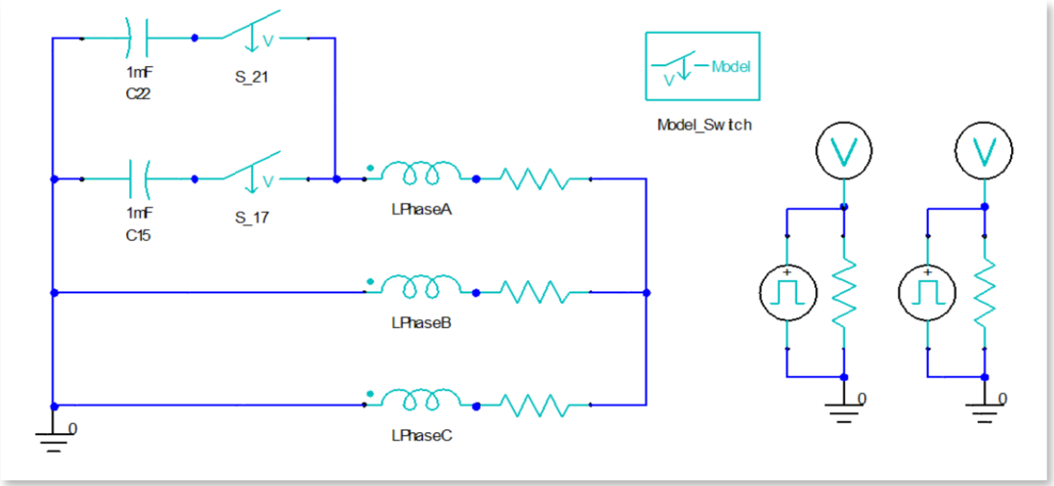


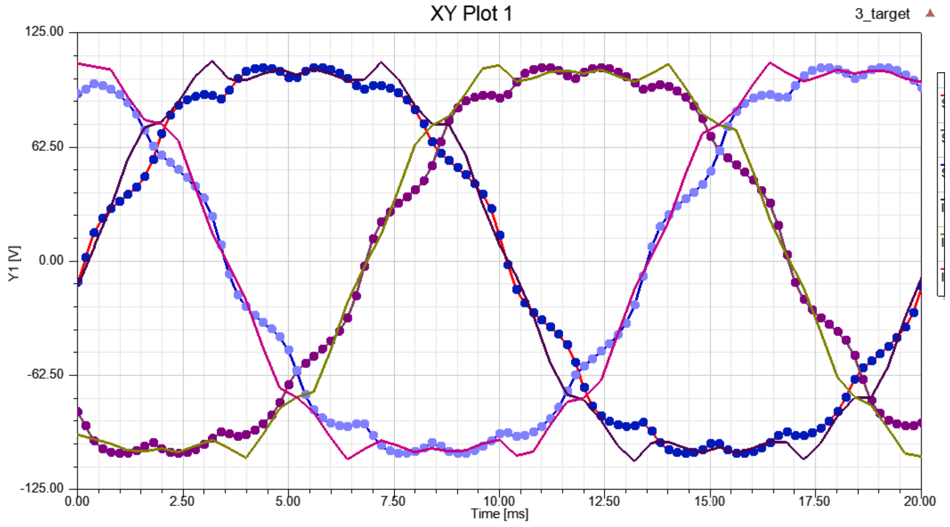
故障工况



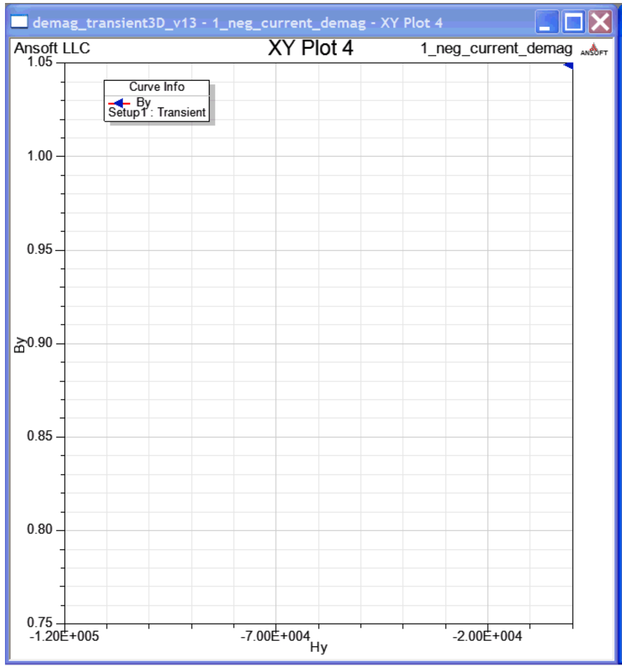
电机整体充磁分析

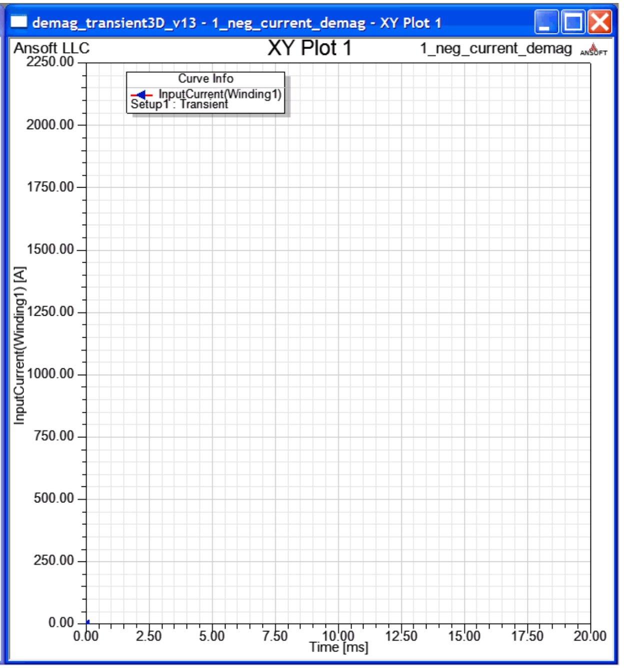

J [A/m^2]
4.2925E+007
3.7202E+007
3.1478E+007
2.5755E+007
2.0032E+007
1.4308E+007
8.5850E+006
2.8617E+006
-2.8617E+006
-8.5850E+006
-1.4308E+007
-2.0032E+007
-2.5755E+007
-3.1478E+007
-3.7202E+007
-4.2925E+007
Time =0ns
Speed =0.000000rpm
Position =7.500000deg
0
40
80 (mm)


1mF
C22
S_21
1mF
C15
S_17
LPhaseA
LPhaseB
LPhaseC
Model
Model_Switch

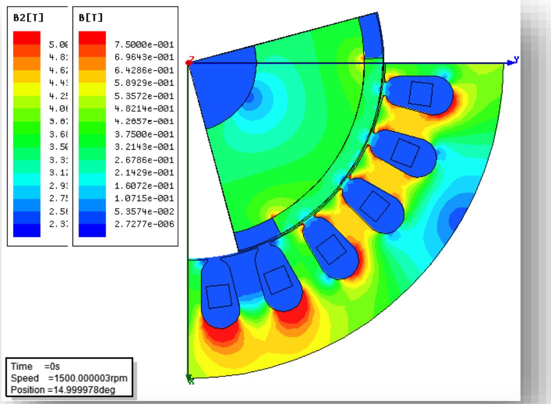

XY Plot 1
3_target
Y1 [V]
Time [ms]

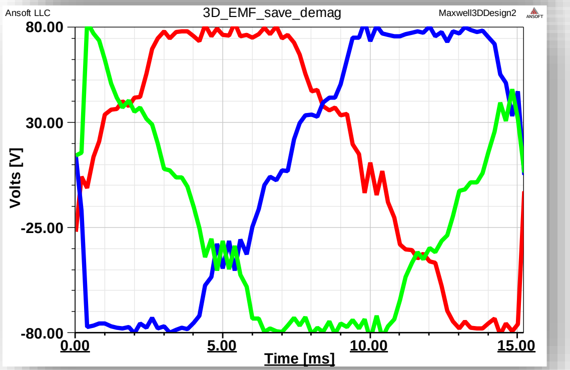
永磁电机退磁分析

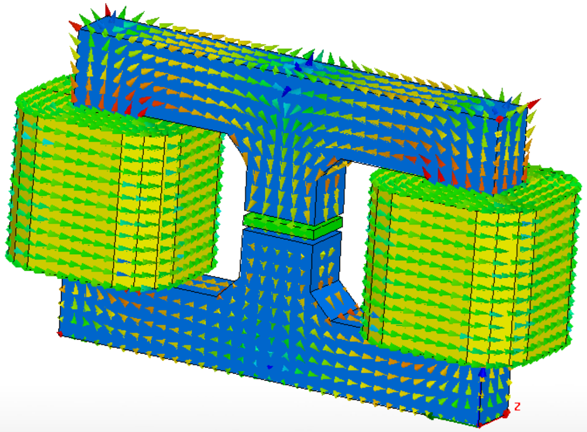


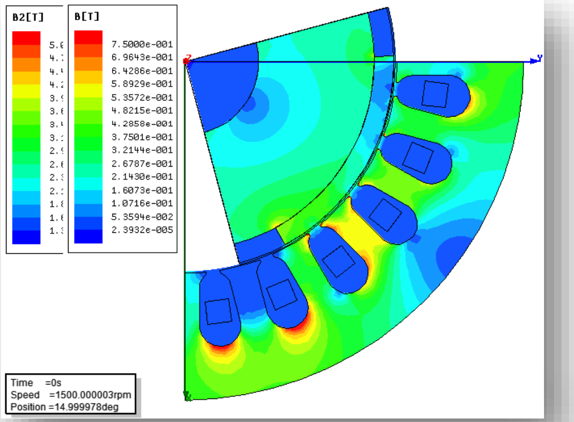


正常工况

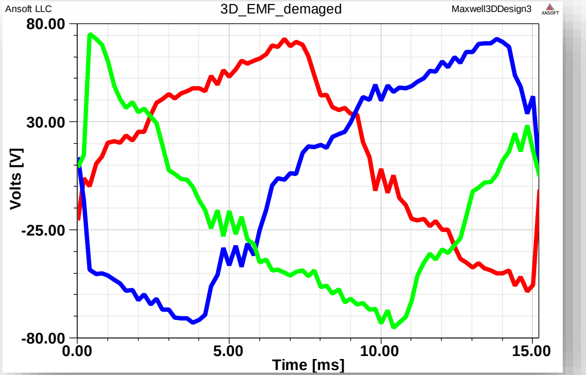






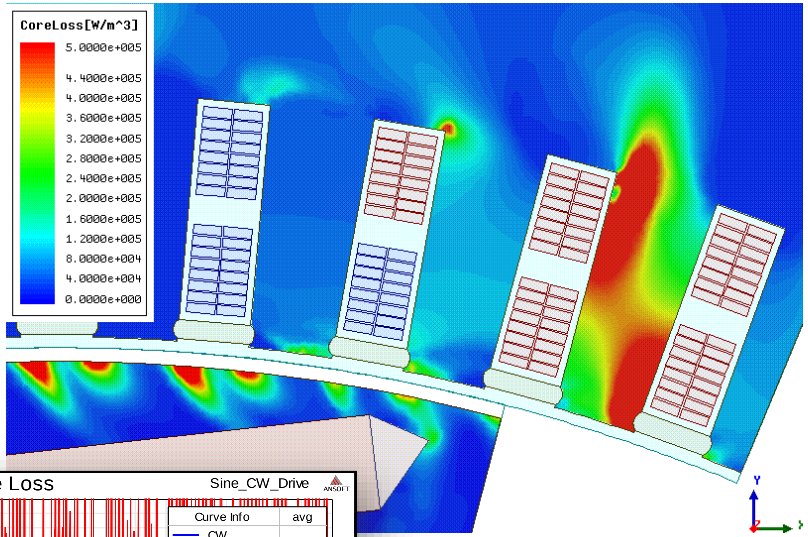


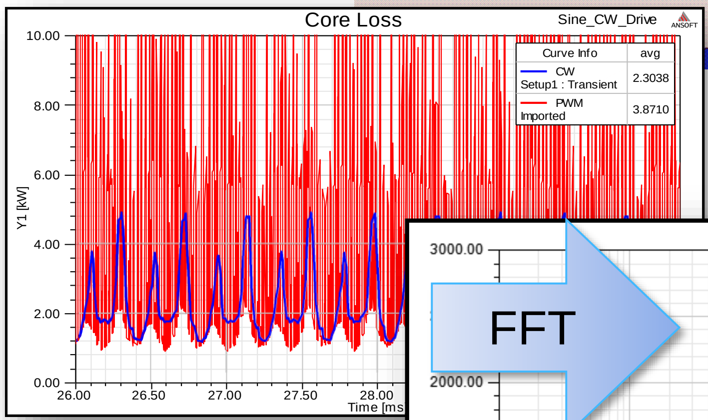
故障工况

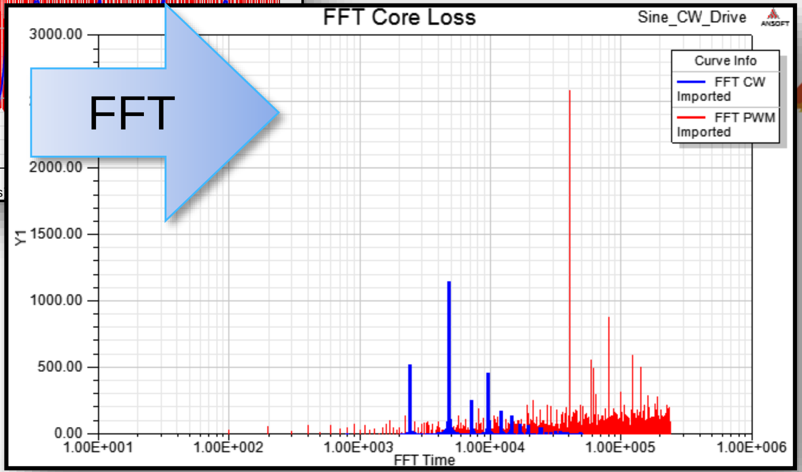


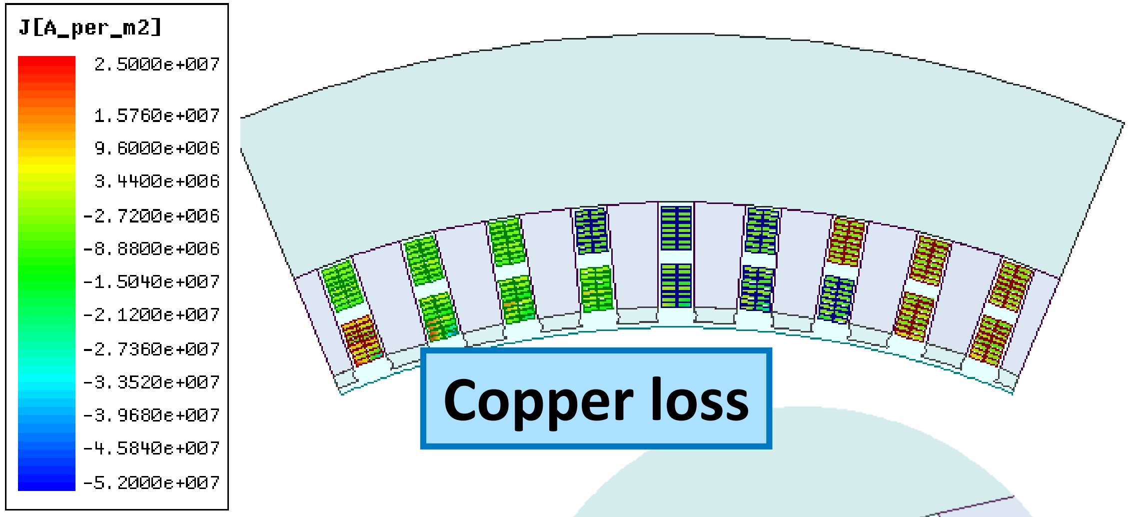
高精度电机损耗分析

Iron loss

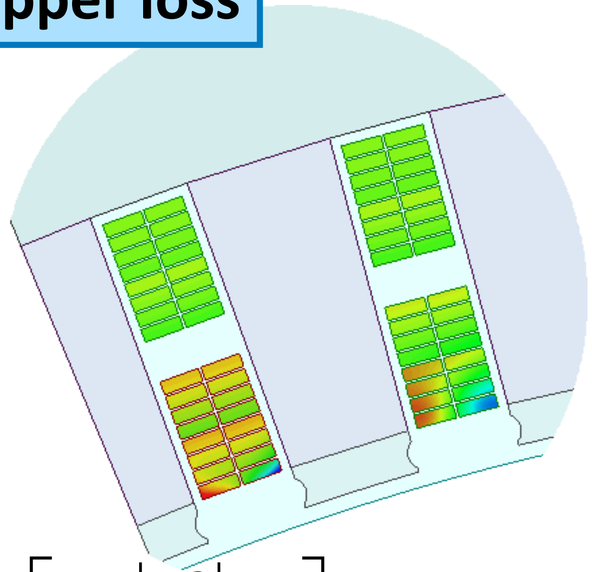


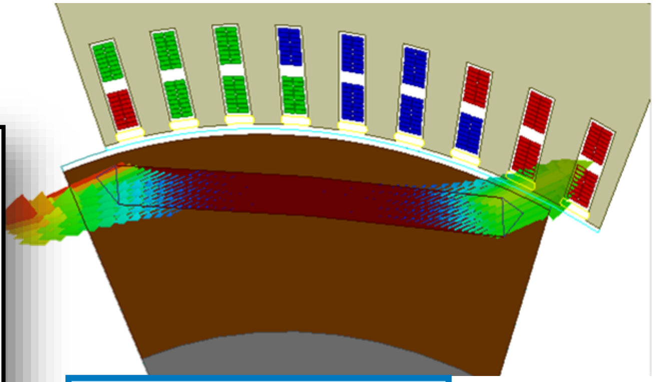






Copper loss





Eddy current loss

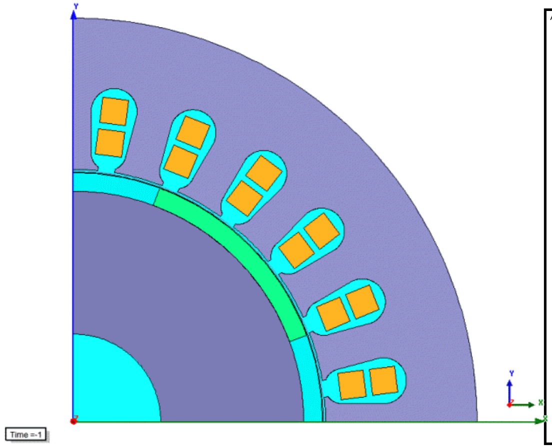
$$Loss = \sum_{n}\left[\int_{mag}\frac{|J|^2}{\sigma}dv\right]$$

