



# ICSC 2017

CAE for virtual product

CAE for innovation

CAE for process transformation

IDAJ CAE Solution Conference

## 新能源汽车电机多物理场耦合综合仿真与最佳实践

IDAJ中国 技术部

唐连伟

## 提纲

- ANSYS电机多物理场耦合仿真解决方案
  - 电机集成CAE设计流程
  - 多物理场求解功能
  - 应用
  
- 典型案例(Lucid电机)及最佳实践
  - 模型介绍及仿真方案
  - 电-磁分析 (Electro-Magnetic Analysis)
  - 热分析 (Thermal Analysis)
  - 结构分析 (Mechanical Analysis)
  
- 总结及致谢

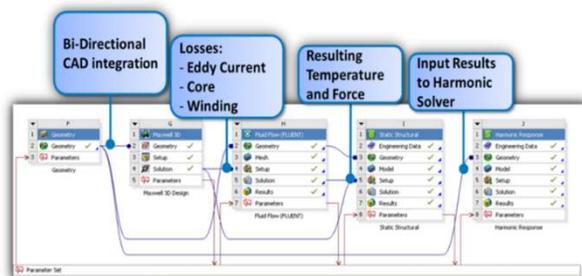
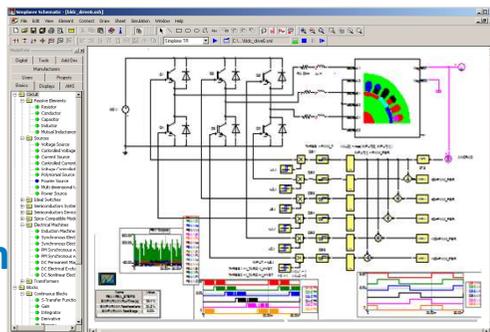
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# 电机集成CAE设计流程

## ■ ANSYS电机设计中的多物理场系统

0-D System



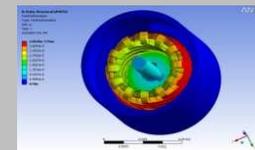
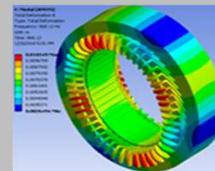
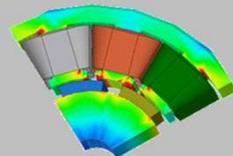
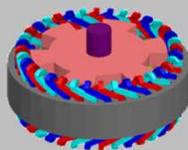
Workbench System