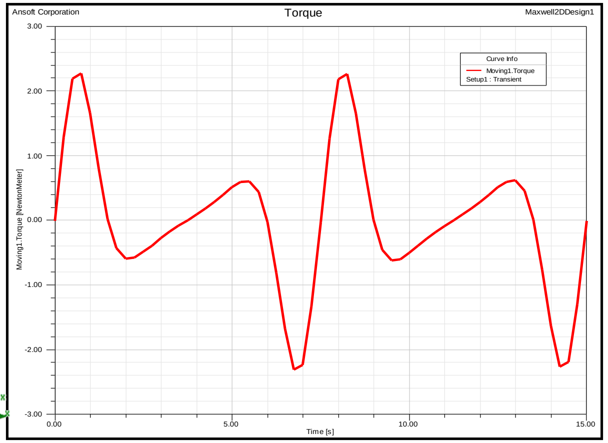
ANSYS

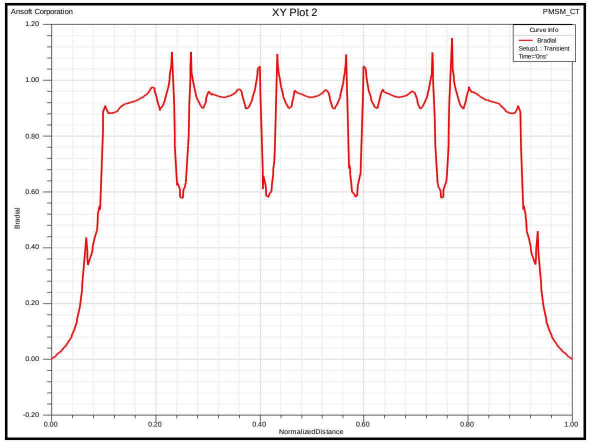
电机齿槽转矩优化分析

- 为什么要优化齿槽转矩：
  - 齿槽转矩是转矩脉动的重要来源
    - 机械振动
    - 噪声
    - 系统不稳定
  - 最终会导致：　效率低下

- 齿槽转矩优化目标：
  - 齿槽转矩降低
    - 气隙磁密变化不大Br
    - 磁钢用量尽可能小



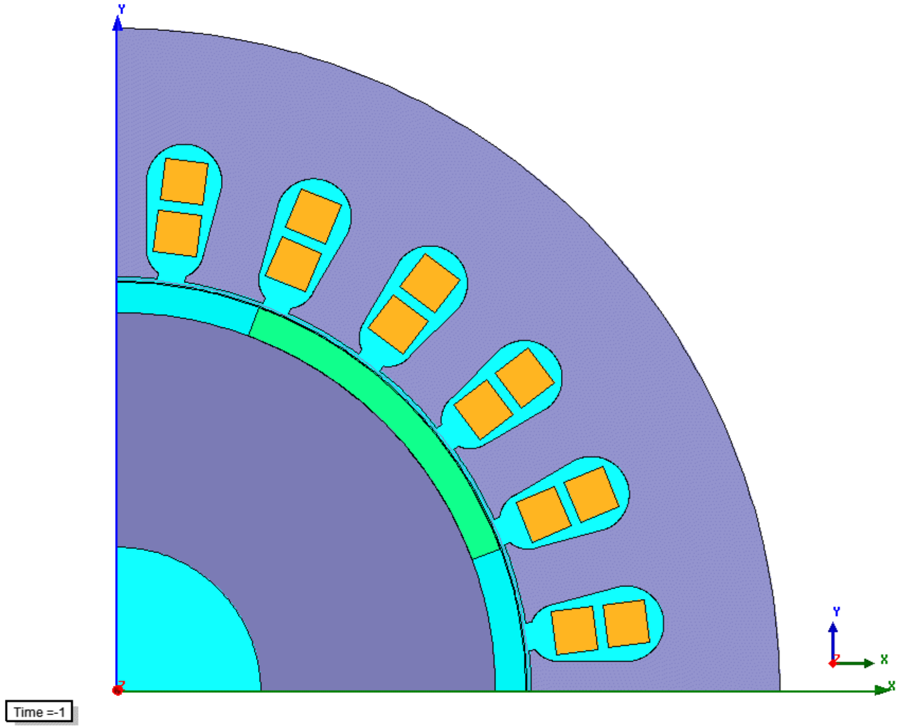




设置优化变量

- Pole Embrace
  - 0.6 < PE < 0.9
- Pole Arc Offset (PAO):

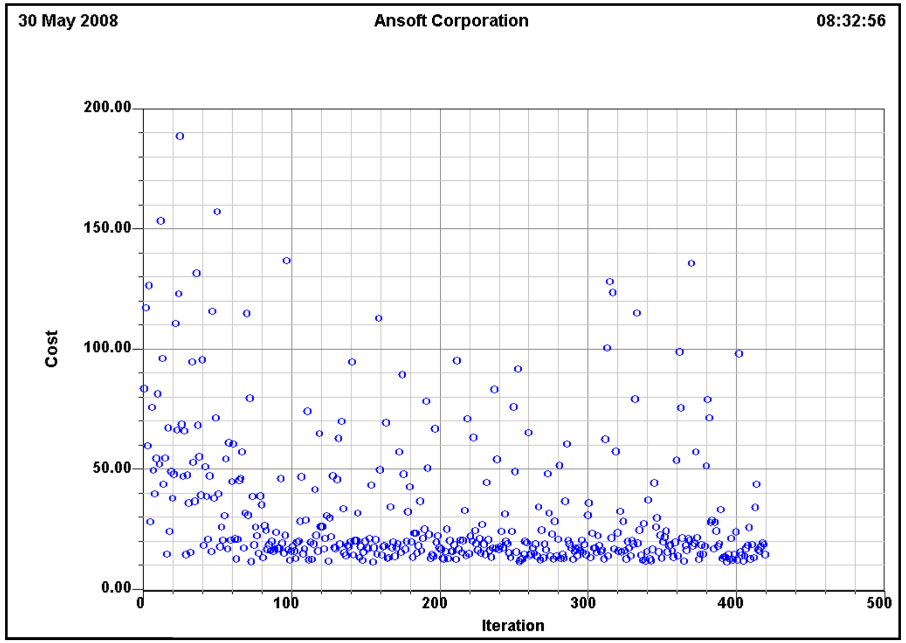
  0 < PAO < 30 mm
- Magnet Thickness:
  - 6.5 mm < MT < 9.5 mm



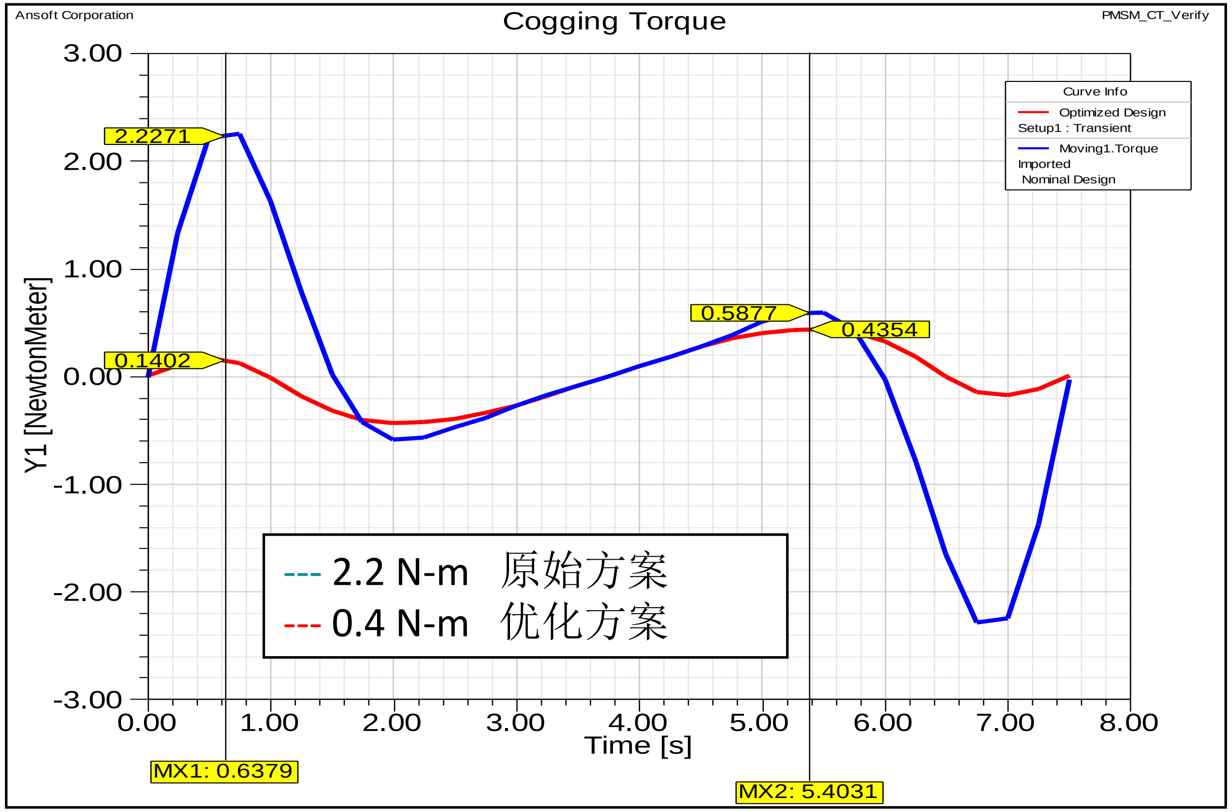
遗传算法

- $G1 = 1 + (max(abs(Torque)) – 0.2) * 9 / 5.3$
- $G2 = 1 + (Brad\_Avg – 0.5) * 9 / 0.31$
- $G3 = 1 + (Mag\_Area – 220) * 9 / 290$

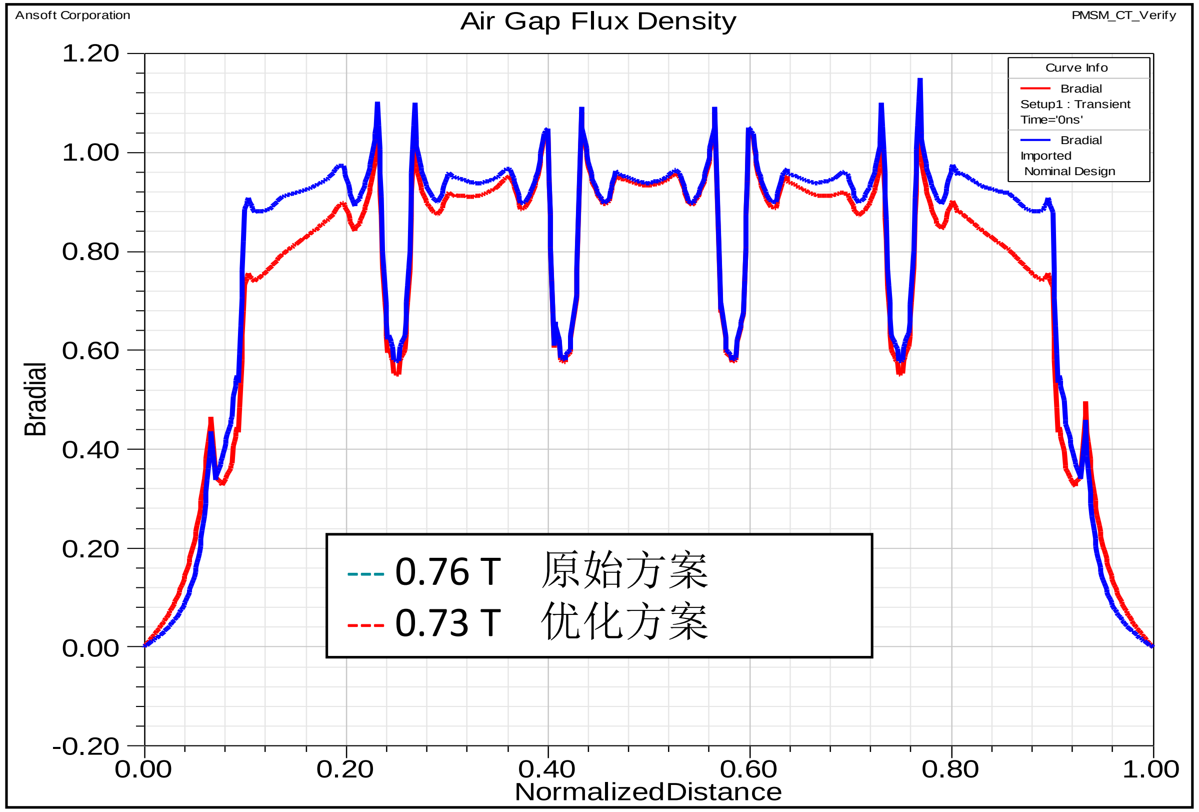
- $Cost1 = (G1 – 1)^2 * W1$
- $Cost2 = (G2 – 8.55)^2 * W2$
- $Cost3 = (G3 – 1)^2 * W3$
- $Total\_Cost = Cost1+Cost2+Cost3$



优化结果对比

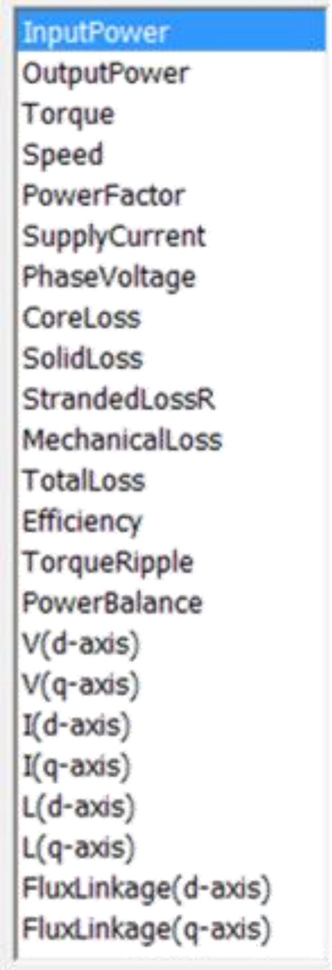


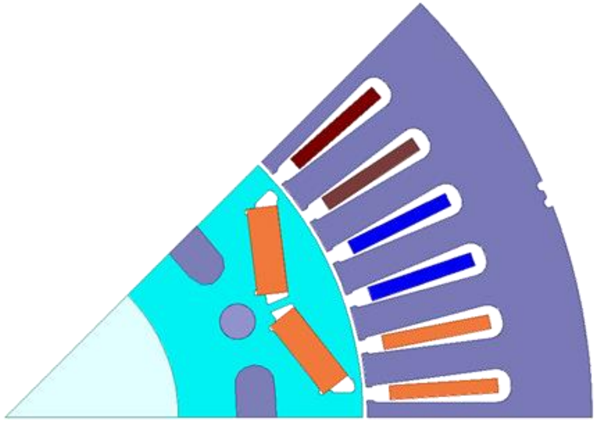
Ansoft Corporation
Cogging Torque
PMSM_CT_Verify
Curve Info
Optimized Design
Setup1 : Transient
Moving1.Torque
Imported
Nominal Design
2.2271
0.1402
0.5877
0.4354
MX1: 0.6379
MX2: 5.4031
Y1 [NewtonMeter]
Time [s]
--- 2.2 N-m 原始方案
--- 0.4 N-m 优化方案

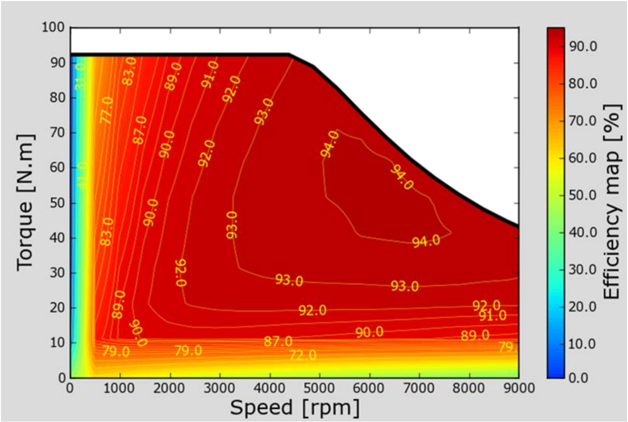


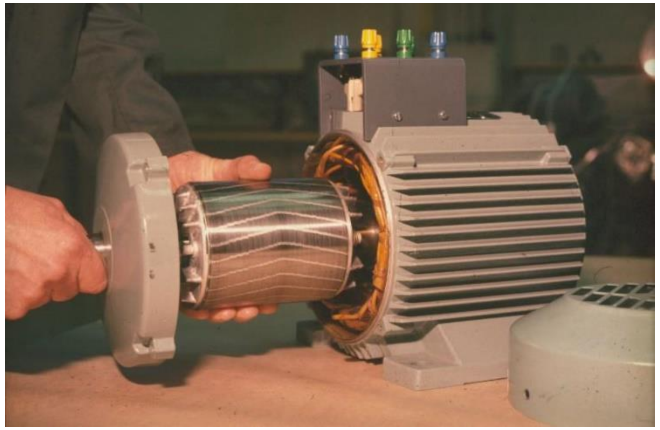
Ansoft Corporation
Air Gap Flux Density
PMSM_CT_Verify
Curve Info
Bradial
Setup1 : Transient
Time='0ns'
Bradial
Imported
Nominal Design
Bradial
NormalizedDistance
--- 0.76 T 原始方案
--- 0.73 T 优化方案

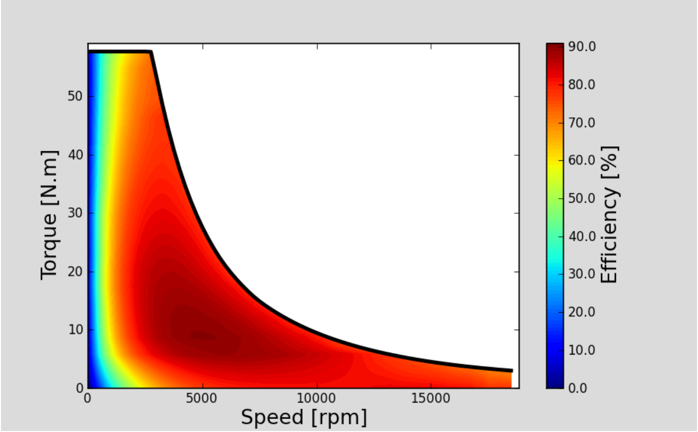
电机设计工具包（UDO/Toolkits）





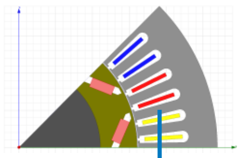




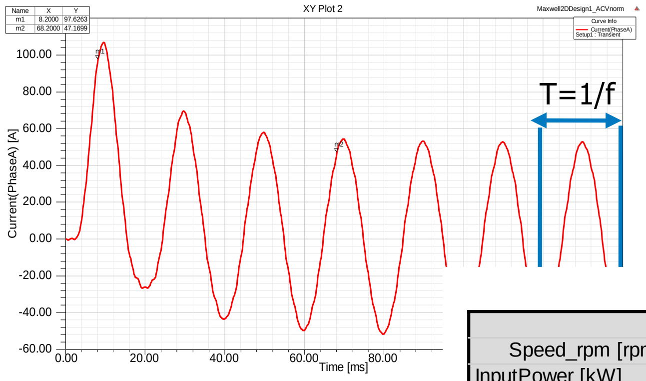


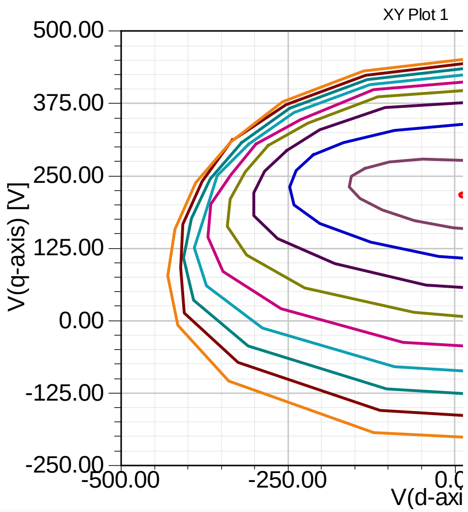
- UDO和Toolkits是针对客户需求定制化开发的电机设计工具包，可直接输出电机电磁性能数据，自动化计算转矩转速特性、效率Map图等，在电机设计领域应用广泛。