Sizing Tools

Electromagnetics

Thermal

Structural



Initial Design

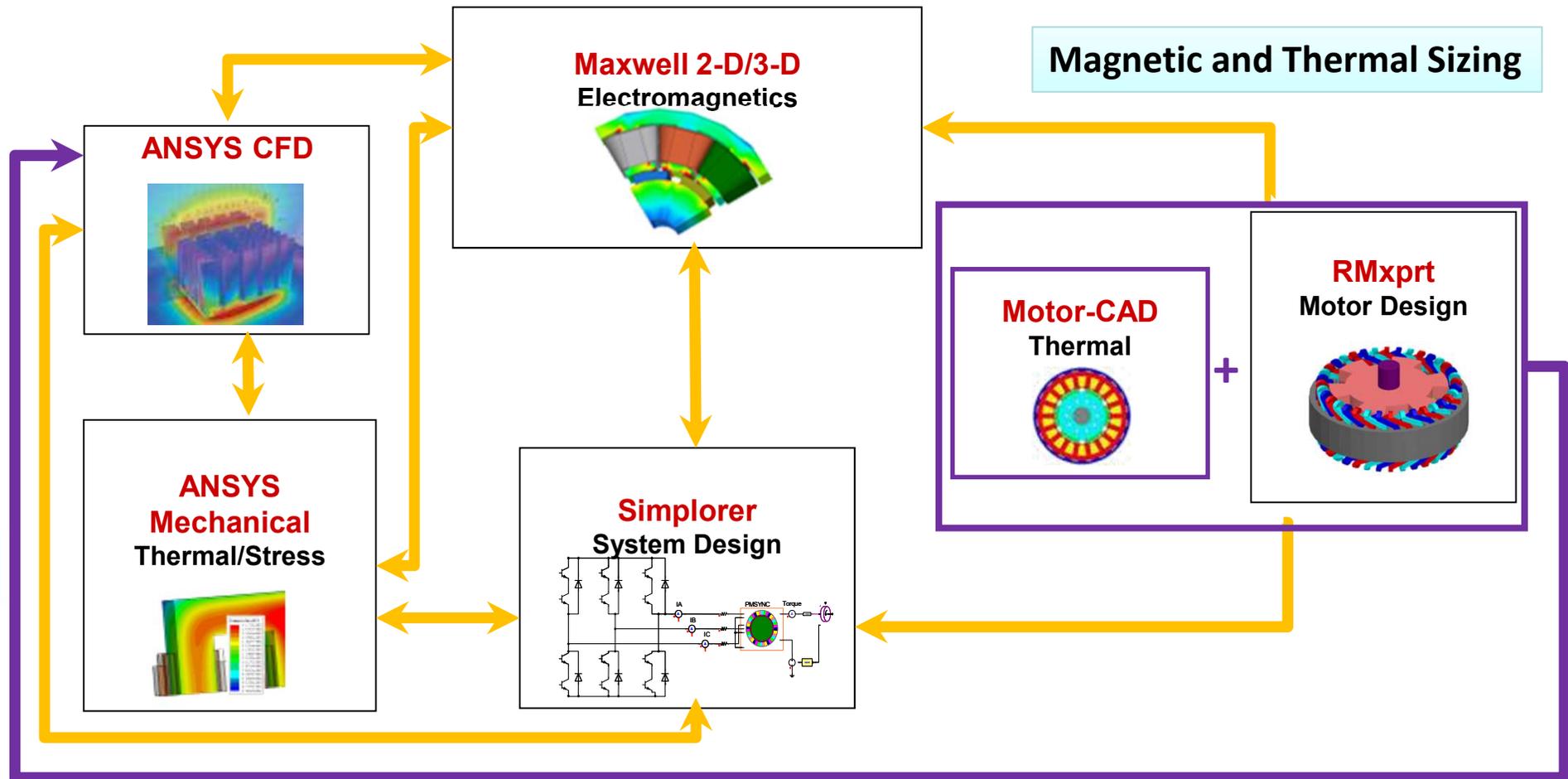
Electromagnetic Components

Temperature

Stress/Acoustic

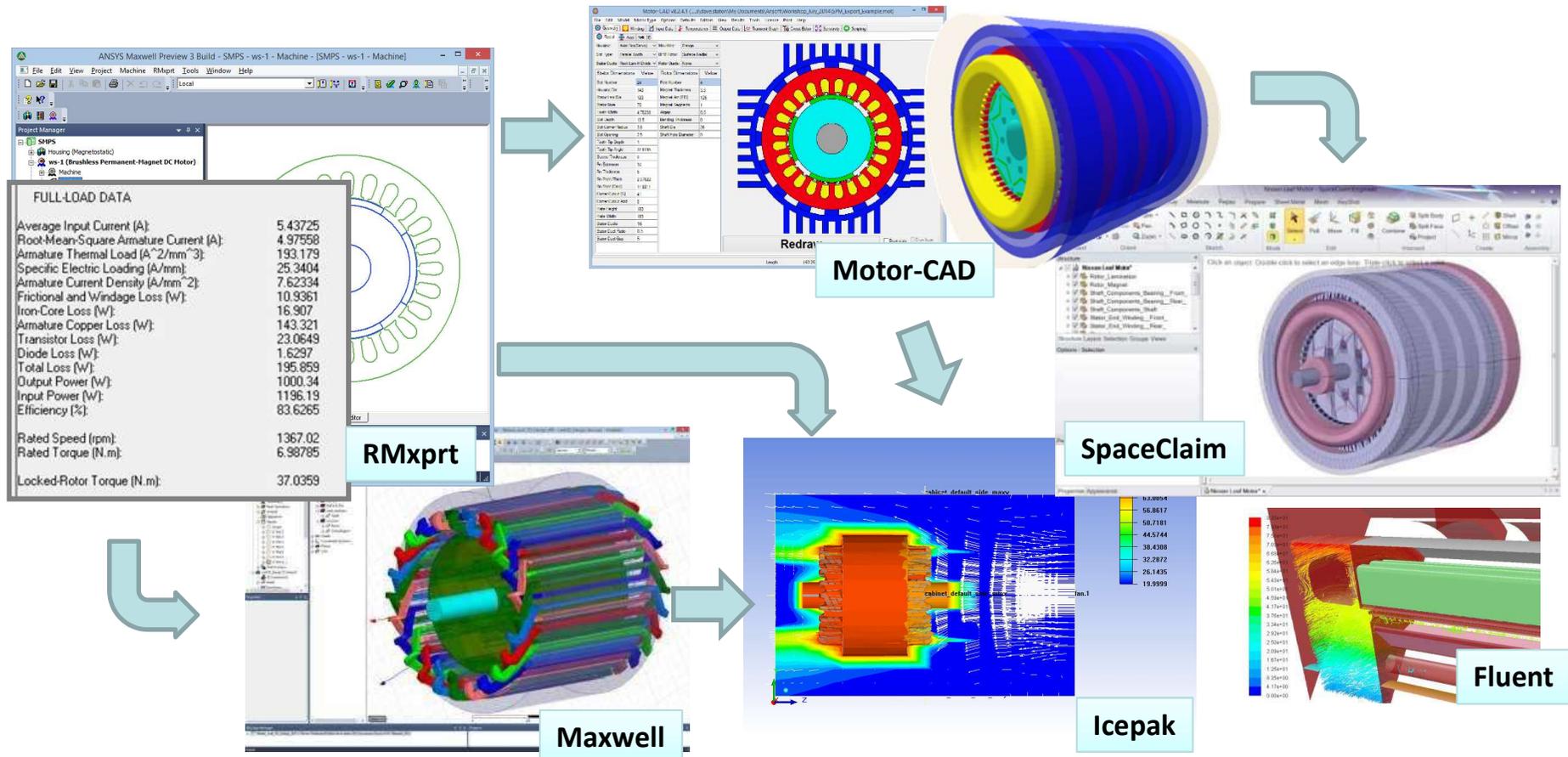
## 电机集成CAE设计流程

### ■ 初始磁和热的选型(Initial Magnet and Thermal Sizing)



# 电机集成CAE设计流程

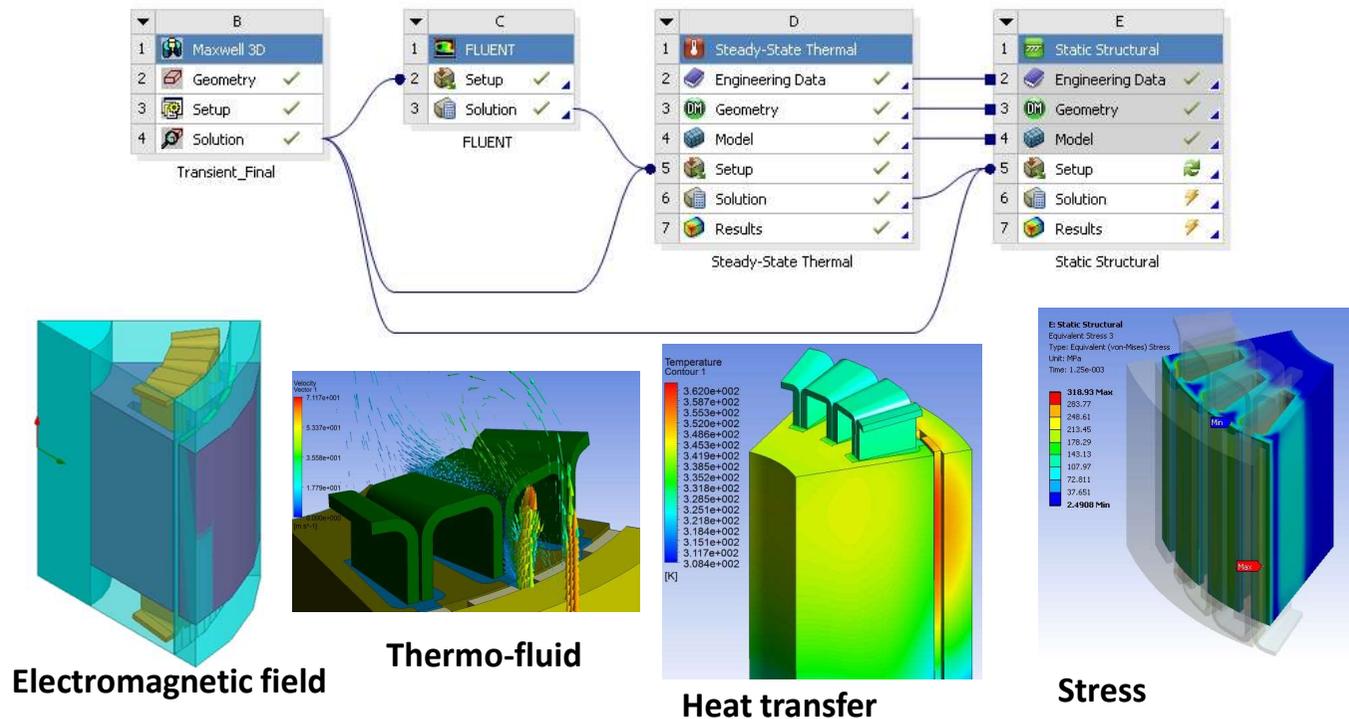
## ANSYS工具同Motor-CAD的集成



## 电机集成CAE设计流程

### ■ ANSYS Workbench多物理场仿真

➤ 从电磁场到传热、冷却及应力



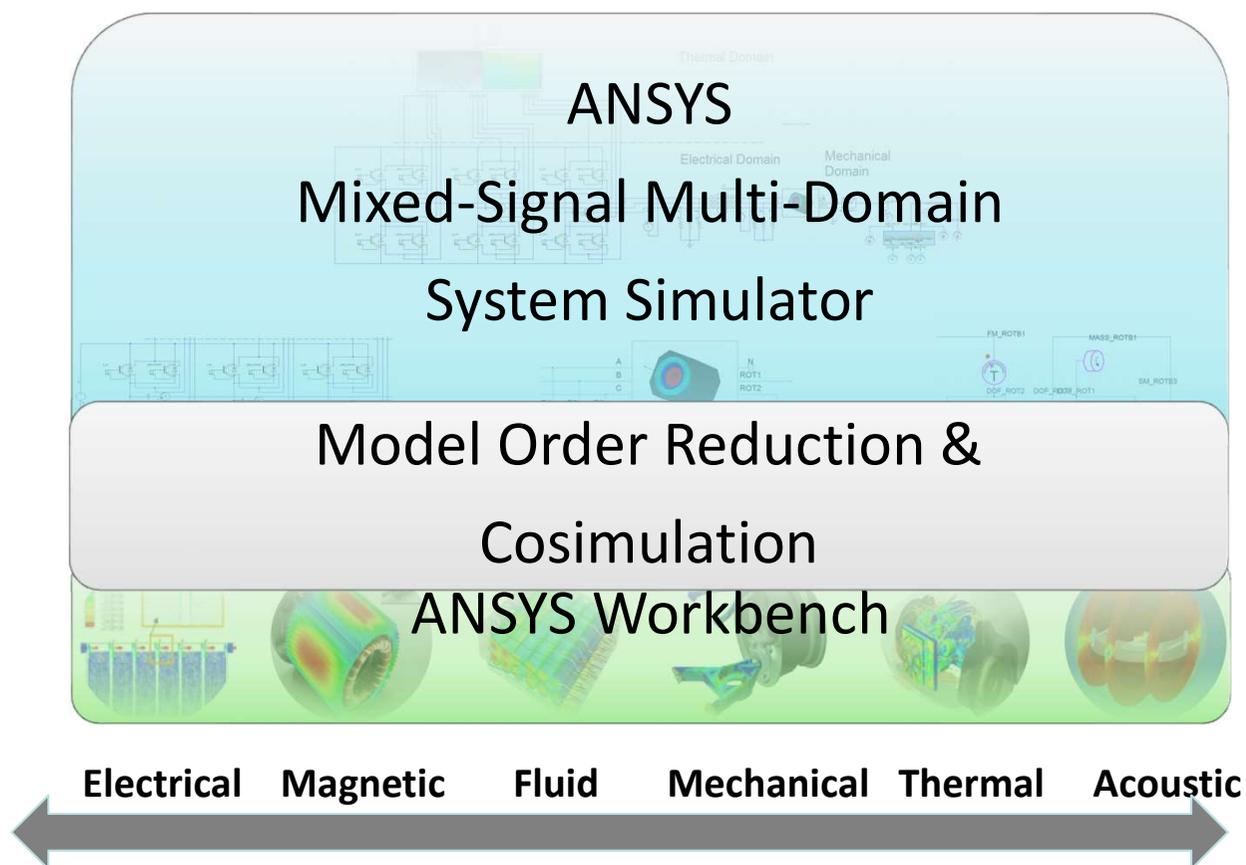
## 电机集成CAE设计流程

### ■ ANSYS 综合解决方案

系统级

电路

部件级

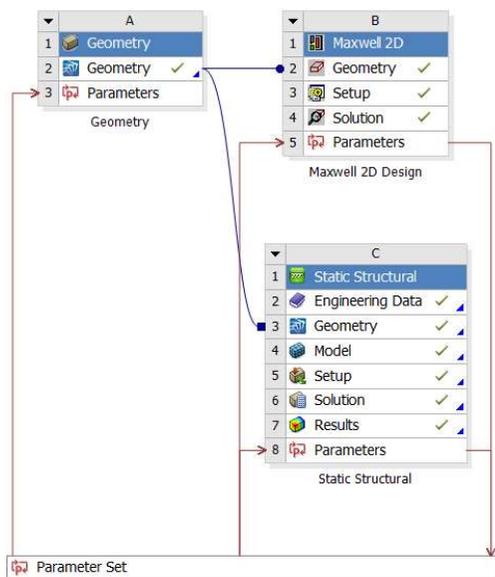


## 多物理场求解功能

### ■ ANSYS Workbench中求解若干物理场(Multiple Physics) 或者多物理场(Multi-Physics)

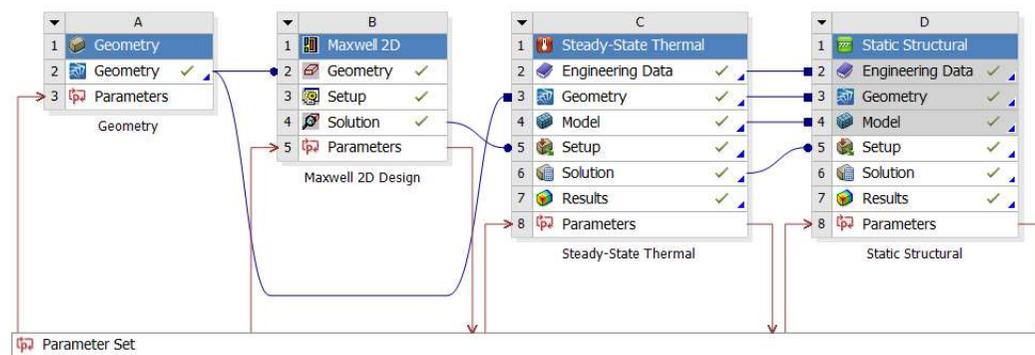
#### Multiple Physics

- 优化单个电机几何形状以满足多物理场要求.