电机设计工具包组成



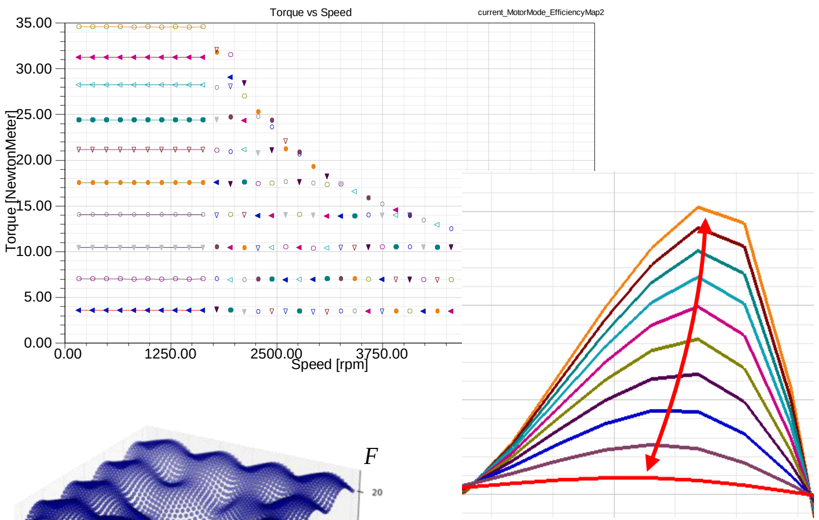
User Defined Outputs

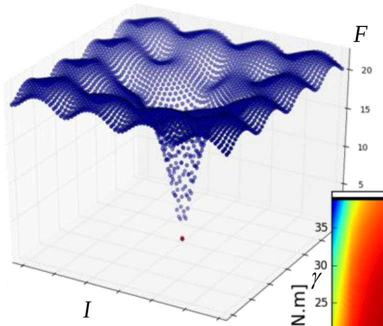


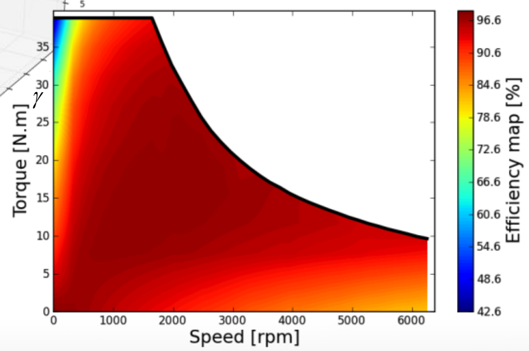


	1
Speed_rpm [rpm]	1000.000000
InputPower [kW]	27.026186
OutputPower [kW]	22.435100
Torque [NewtonMeter]	214.239426
Speed [rpm]	1000.000000
PowerFactor	0.584396
SupplyCurrent [A]	141.417974
PhaseVoltage [V]	109.005576
CoreLoss [W]	113.115481
SolidLoss [fW]	0.000000
StrandedLossR [kW]	2.400000
MechanicalLoss [W]	99.999532
TotalLoss [kW]	2.613115
Efficiency	89.567660
PowerBalance	8.897381
V(d-axis) [V]	-137.705223
V(q-axis) [V]	37.234678
I(d-axis) [A]	-68.404310
I(q-axis) [A]	187.938422
L(d-axis) [mH]	1.600205
L(q-axis) [mH]	1.982361
FluxLinkage(d-axis) [Wb]	0.068288
FluxLinkage(q-axis) [Wb]	0.331973