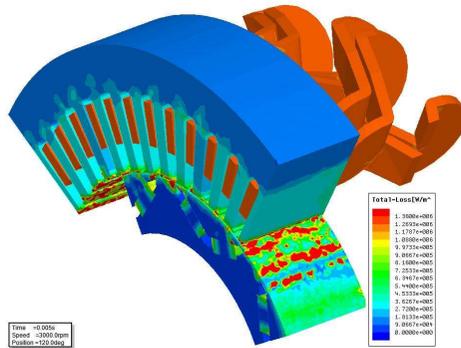
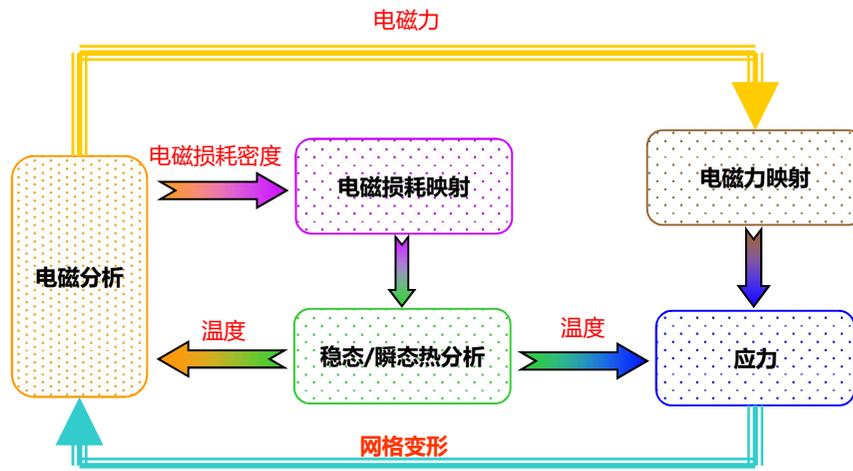
#### Multi-Physics

- 将电机作为一个物理场相互作用的系统来研究。

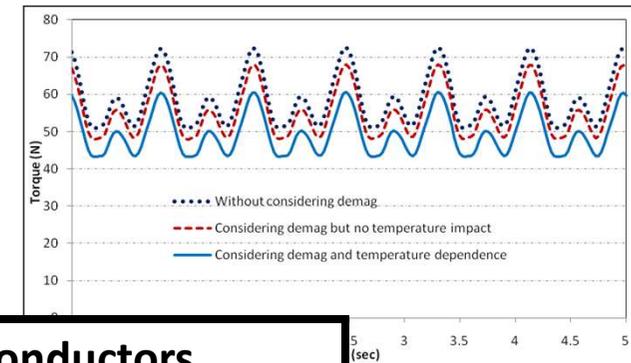
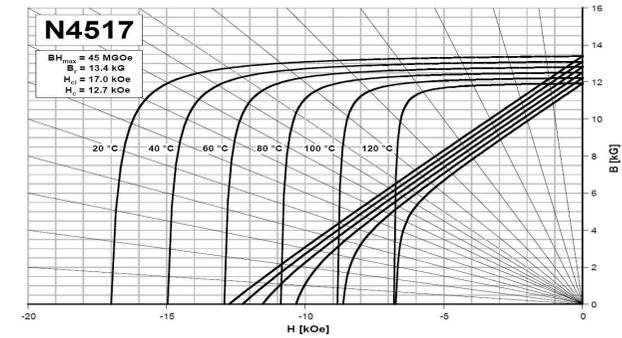
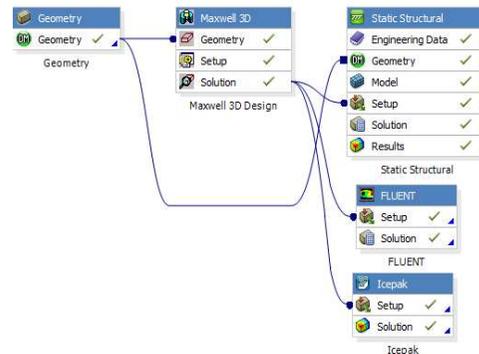


# 多物理场求解功能

## ■ 单向(One-way)及双向(Two-way)映射



电磁损耗分布



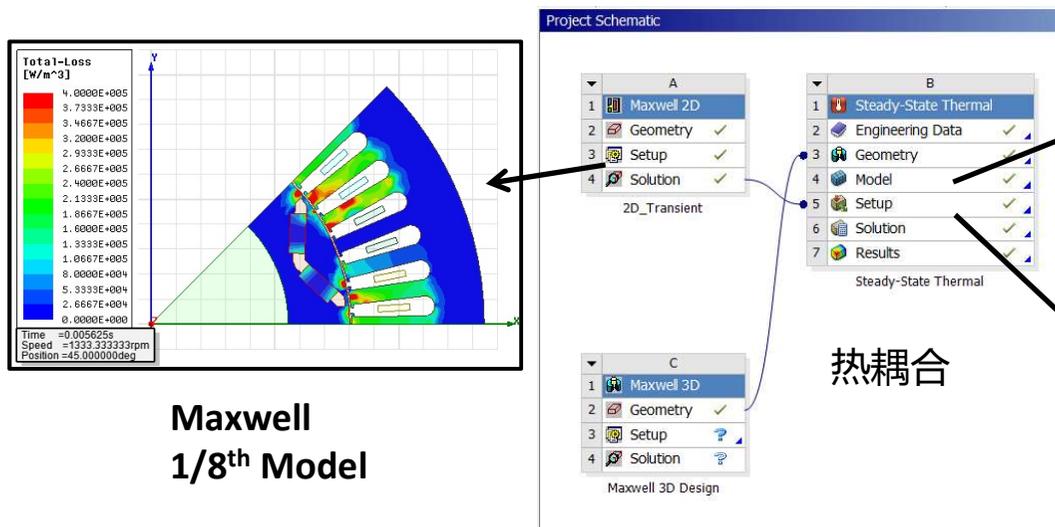
**Conductors**

$$\sigma = \sigma_{ref} / (1 + \alpha \cdot \Delta T)$$

# 多物理场求解功能

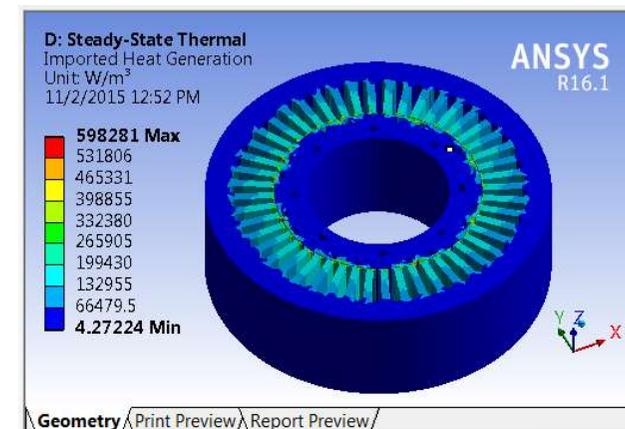
## ■ ANSYS Workbench物理场耦合

在Maxwell中仅对必须的对象建模



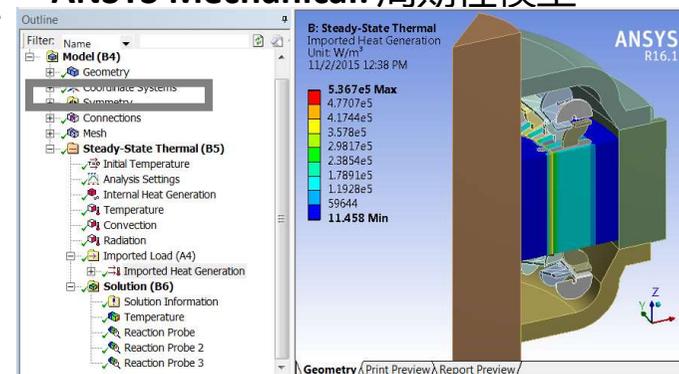
Maxwell  
1/8<sup>th</sup> Model

- 在Maxwell中可以根据对称设置将力和损耗分布进行复制
- 适用于各种求解器及其相互耦合



ANSYS Mechanical: 全模型  
或

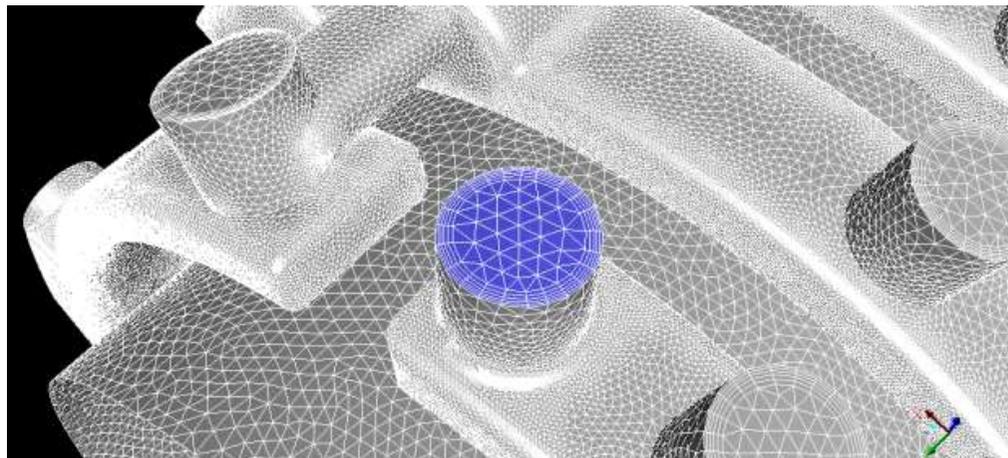
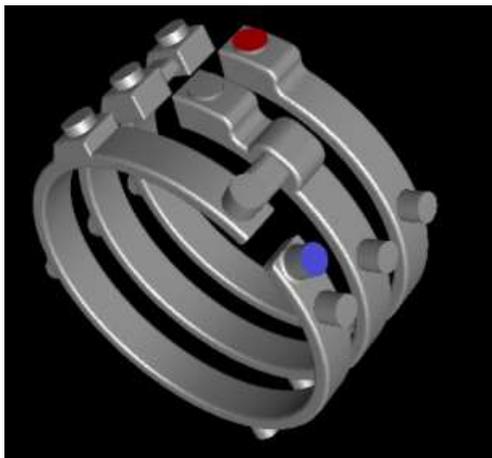
ANSYS Mechanical: 周期性模型