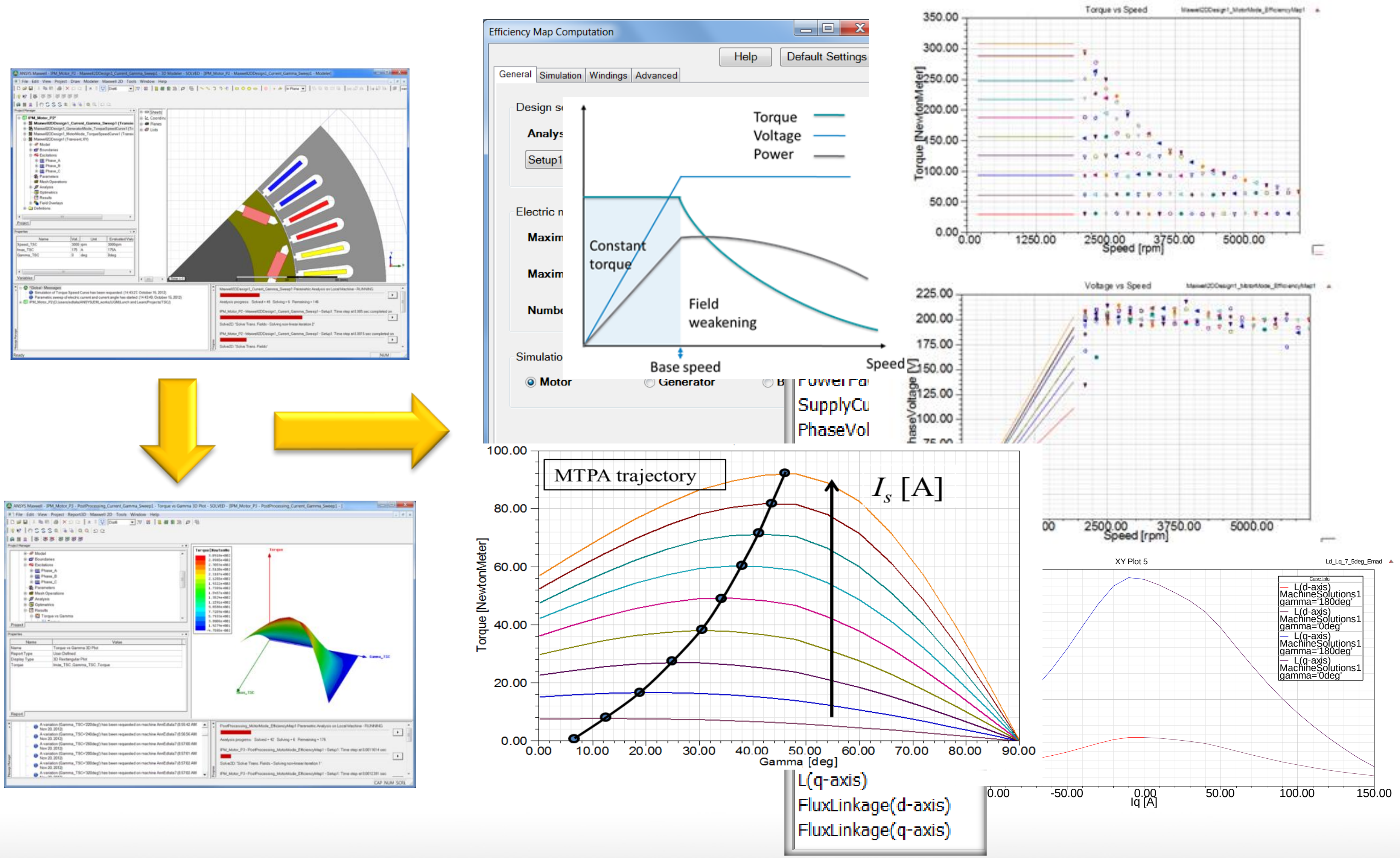
Electric Machine Toolkits



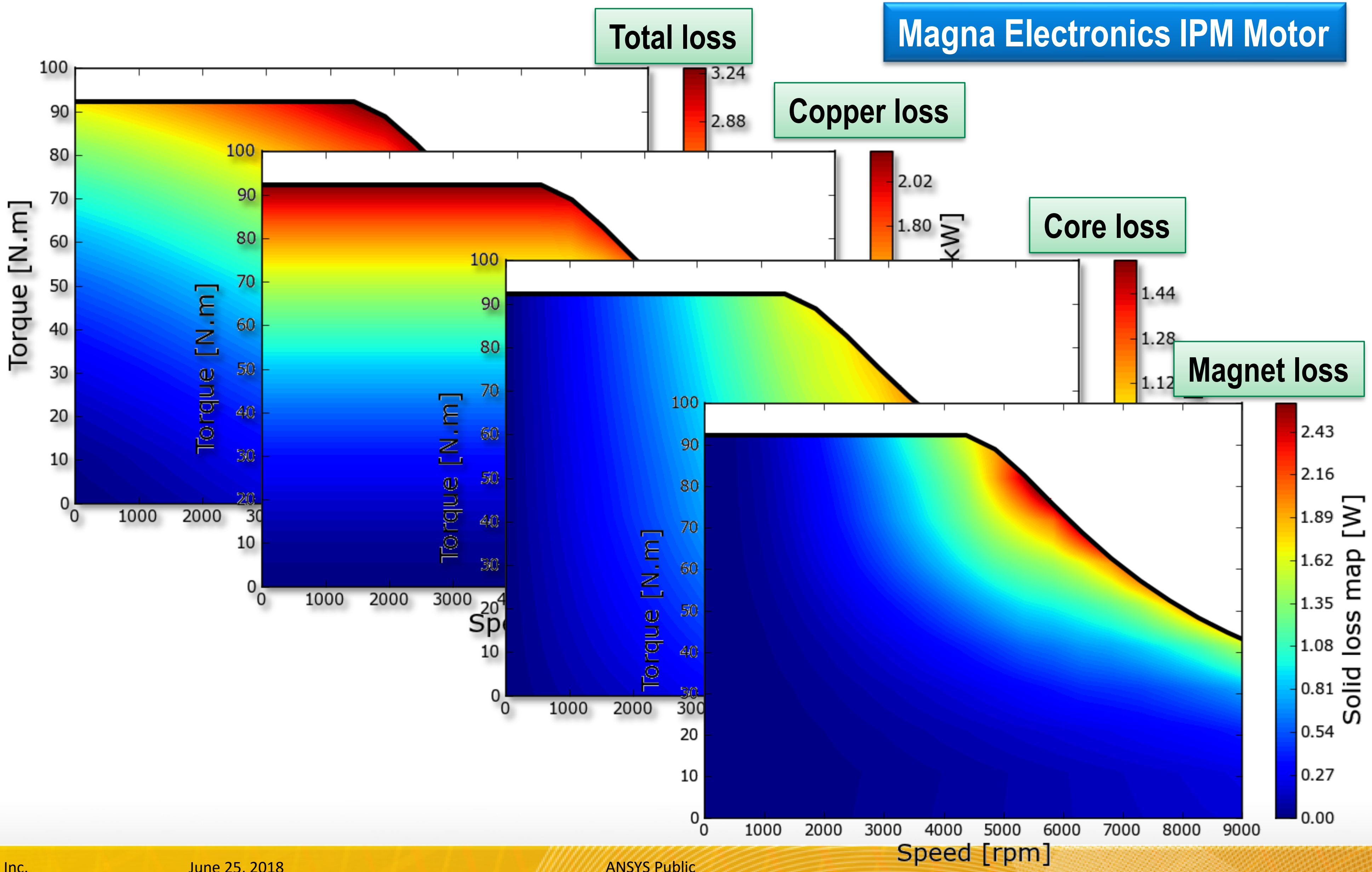




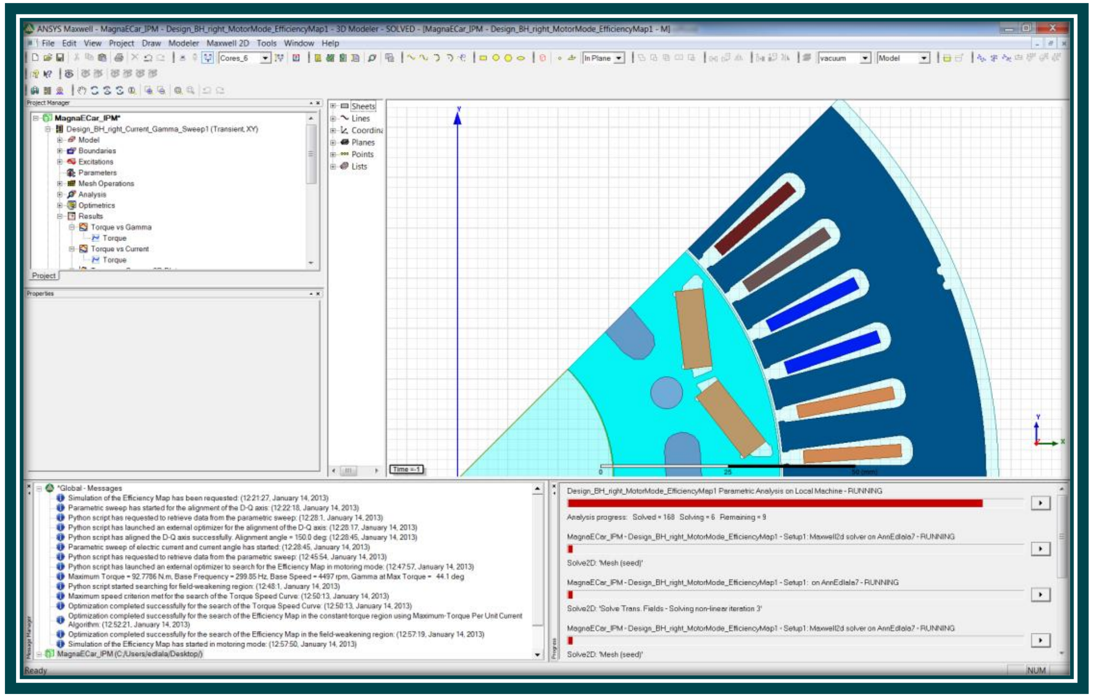
无缝集成的电机设计工具包

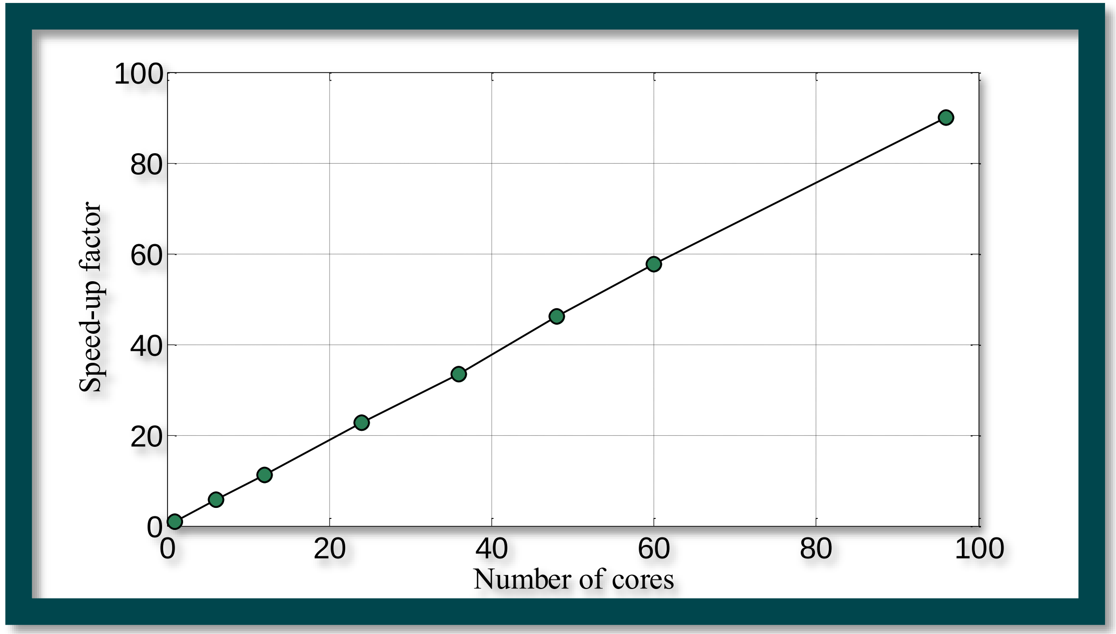


无缝集成的电机设计工具包

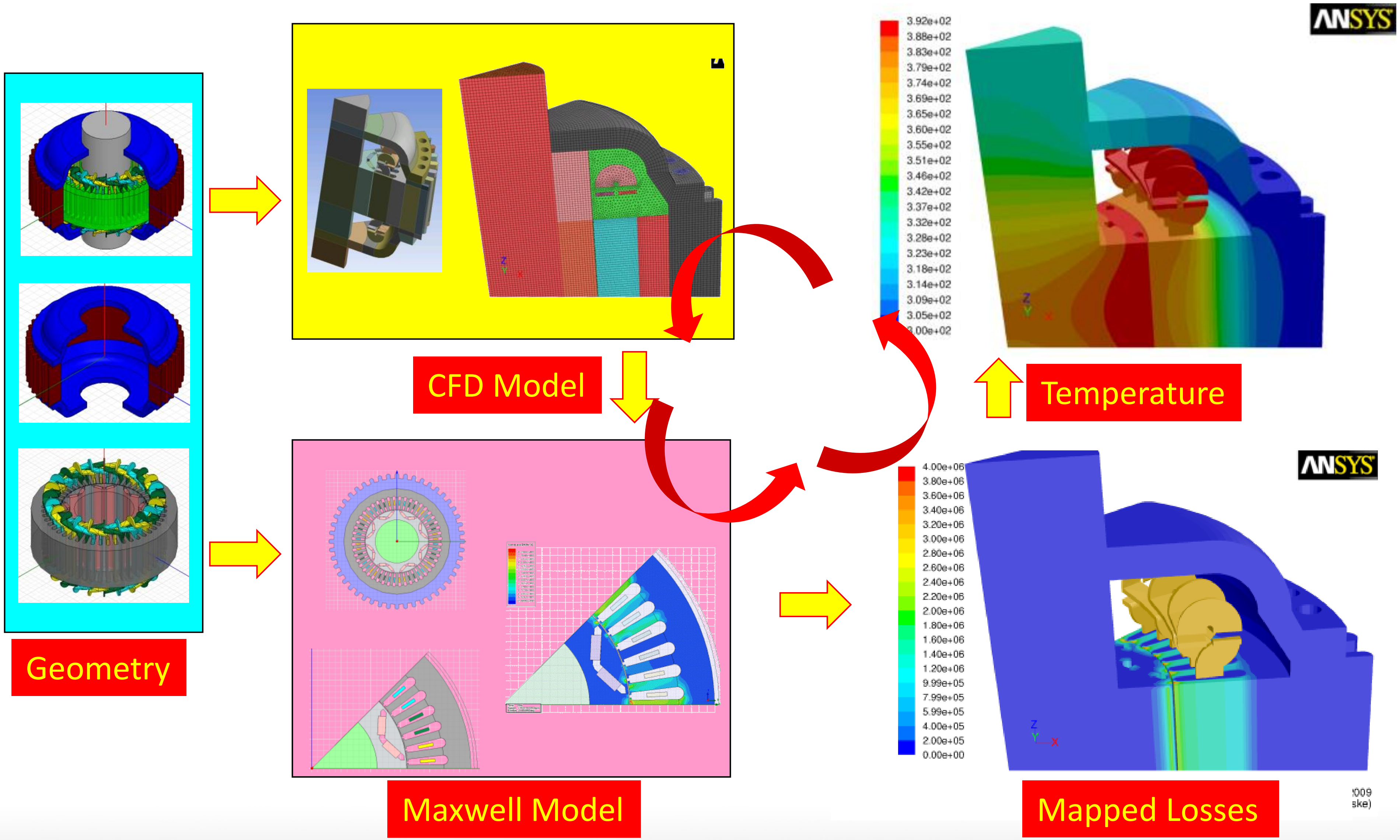


DSO选项提升求解速度

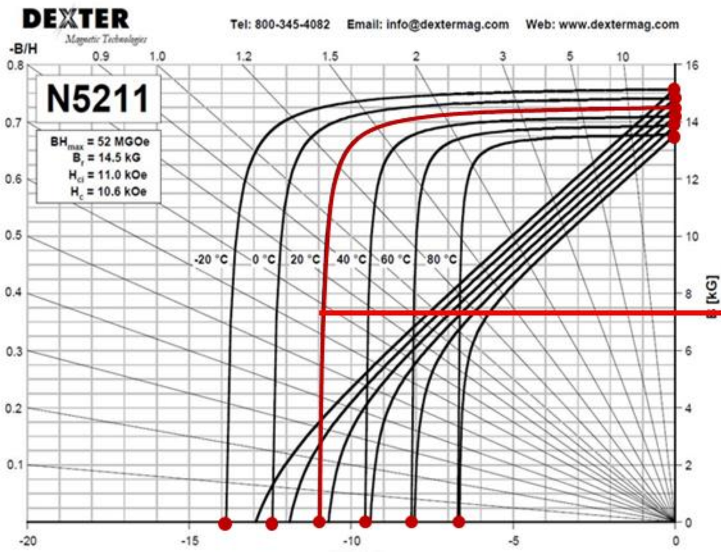


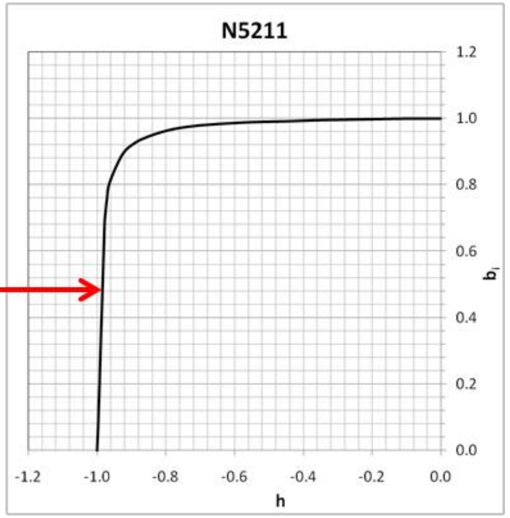


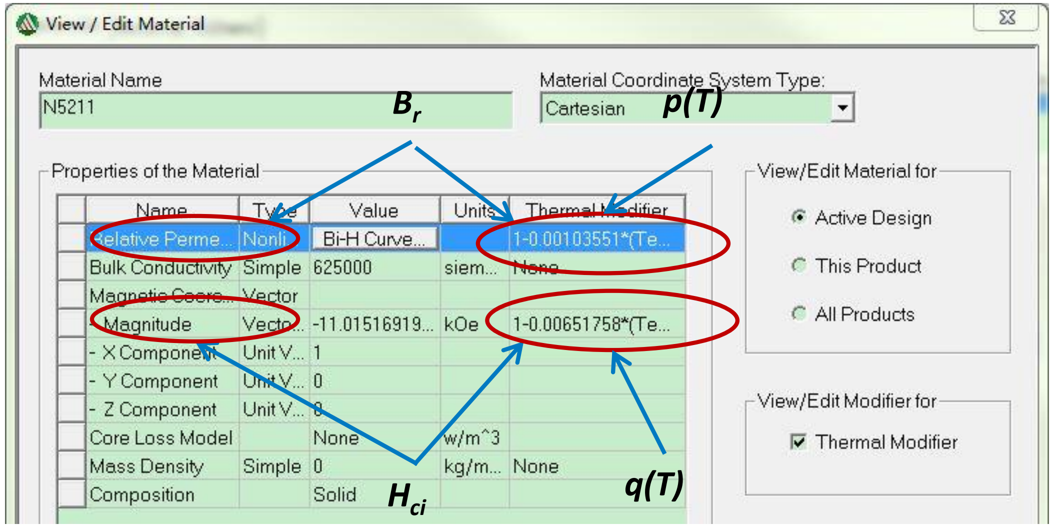
电机温升、散热分析流程

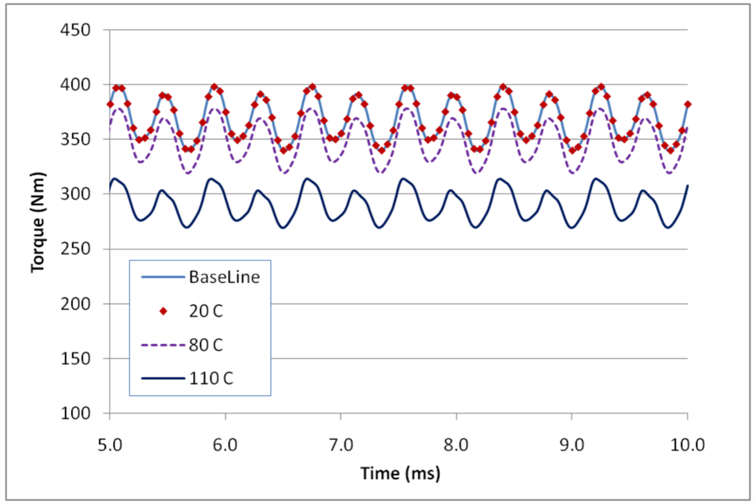

CFD Model
Temperature
Geometry
Maxwell Model
Mapped Losses

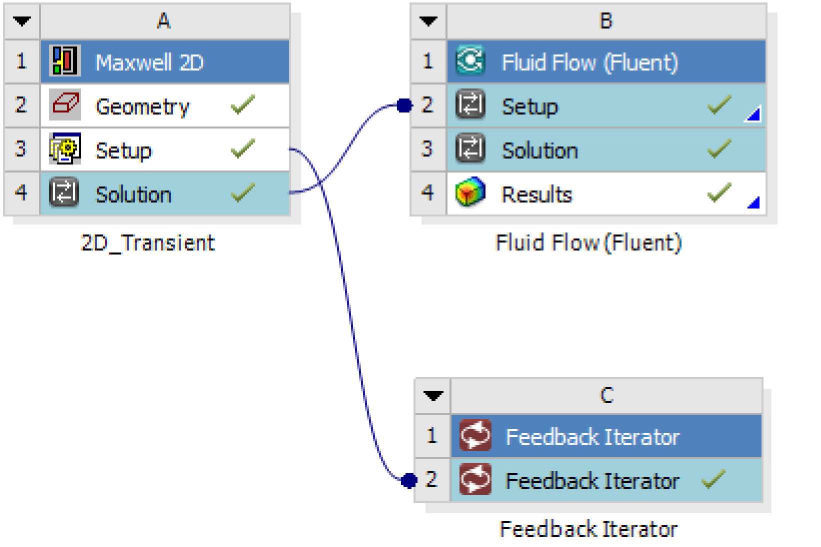
考虑磁钢温度特性的电机特性仿真

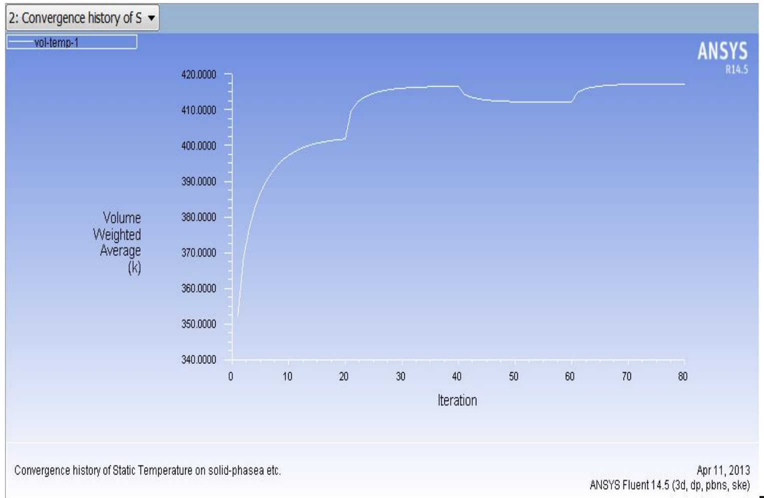




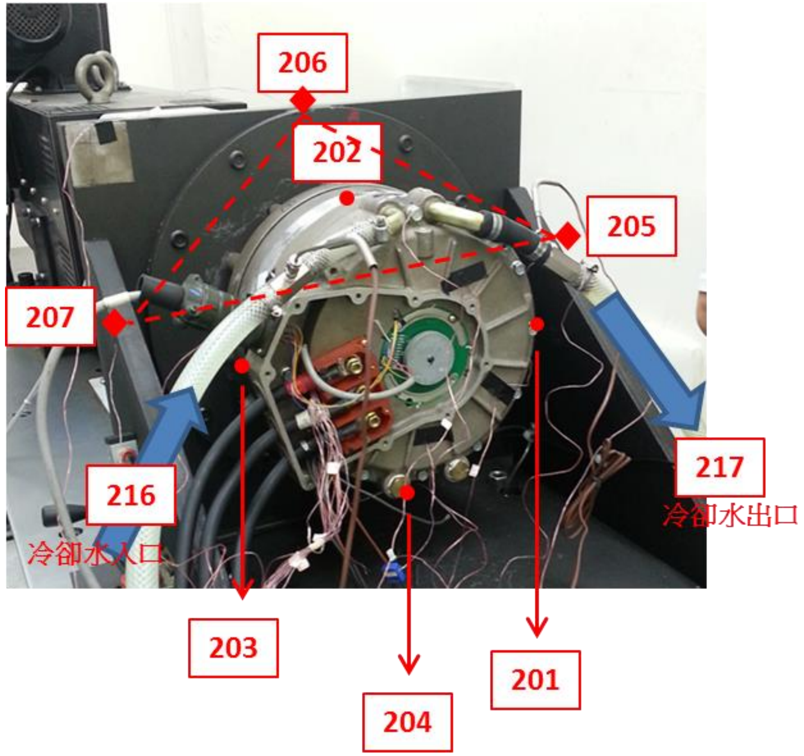


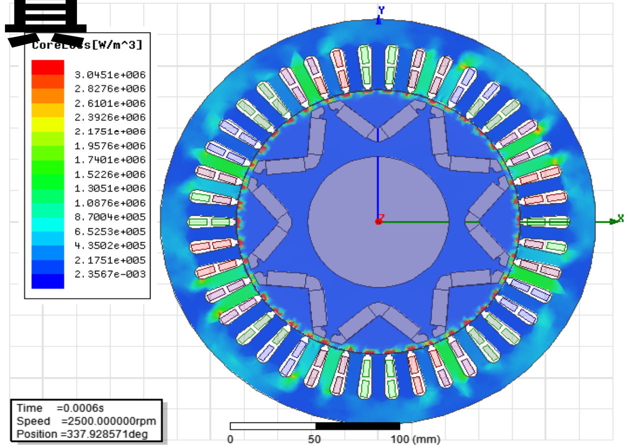


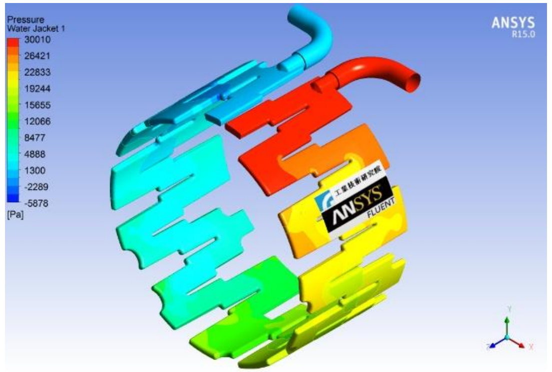


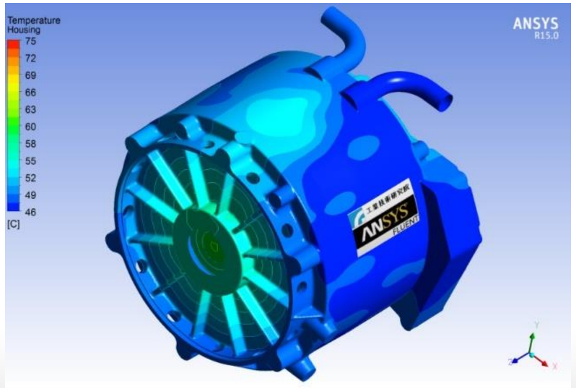


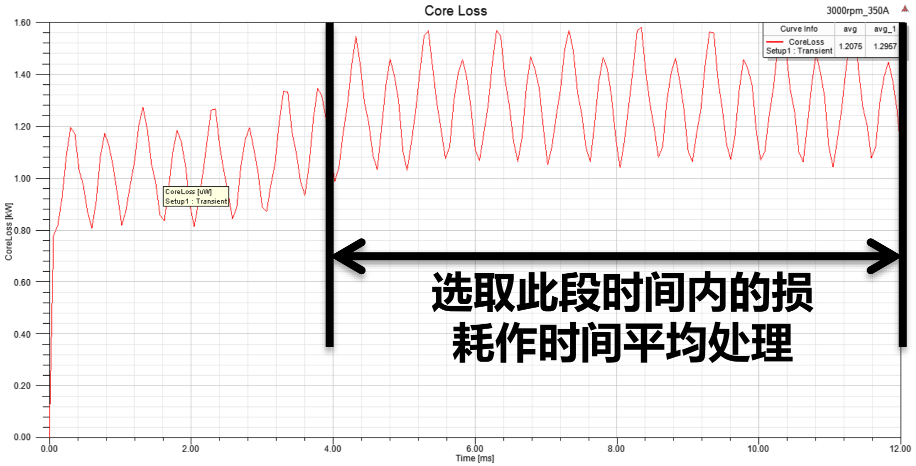
永磁电机定子水冷仿真





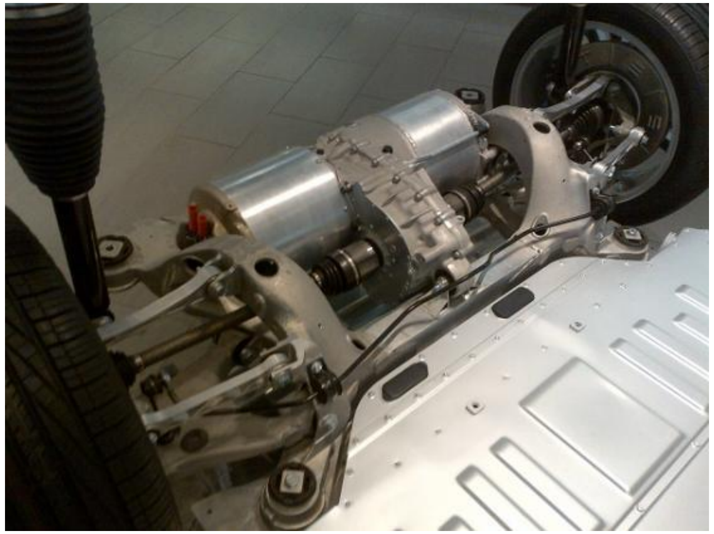


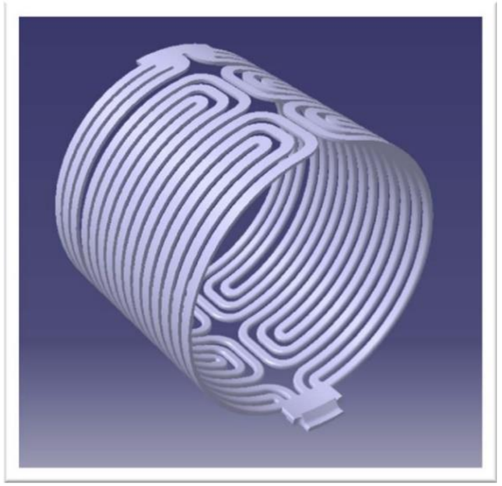


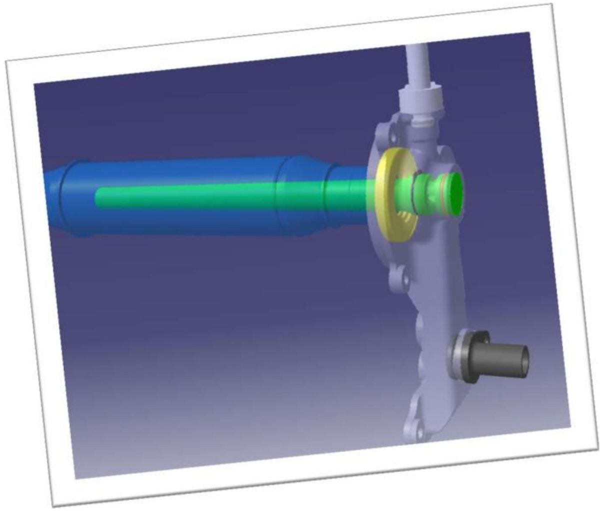


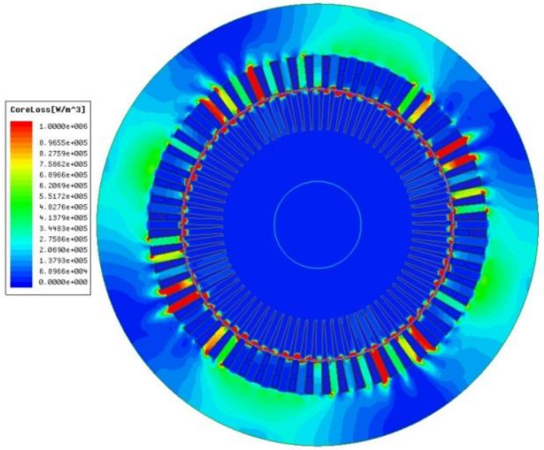
	实验值 ℃	计算值℃
进水口和出水口温升	2.4	2.58
绕组温度	137	132.5
机壳点201温度	46.5	48.7
机壳点201温度	48	53
机壳点201温度	45.9	47.2
机壳点201温度	45.8	47.7