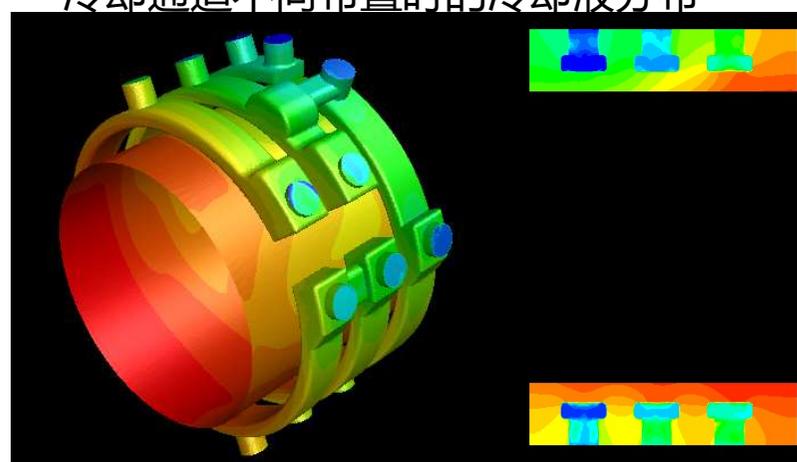
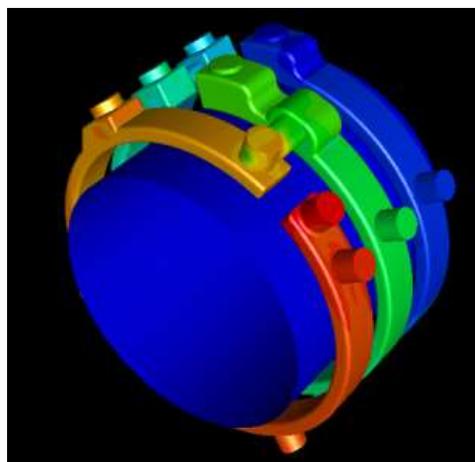
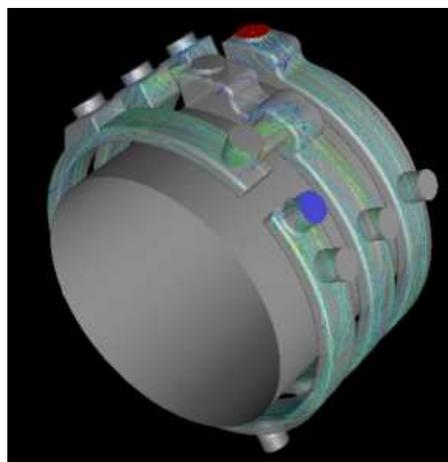
# 应用

## ■ 水冷电机水套模拟

Maxwell3D → Fluent

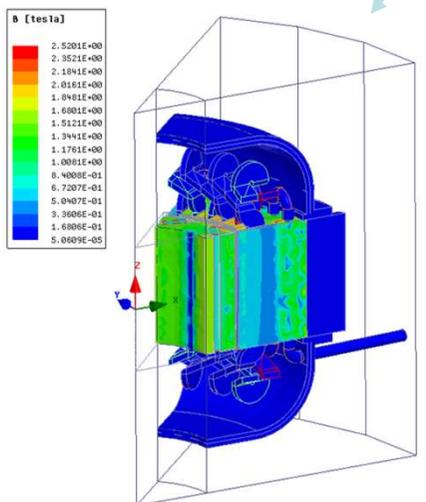
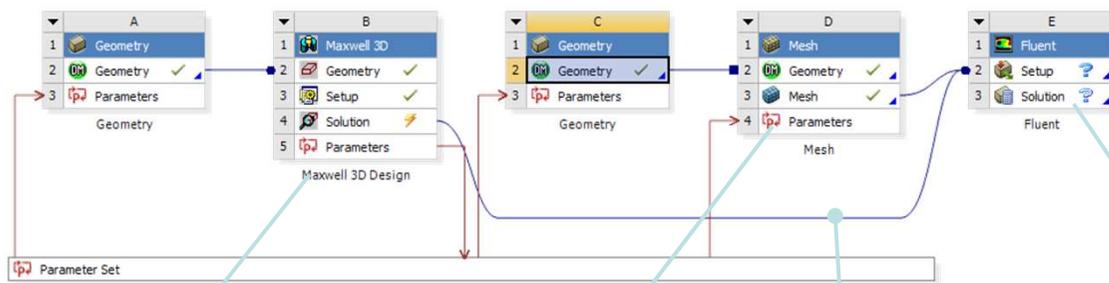


冷却通道不同布置时的冷却液分布

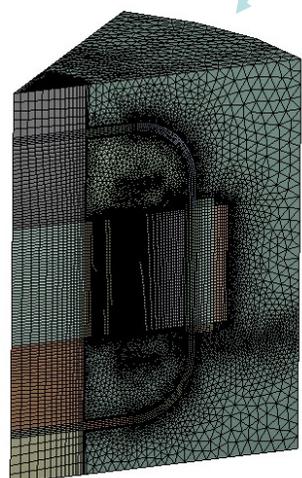


# 应用

## 空冷电机

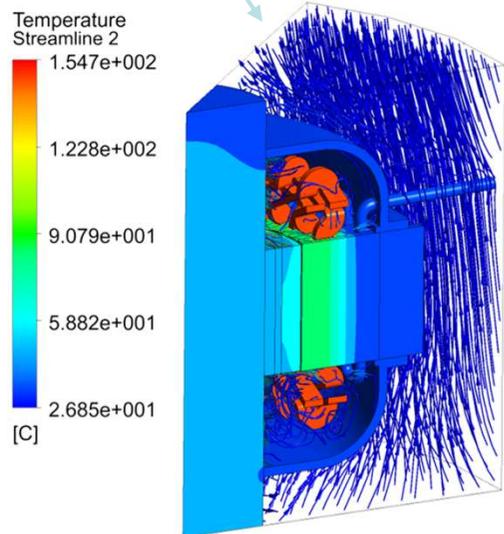


非稳态电磁计算获得损耗



流体域单独生成网格

传递电磁损耗数据并自动映射



通过CFD计算流场/温度场



**应用**

■ ANSYS电机设计多物理场仿真

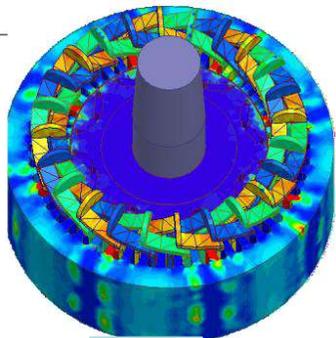
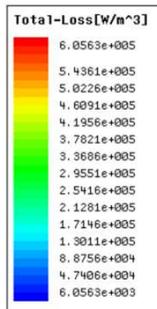
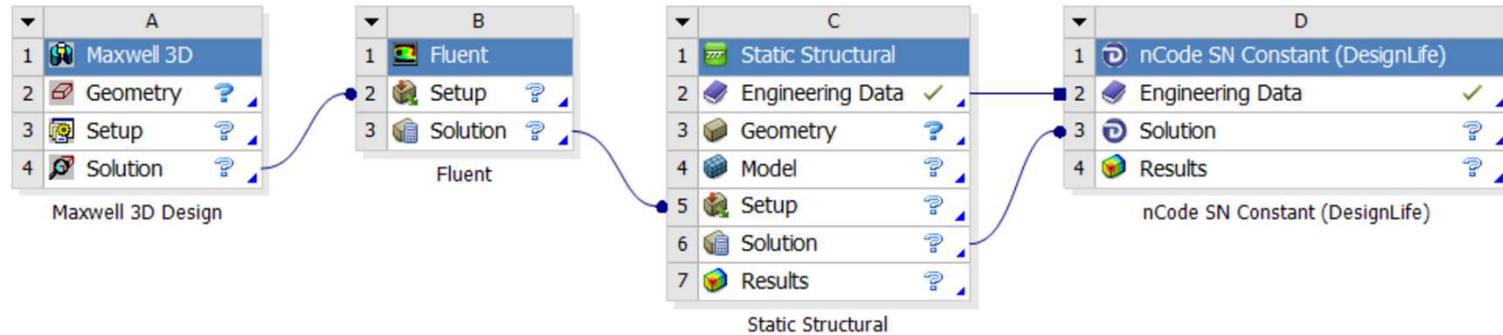
Maxwell3D