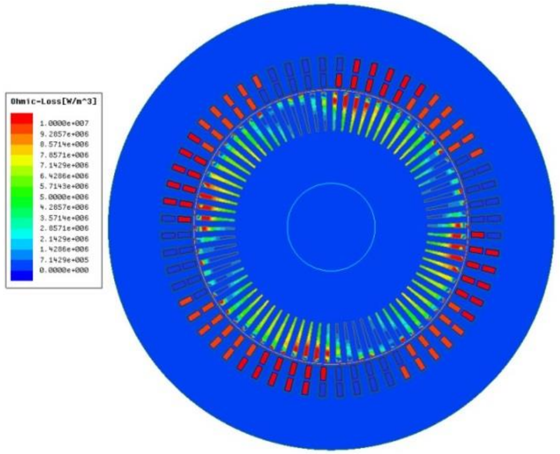
三相感应电机液冷仿真

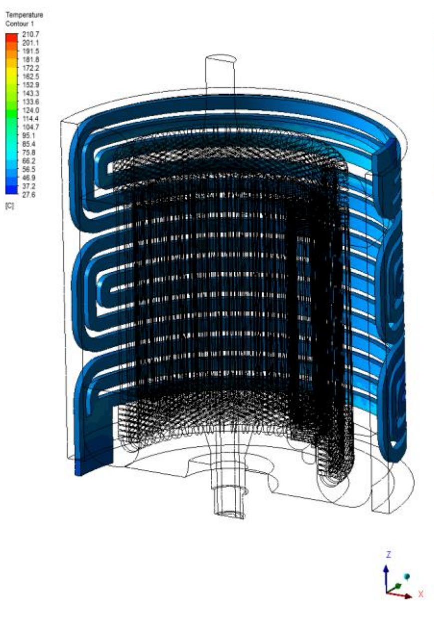


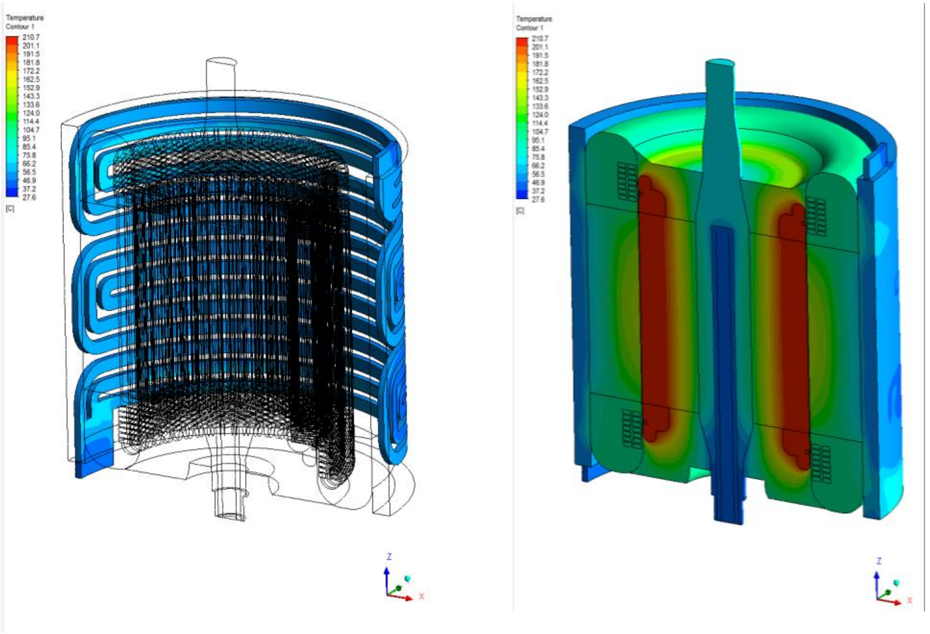




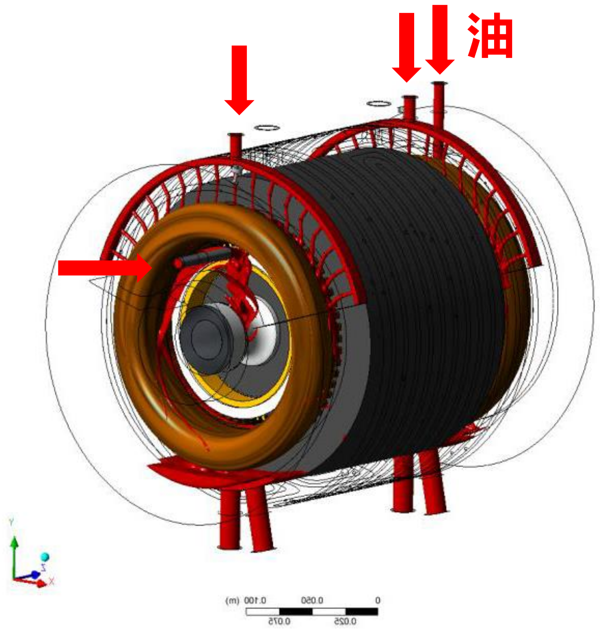


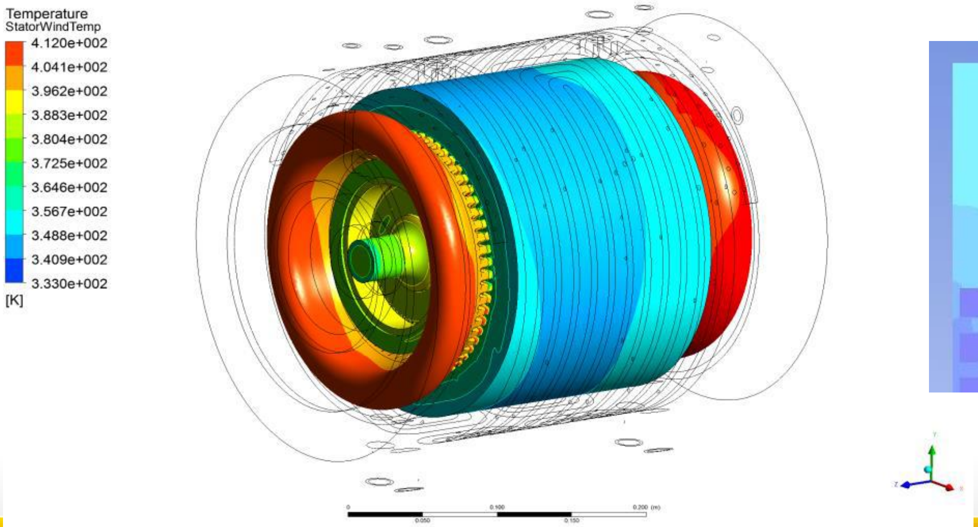


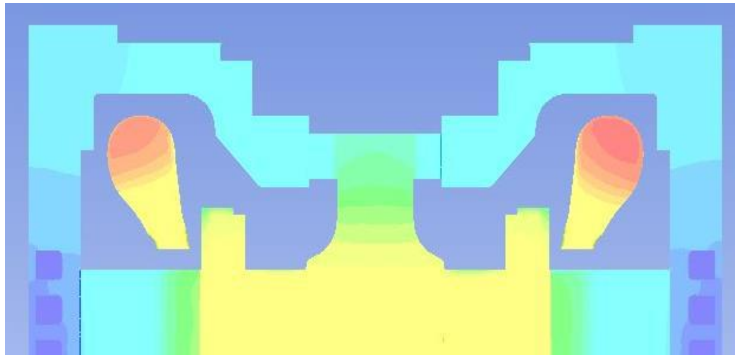


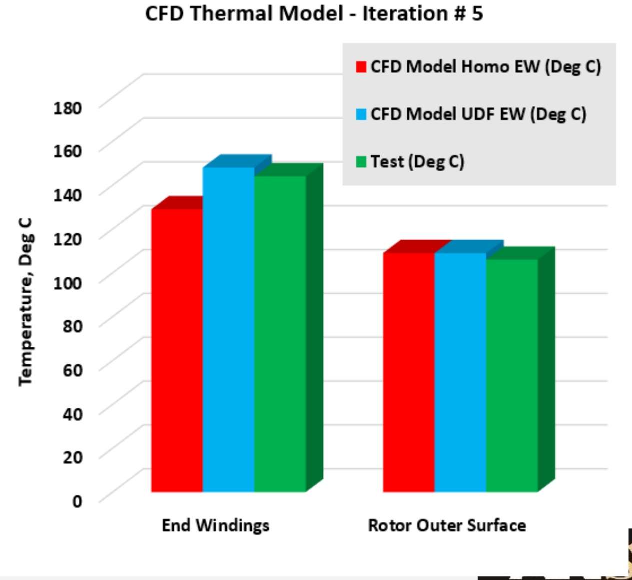


三相感应电机喷油及液冷仿真

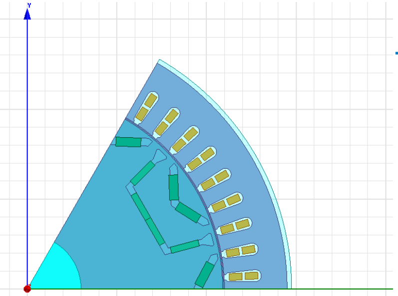


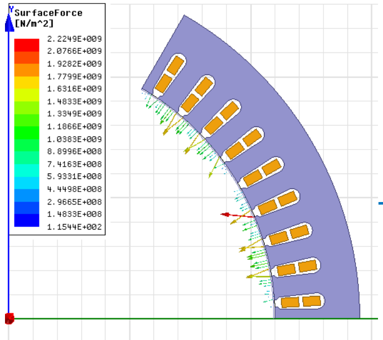






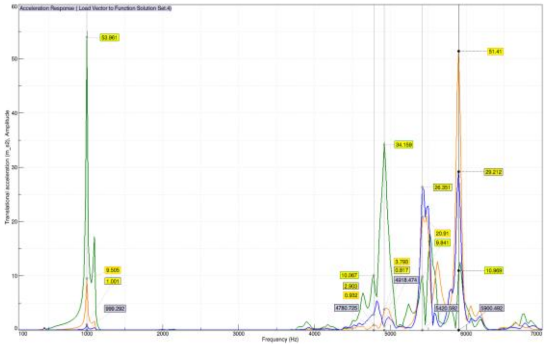
电机电磁振动噪声耦合分析流程

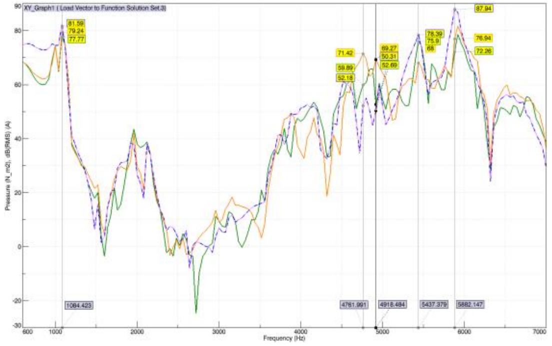




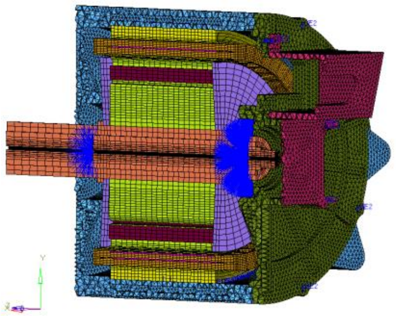
电磁力

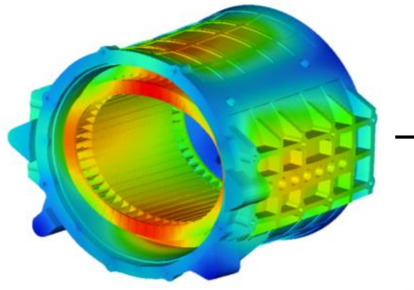
输入

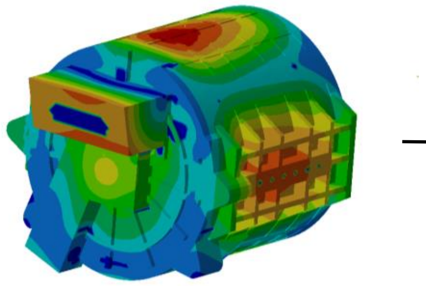


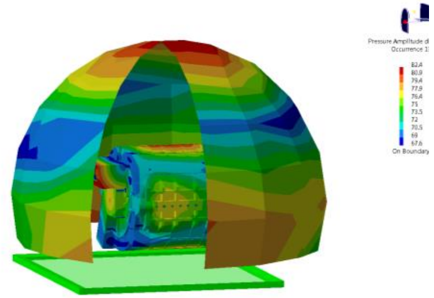


有限元模型 → 模态分析 → 振动响应分析 → 噪声分析

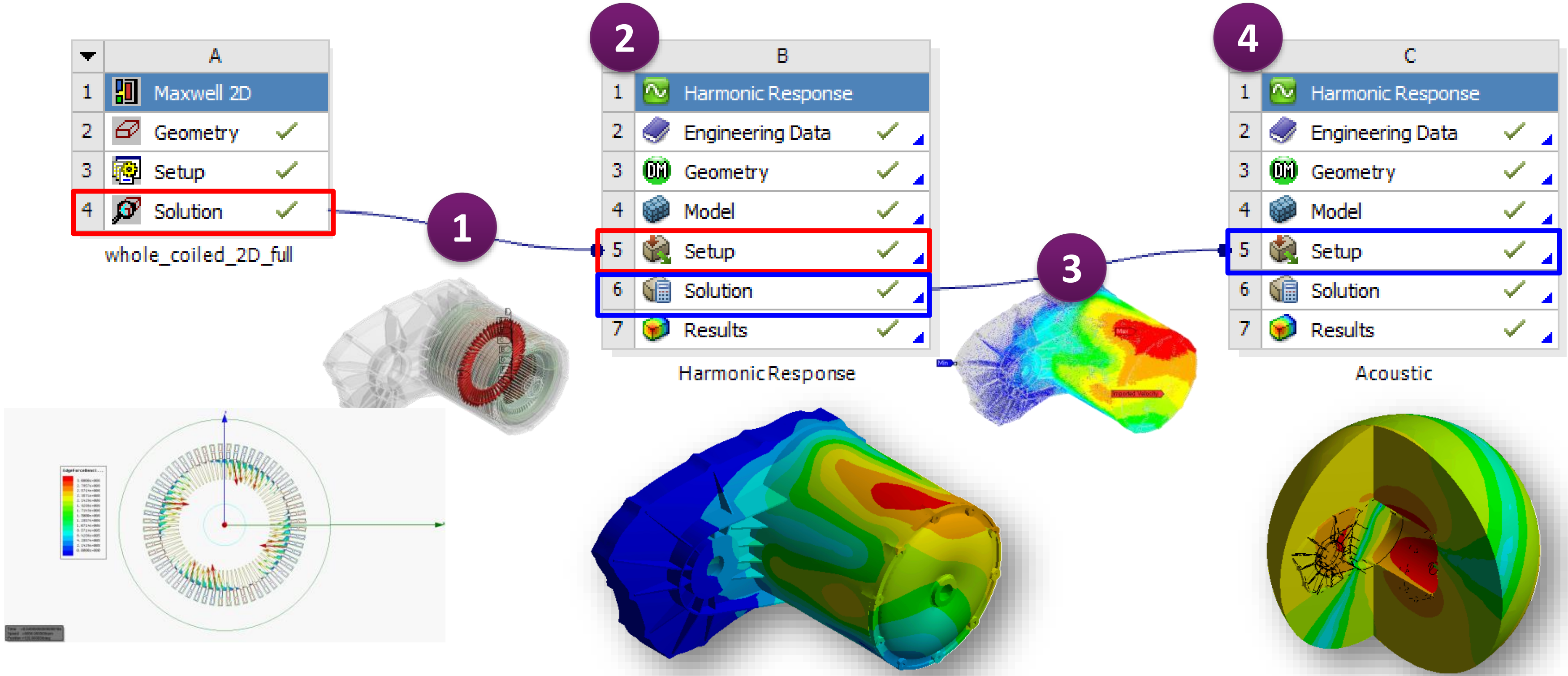


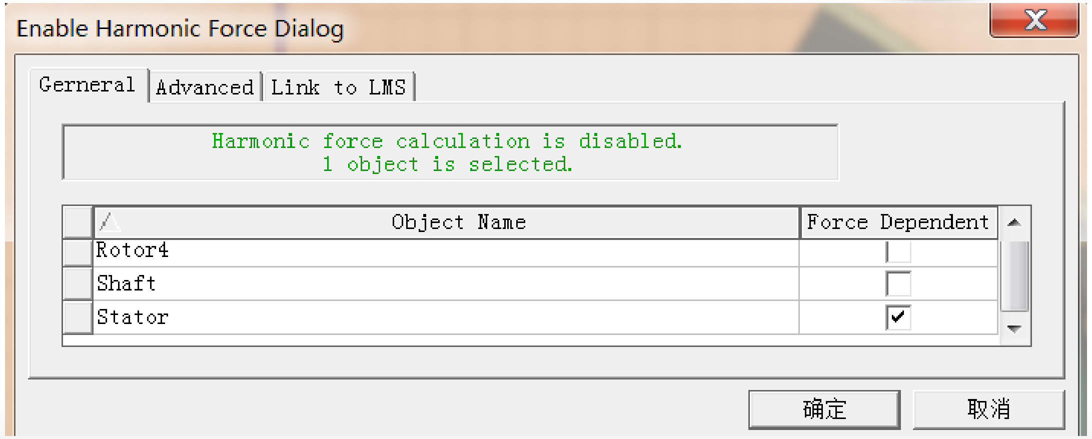


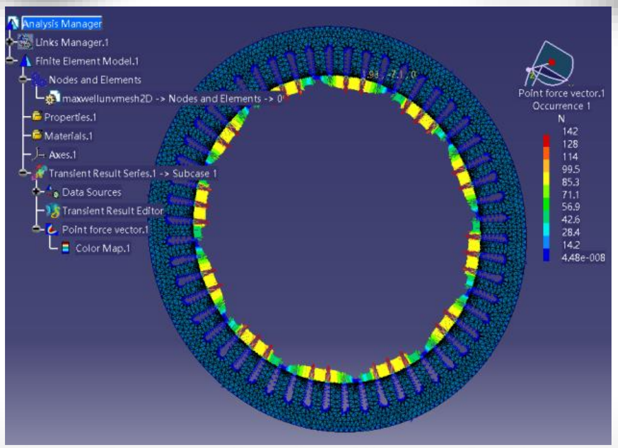


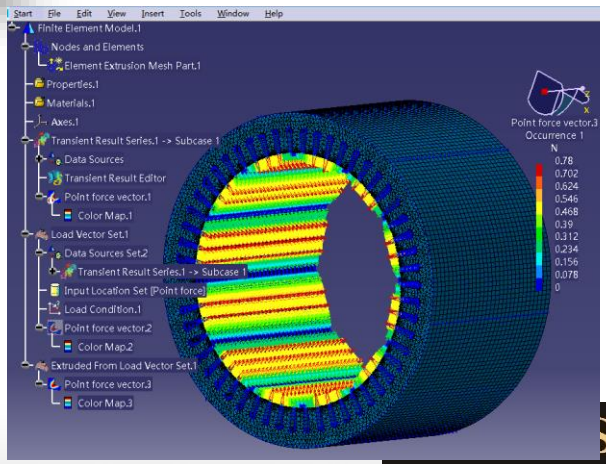


电磁力与振动分析的两种耦合流程

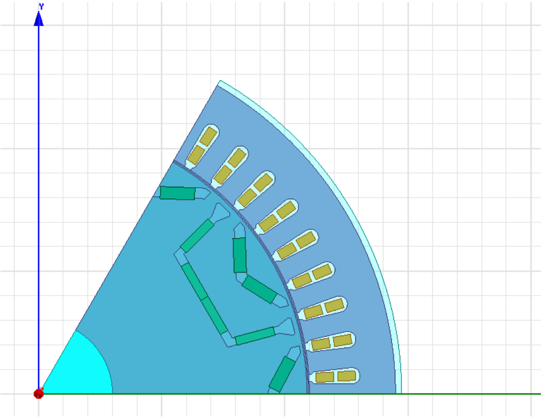


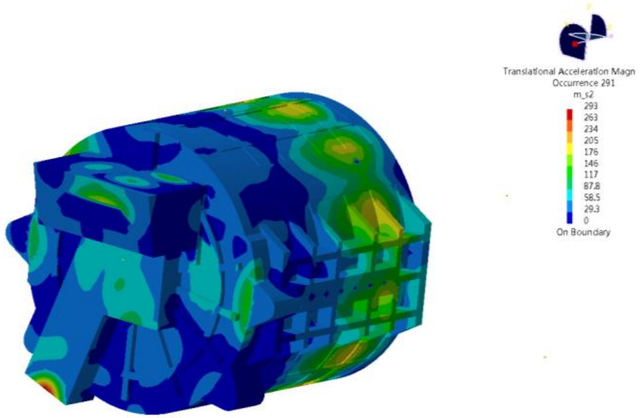


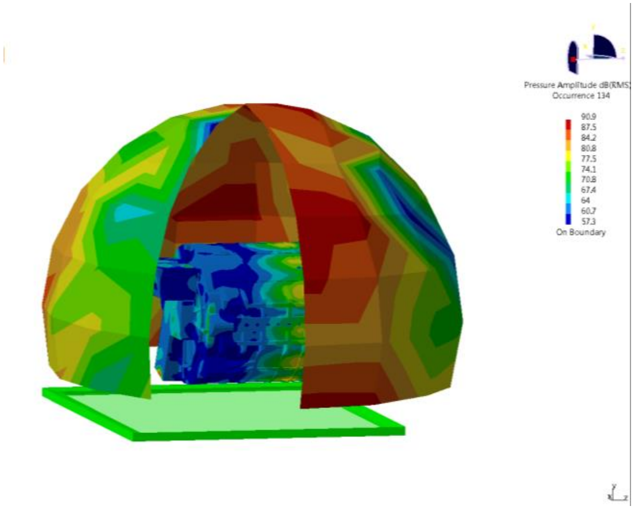


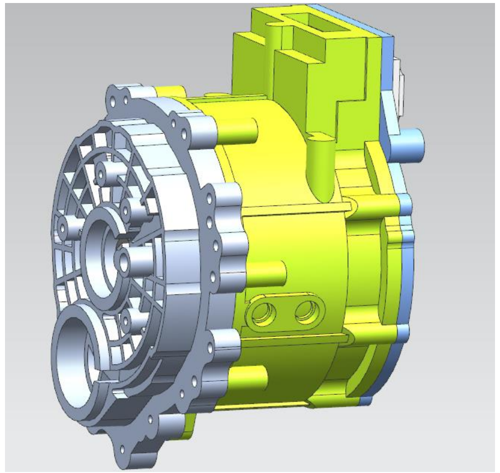


振动噪声分析案例

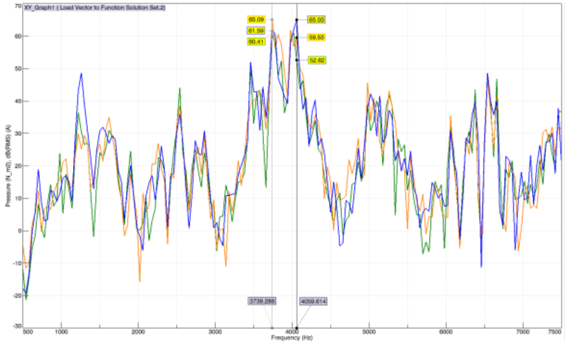




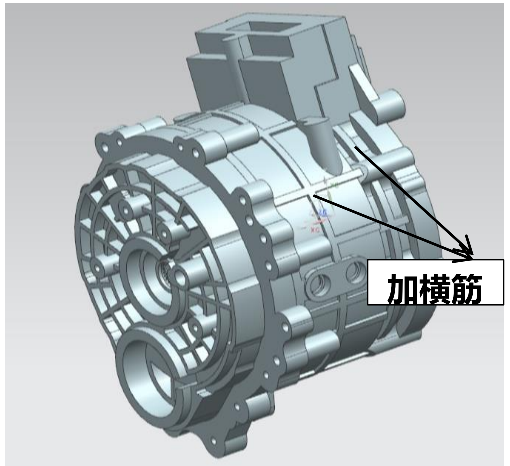




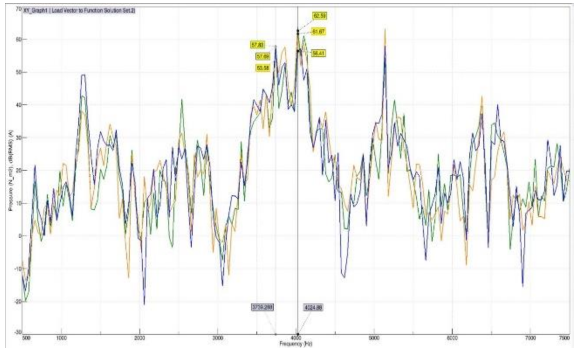
优化前



优化前：电机在3740Hz和4060Hz处存在共振，噪声分别为65.09和65.03dB（A）。



优化后

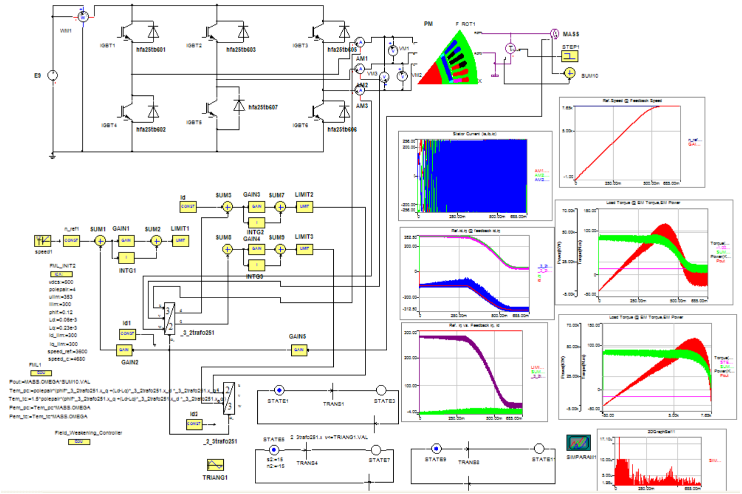


优化后：电机在3739Hz和4024Hz处存在共振，噪声分别为57.83和62.59dB（A）。

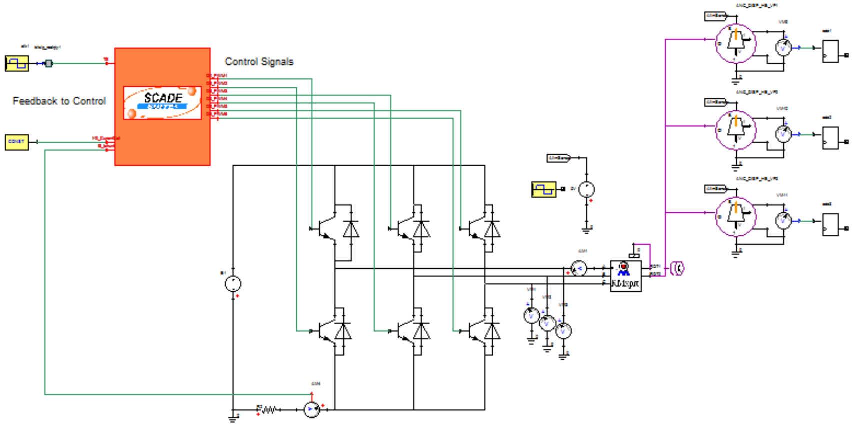
华域电动 Huayu E-drive

ANSYS

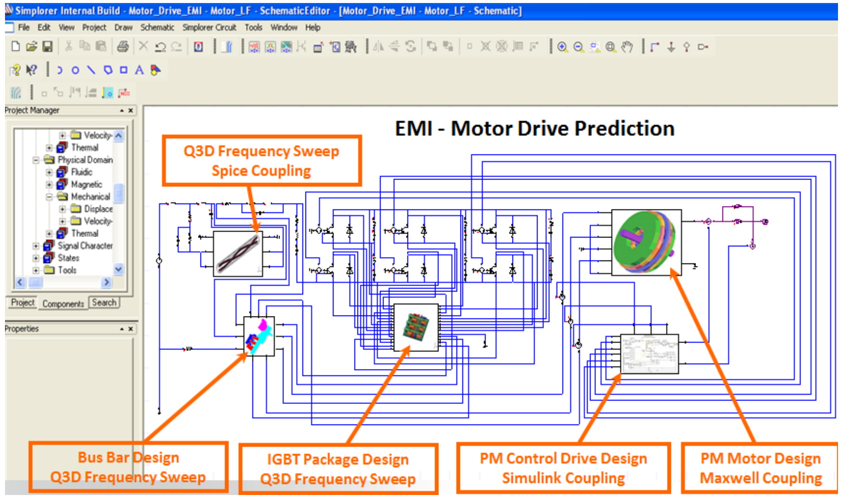
电机控制及其机电系统仿真



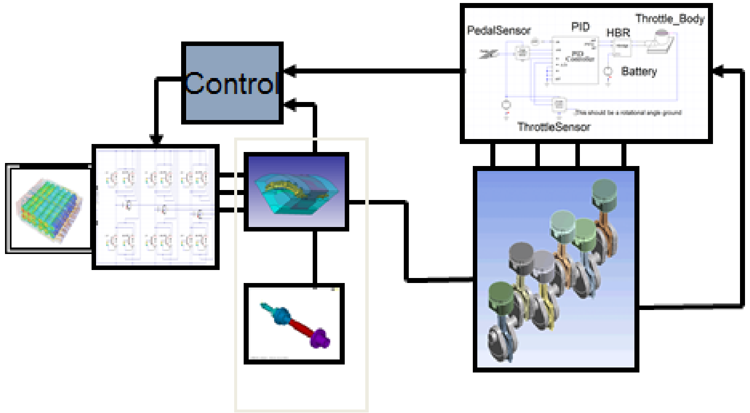
IPM电机弱磁控制



电机控制系统嵌入式代码生成