Fluent

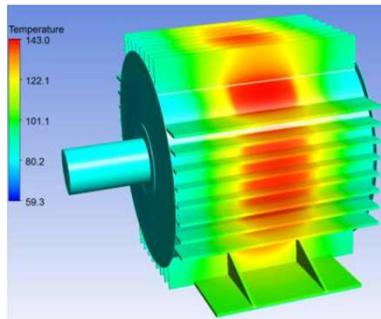
ANSYS Mechanical

nCode

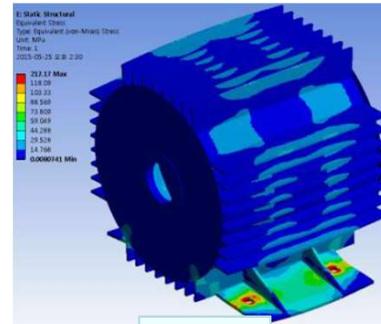
**Electric – Fluid – Mechanical (Thermal Stress) - Fatigue**



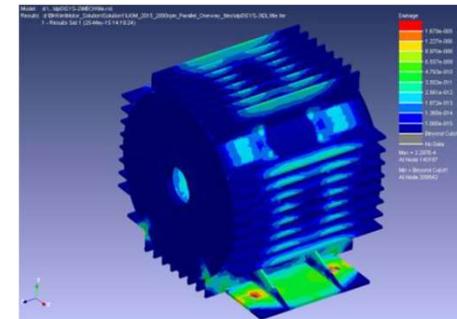
Loss



Temperature



Stress

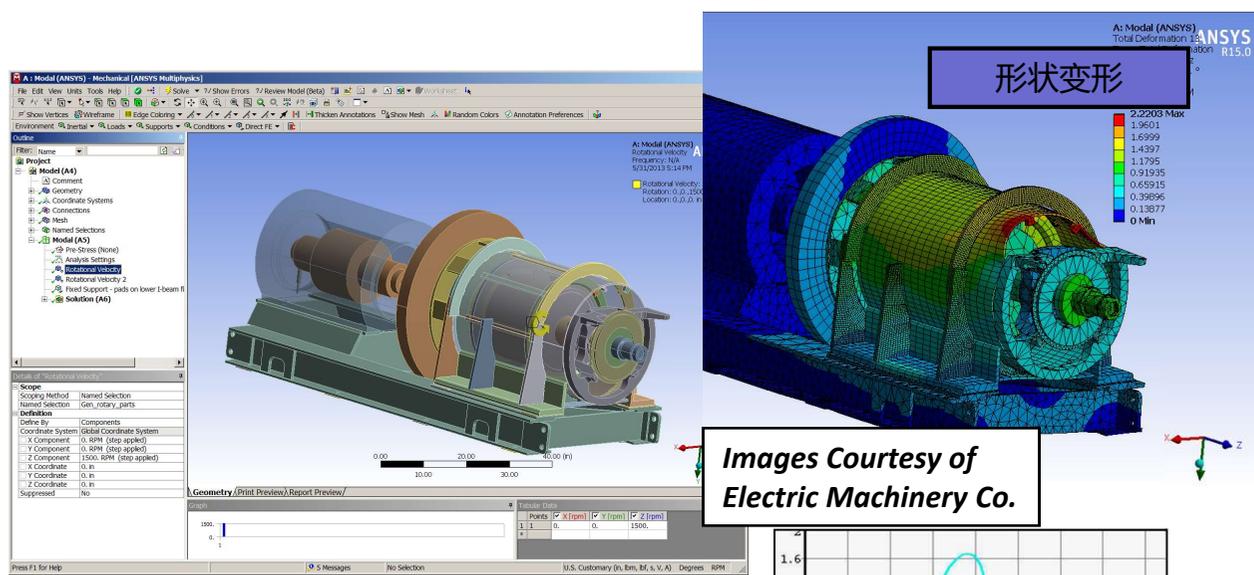


Damage

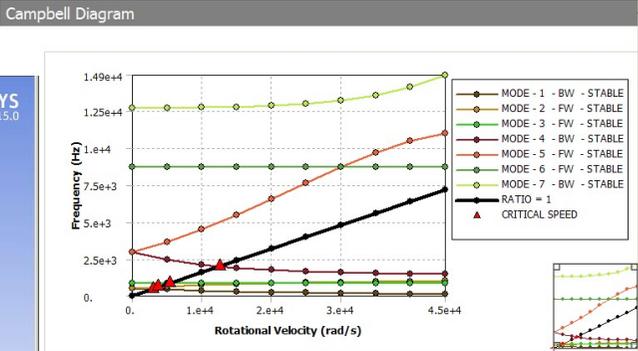
应用

■ 结构分析 – 转子动力学

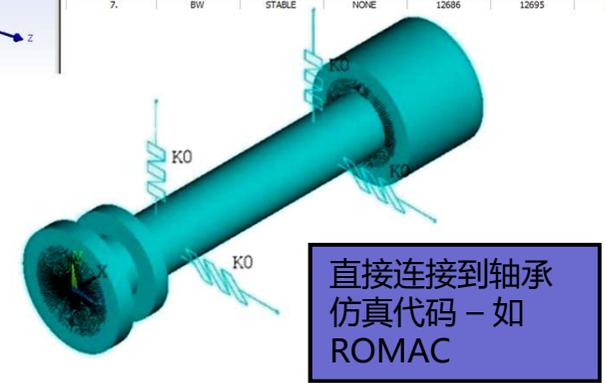
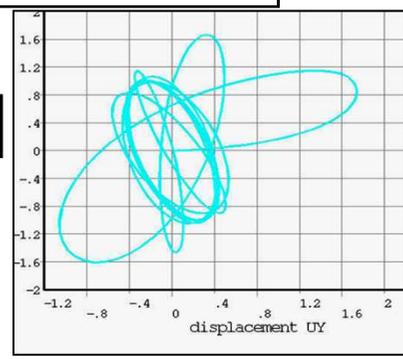
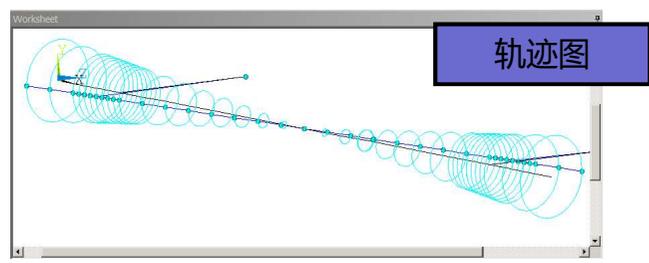
ANSYS Mechanical



Images Courtesy of Electric Machinery Co.



Mode	Whirl Direction	Mode Stability	Critical Speed	0	5000	10000