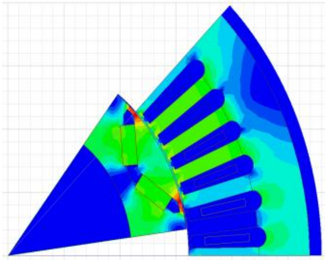


电机控制系统传导干扰分析



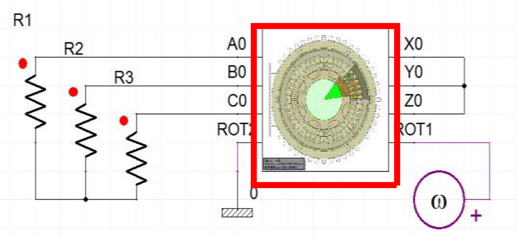
多域系统仿真

电机ECE模型抽取

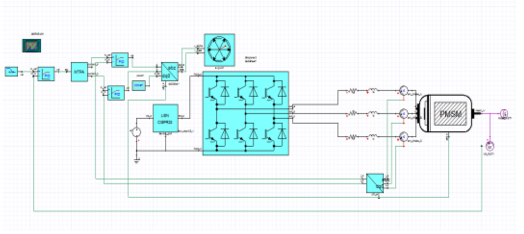


有限元模型/Maxwell

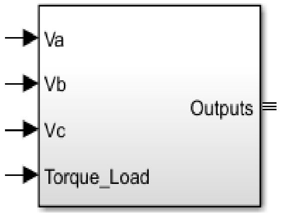
Extraction



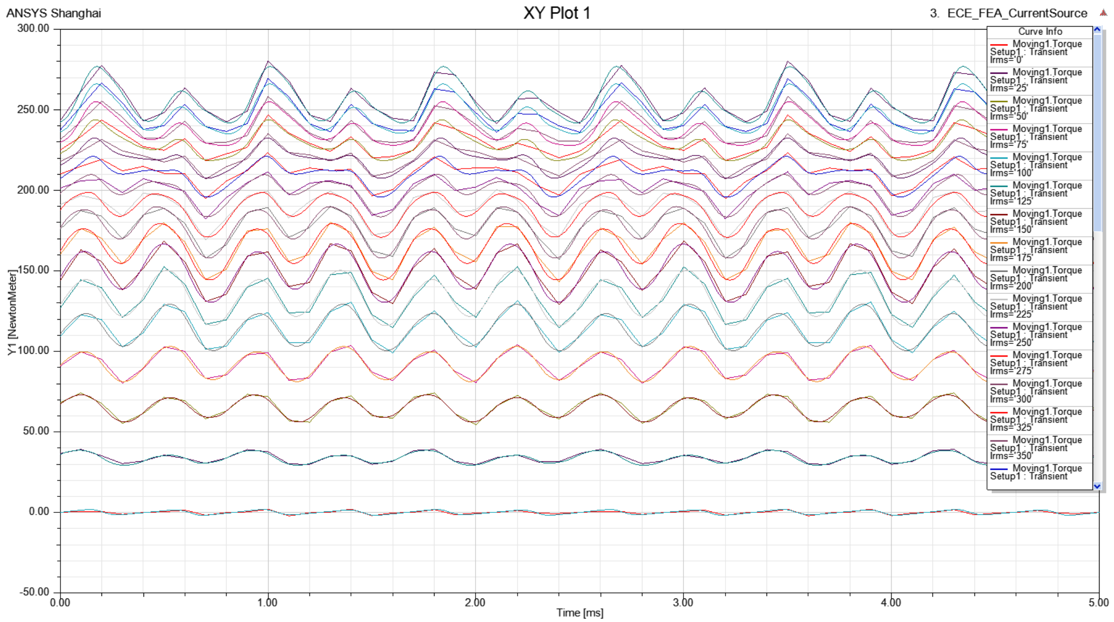
ECE 模型/Simplorer



高级控制/Simplorer

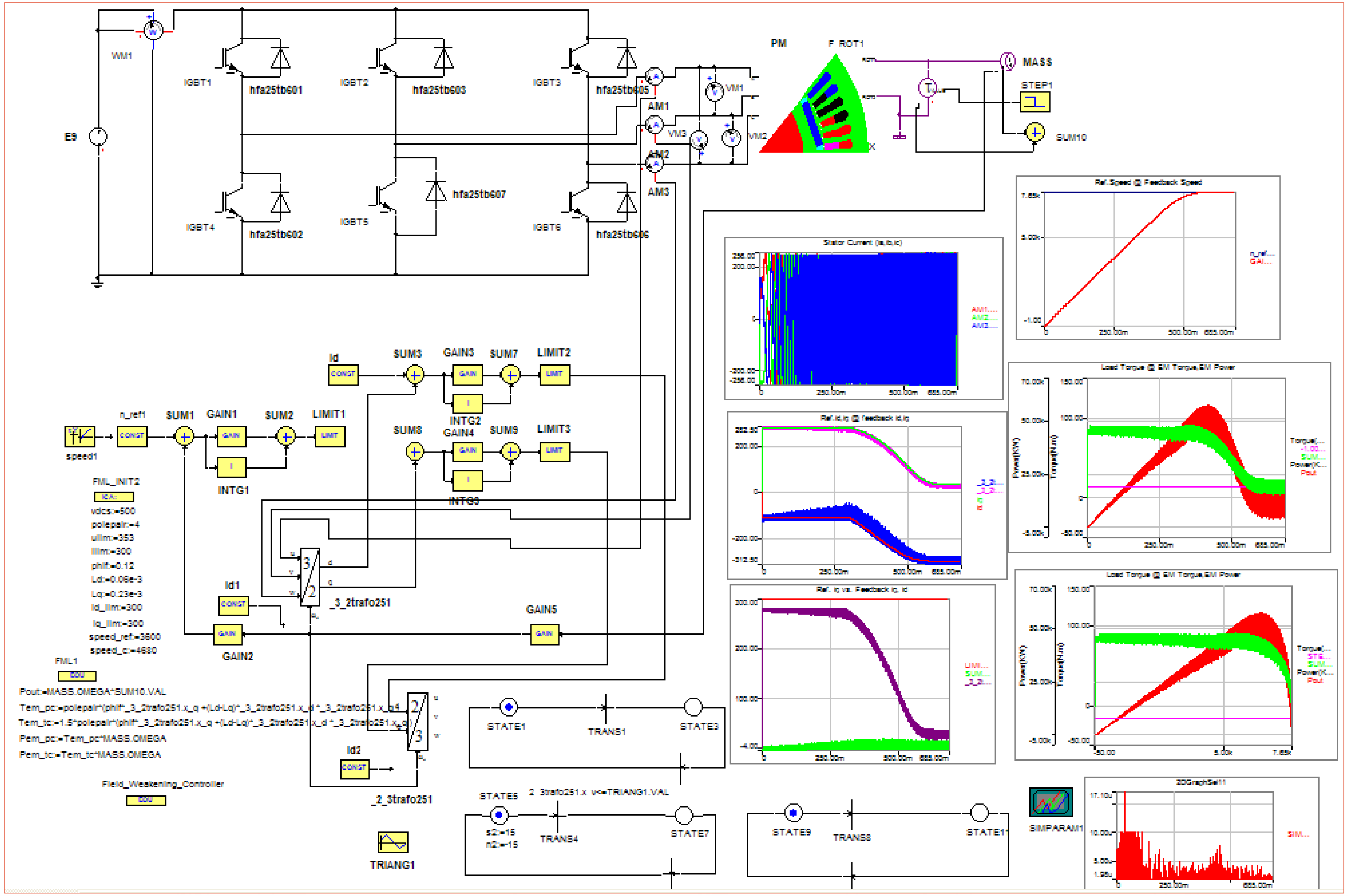


第三方工具/Simulink

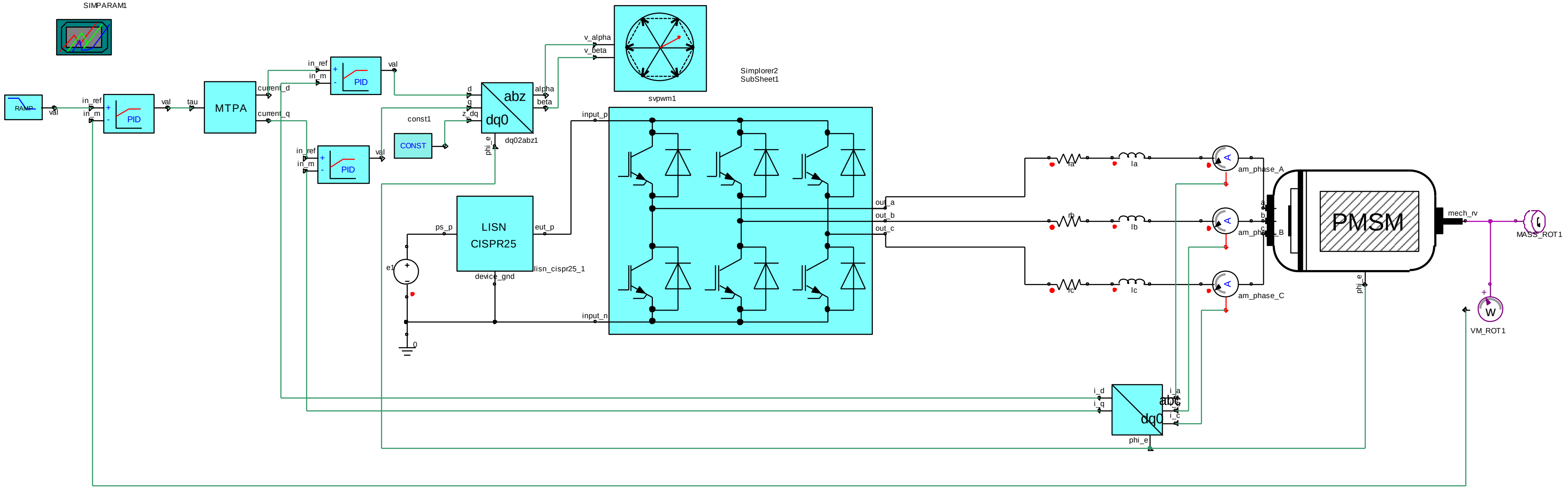


HPC Setting	Cores	Time/min	Time %
NON	1	347	100
TDM - Auto	2	361	104
TDM- Auto	4	312	90
TDM- Auto	8	149	43
TDM- Auto	16 （hyperthreading）	110	32
Regular HPC	16（hyperthreading)	360	104

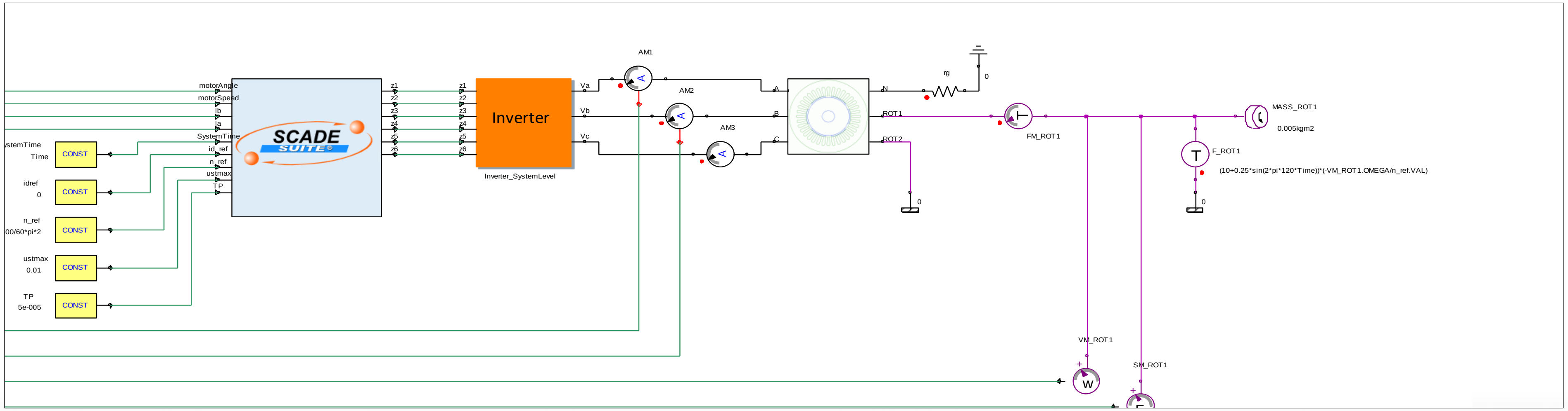
IPM弱磁控制调速



PMSM 高级控制仿真



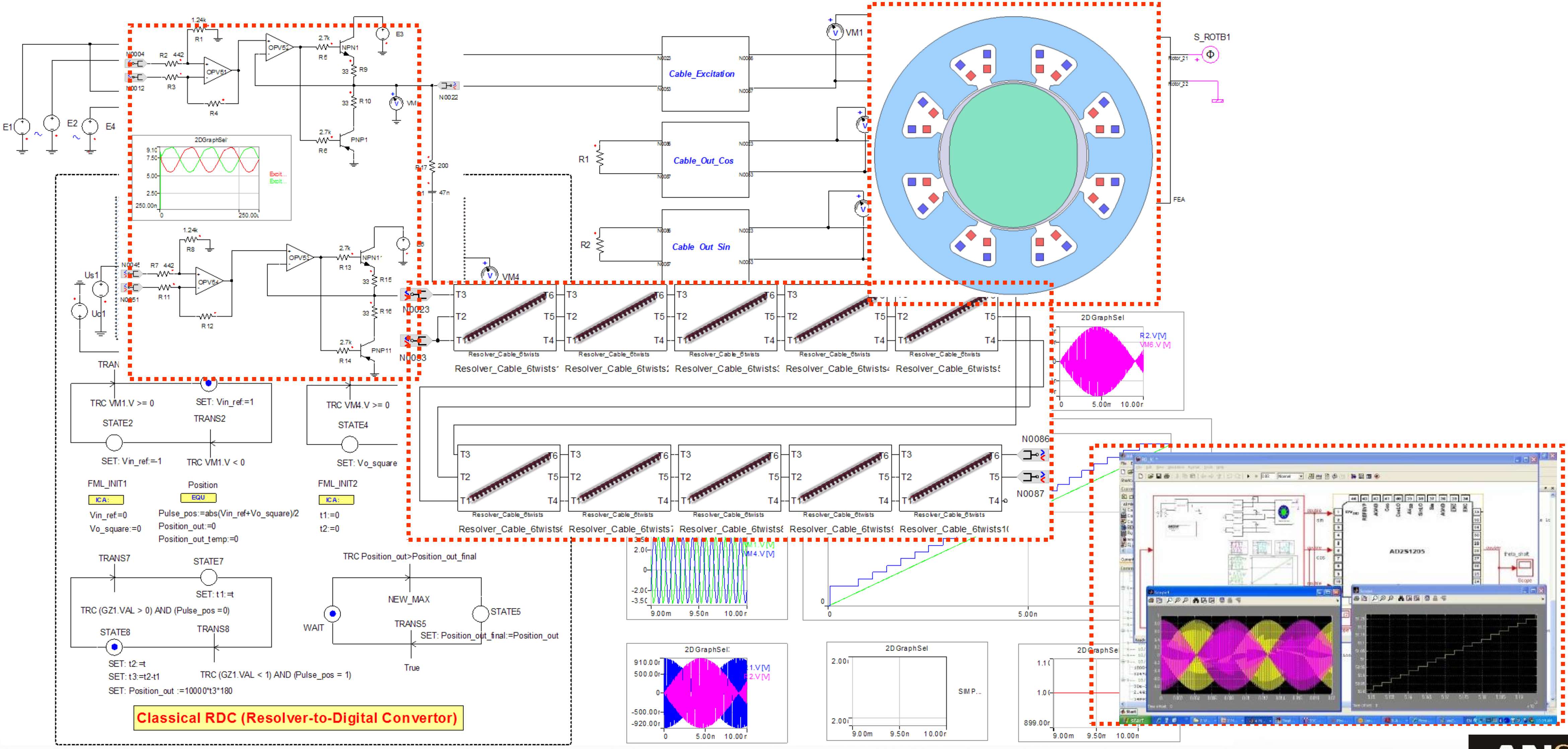
SIMPARAM1
RAMP
PID
MTPA
current_d
current_q
abz
dq0
dq02abz1
const1
CONST
svpwm1
v_alpha
v_beta
Simplorer2
SubSheet1
LISN
CISPR25
lisn_cispr25_1
PMSM
mech_rv
MASS_ROT1
VM_ROT1
am_phase_A
am_phase_C
abc
dq0



SCADE SUITE
Inverter
Inverter_SystemLevel
AM1
AM2
AM3
CONST
idref
0
n_ref
ustmax
0.01
TP
5e-005
MASS_ROT1
0.005kgm2
FM_ROT1
F_ROT1
(10+0.25*sin(2*pi*120*Time))*(-VM_ROT1.OMEGA/n_ref.VAL)
VM_ROT1
SM_ROT1

旋转变压器及其控制器仿真

详见IEEE VPPC2008论文



  June 25, 2018 ANSYS Public

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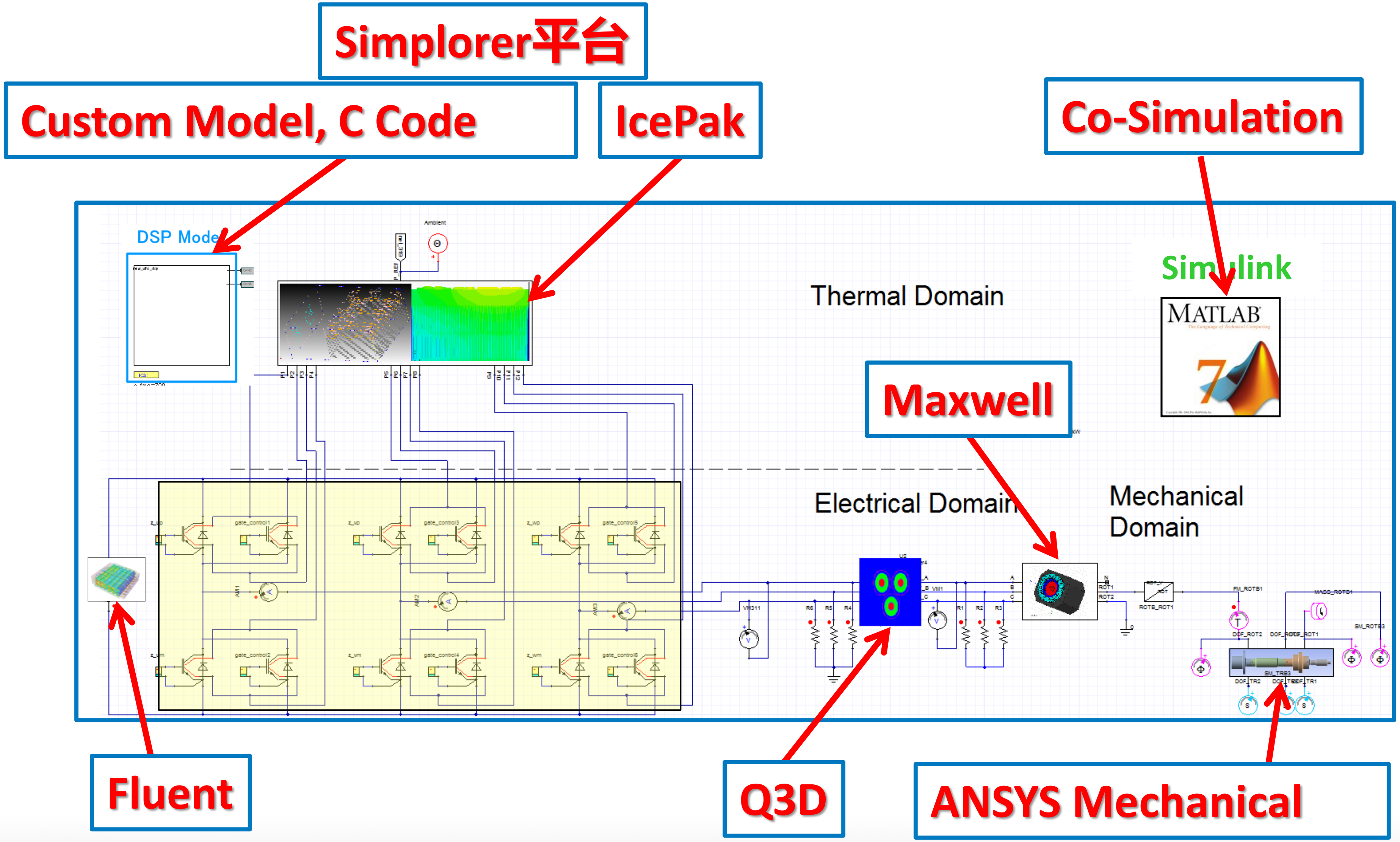
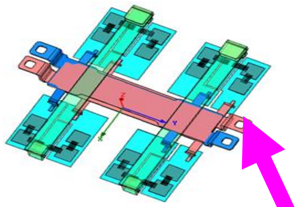
电动汽车驱动系统仿真

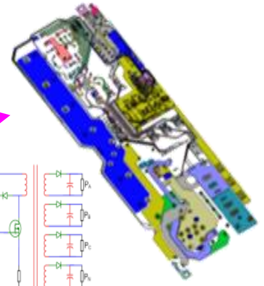


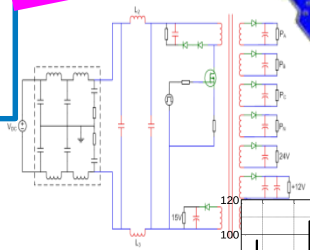
Simplorer平台
Custom Model, C Code
IcePak
Co-Simulation
DSP Model
Simulink
MATLAB
Thermal Domain
Maxwell
Electrical Domain
Mechanical Domain
Fluent
Q3D
ANSYS Mechanical

传导仿真分析流程



Q3D
互连通道寄生参数
线缆/PCB



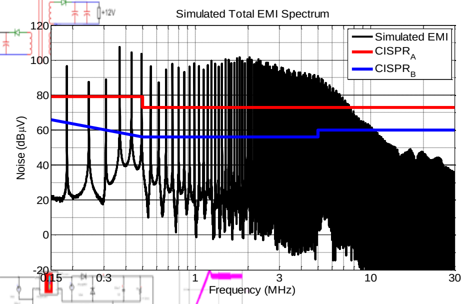


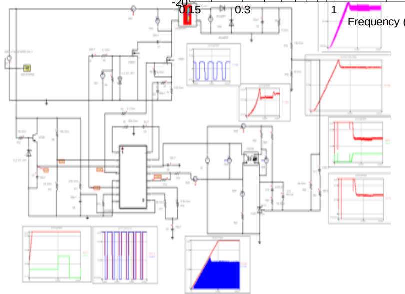
场路协同

PExprt
电感、变压器快速设计
和方案优选

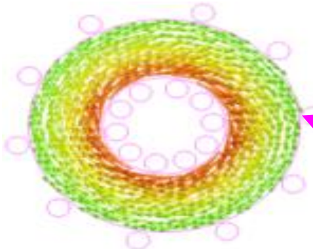
模型动态链接

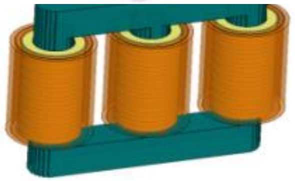
Simplorer
功率电子与电路系统
与传导干扰分析



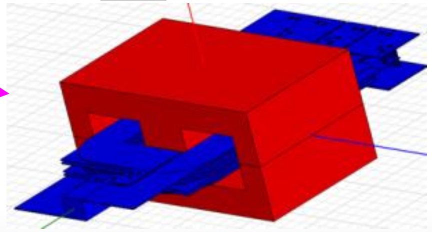


场路协同





Maxwell
电感、变压器精确电磁性能分析、
参数计算和降价模型提取

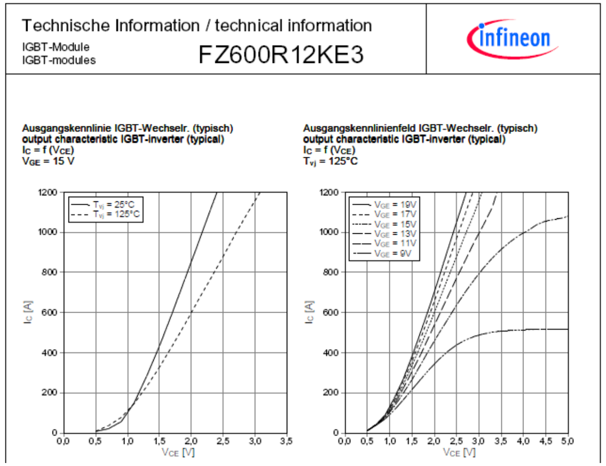


ANSYS

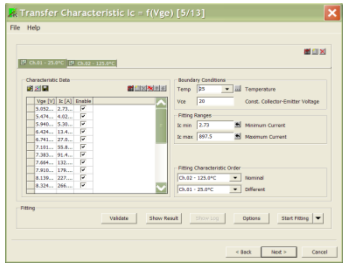
开关器件物理原型建模

专业IGBT开关器件物理原型建模工具，可生成包含MC特性的IGBT模型

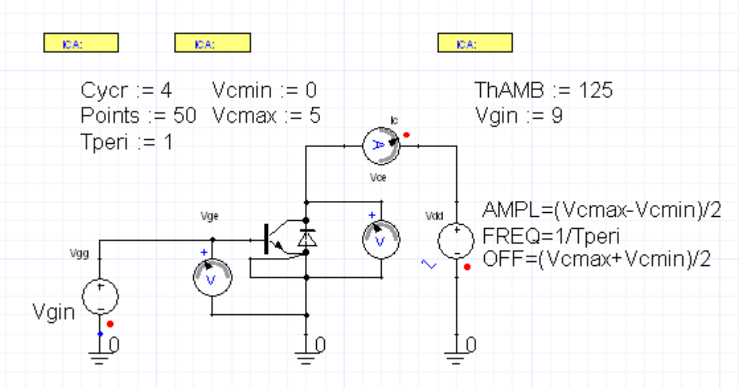
Infineon：FZ600R12KE3

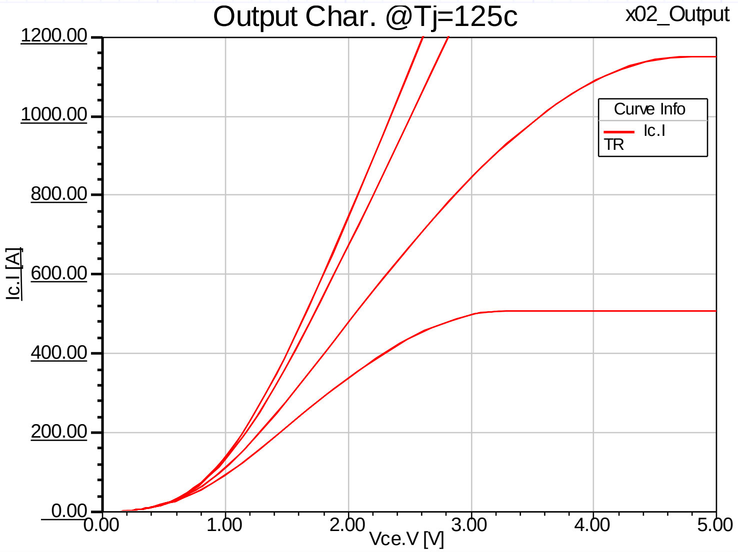


数据手册



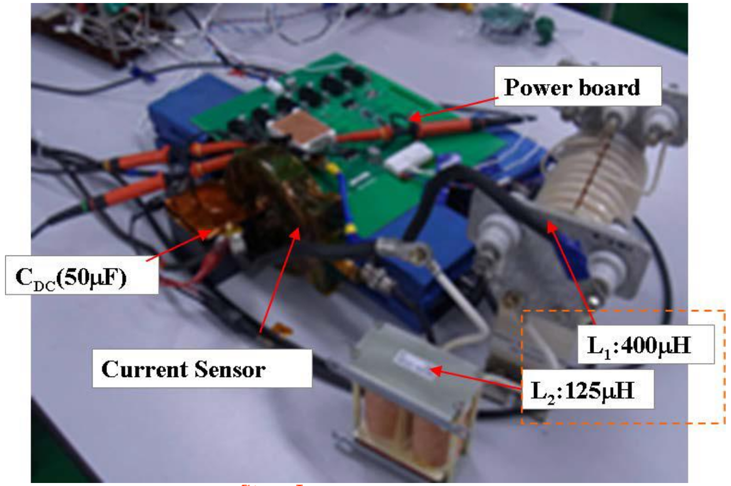
参数提取工具

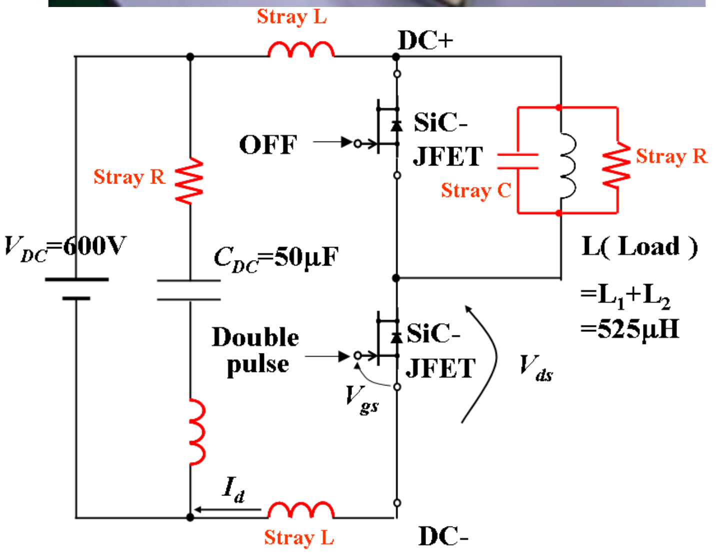


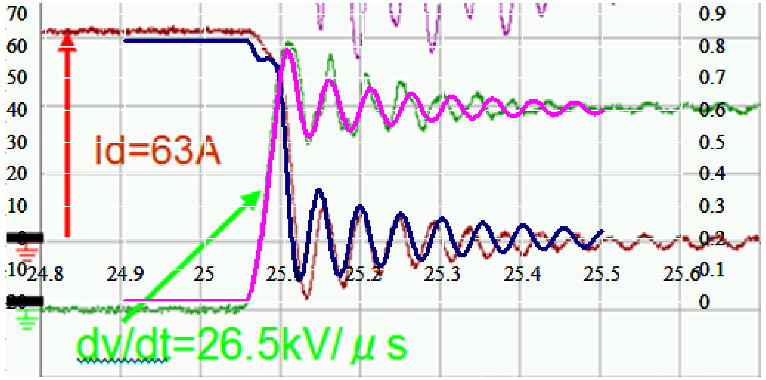


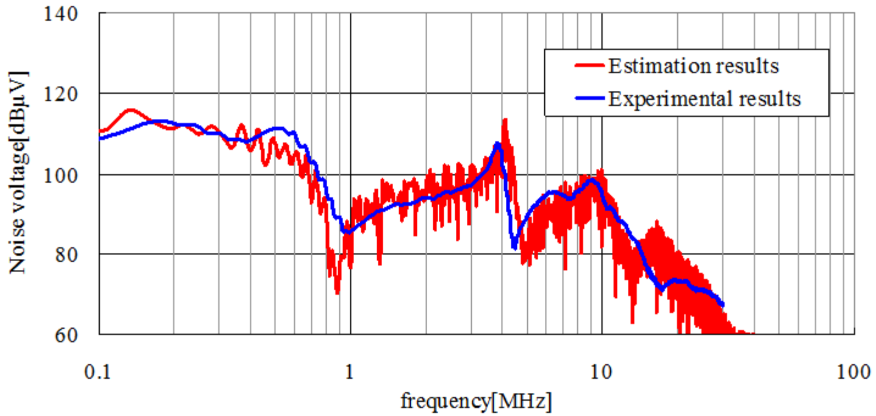
输出特性曲线Vce-Ic

开关模块建模





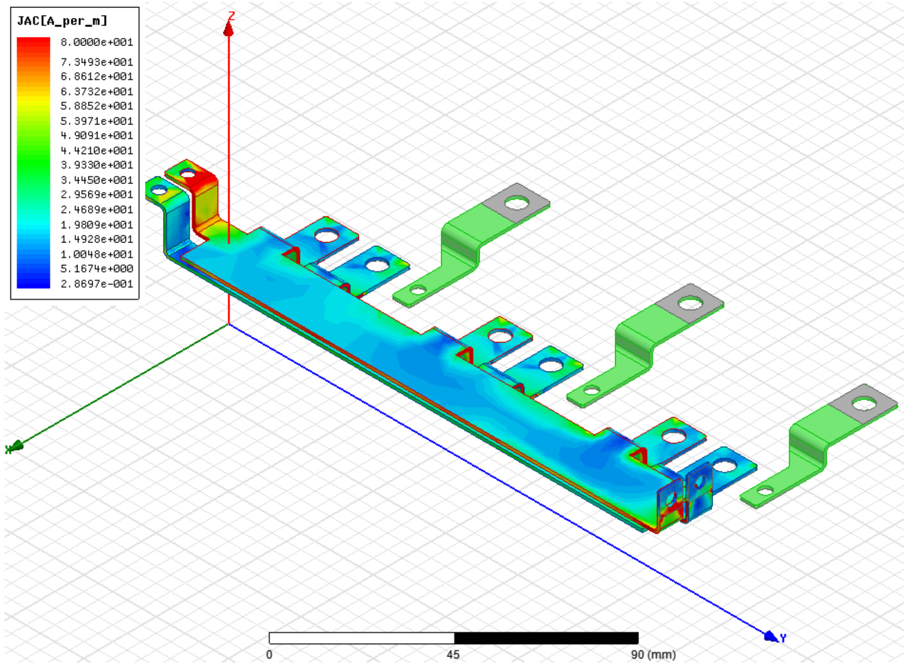


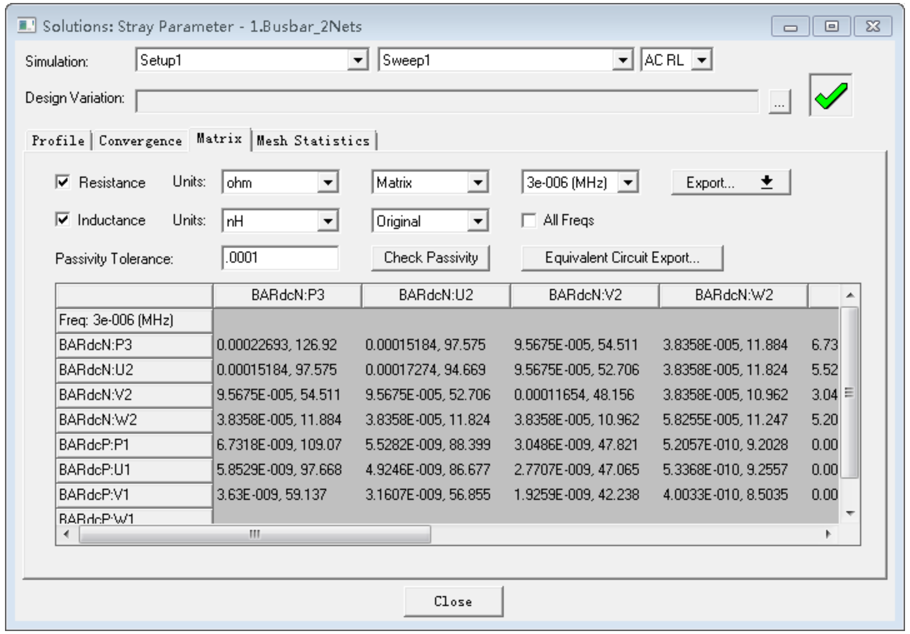


ANSYS Simplorer + Q3D

TOSHIBA
Leading Innovation

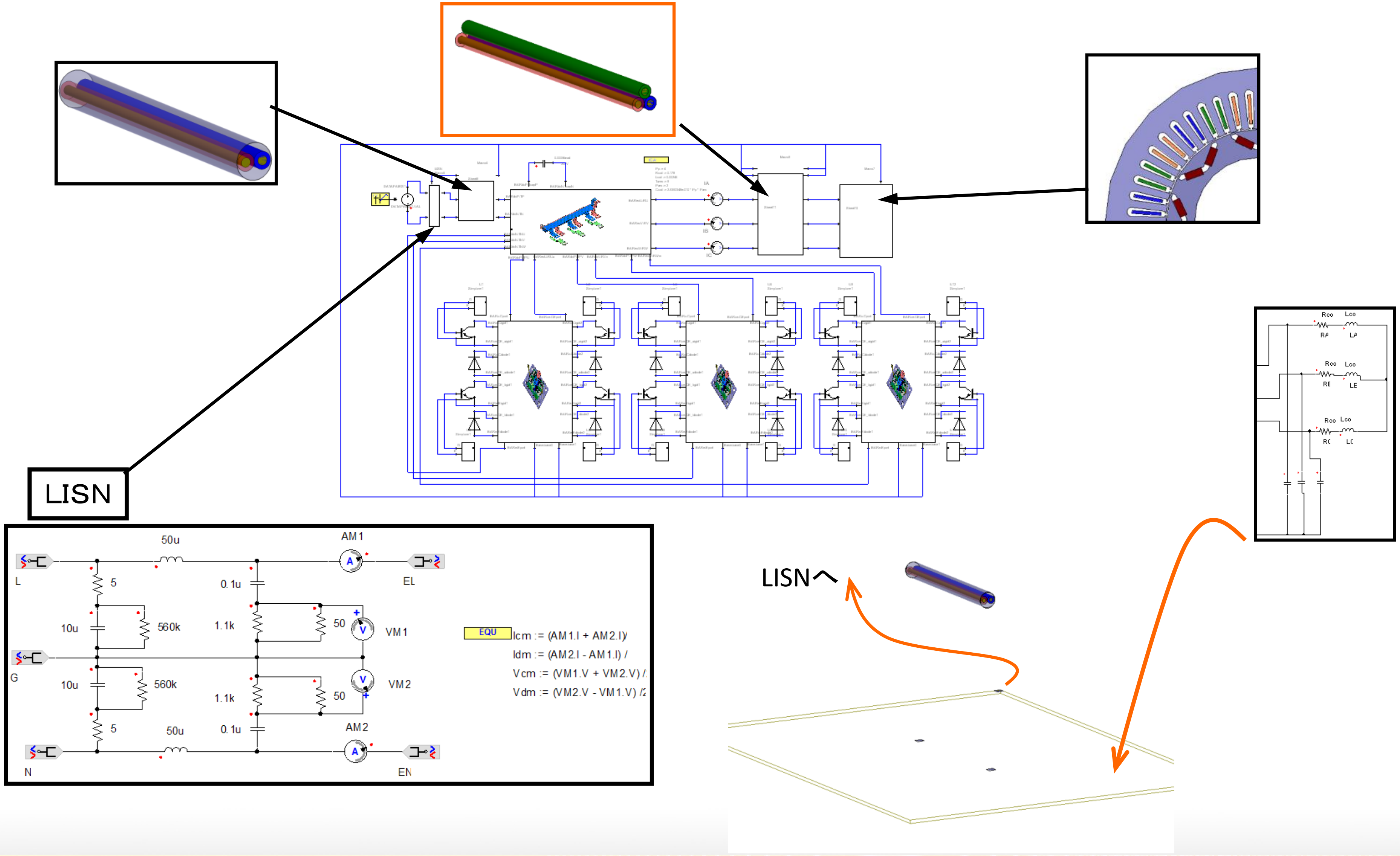
母排寄生参数提取



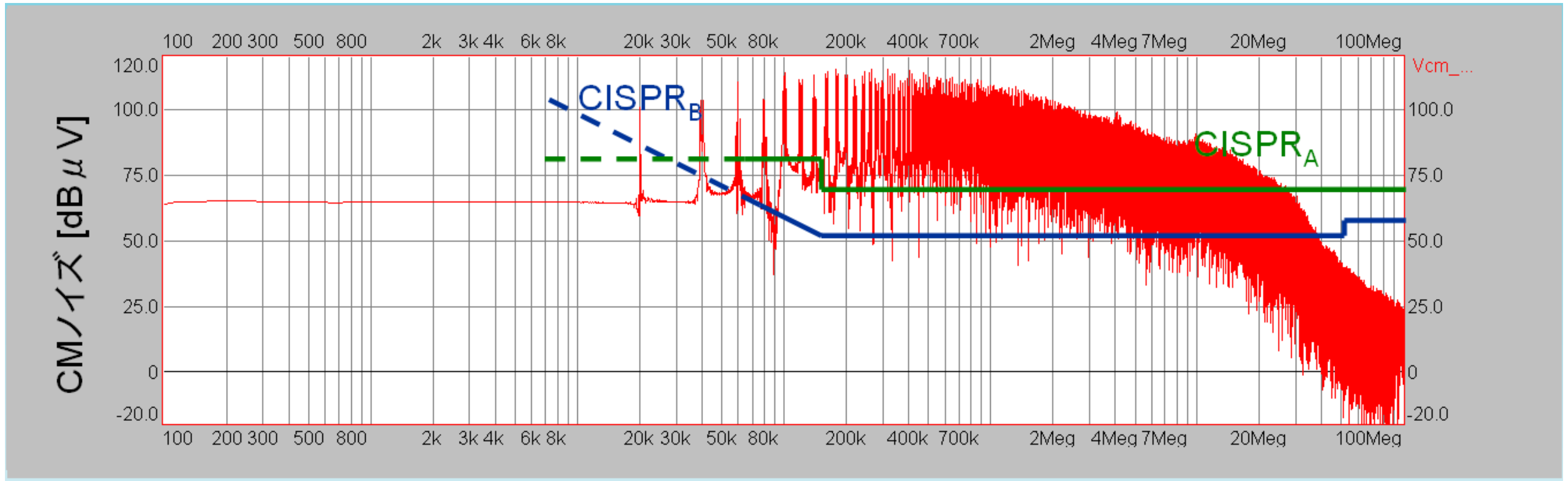


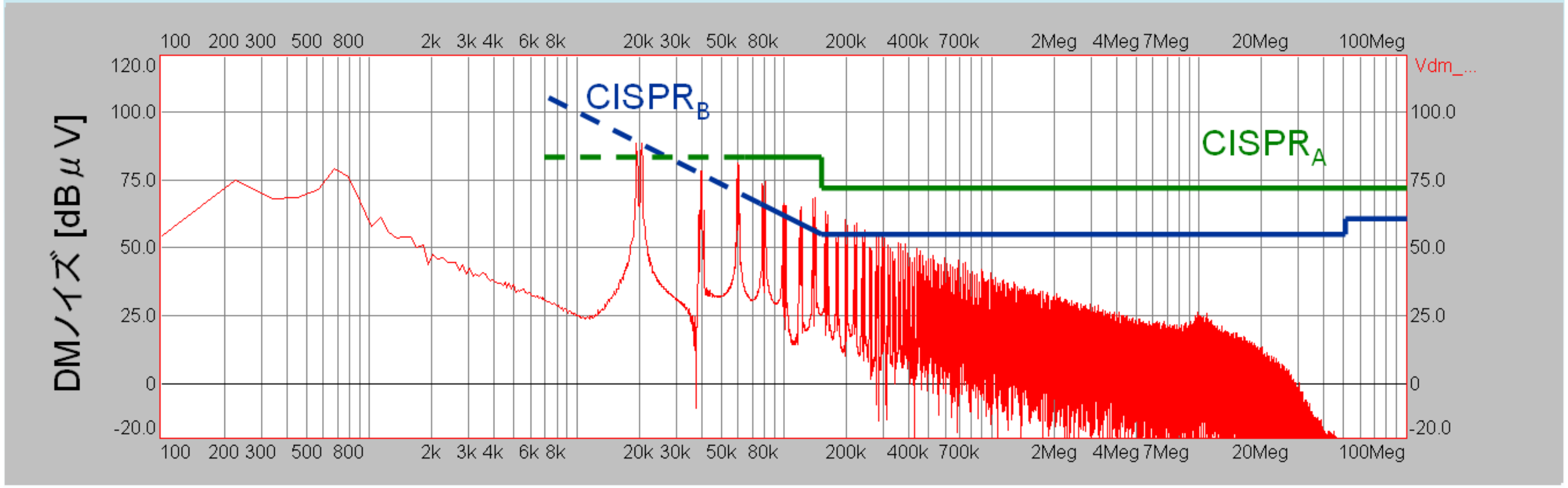
- 母排表面电流由于“集肤效应”与“邻近效应”的影响，明显分布不均匀；
- 通过Q3D可提取模型在不同频率下的RL/CG矩阵，替换掉理想模型的走线。

电机驱动系统传导干扰分析



电机驱动系统传导干扰分析





◆ グランドループを考慮すると CMノイズに大きな影響

交流讨论

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