1.	BW	STABLE	2955.5	526.27	431.73	351.36
2.	FW	STABLE	3774.2	526.48	624.79	714.91
3.	FW	STABLE	5381.8	856.54	856.54	856.54
4.	BW	STABLE	12605	2933.6	2447.1	2118.3
5.	FW	STABLE	NONE	2942.4	3620.9	4482.6
6.	FW	STABLE	NONE	8716.7	8716.7	8716.7
7.	BW	STABLE	NONE	12686	12695	12721



## 应用

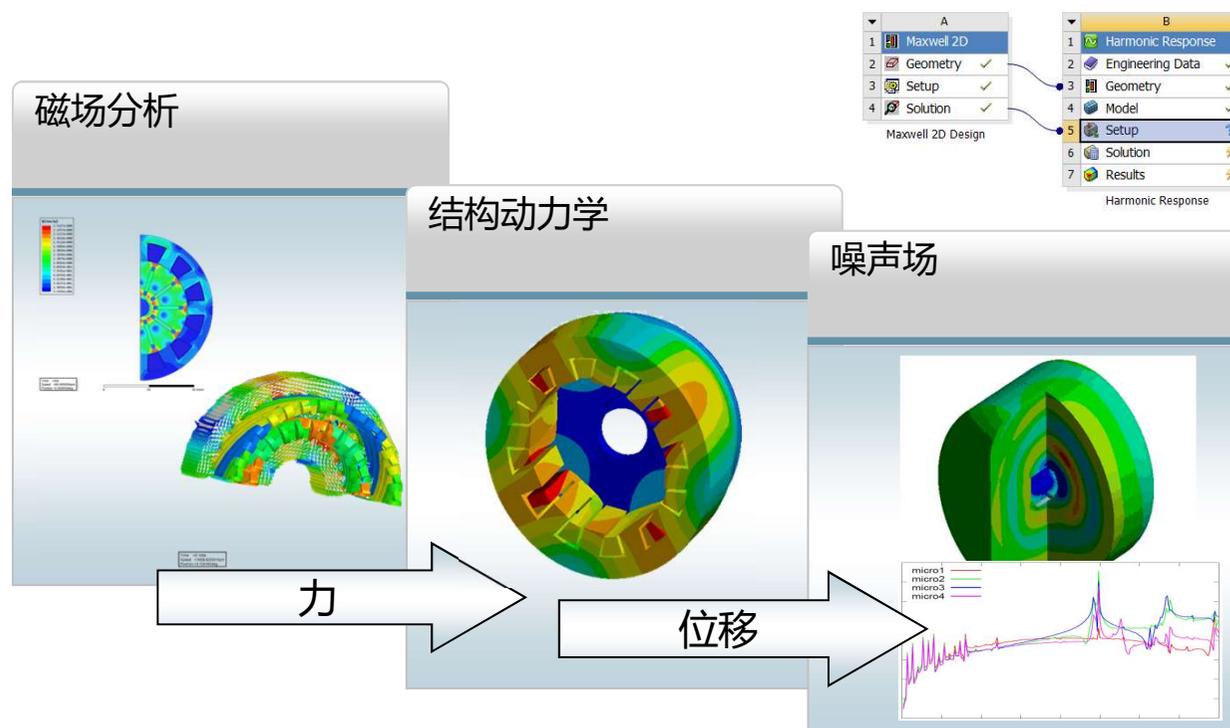
## ■ 电机噪声分析 - NVH

Maxwell

+

ANSYS Mechanical

瞬态Maxwell 2D/3D单向耦合Harmonic stress



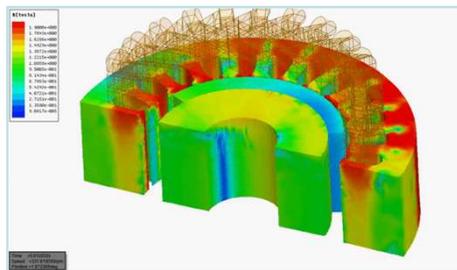
# Harmonic Coupling

Maxwell

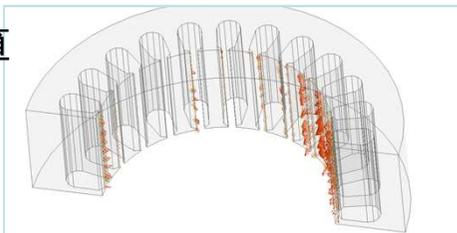
+

ANSYS Mechanical

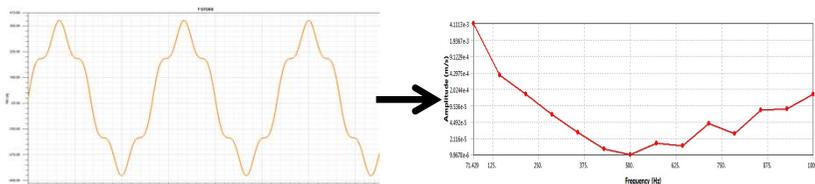
1 磁场计算



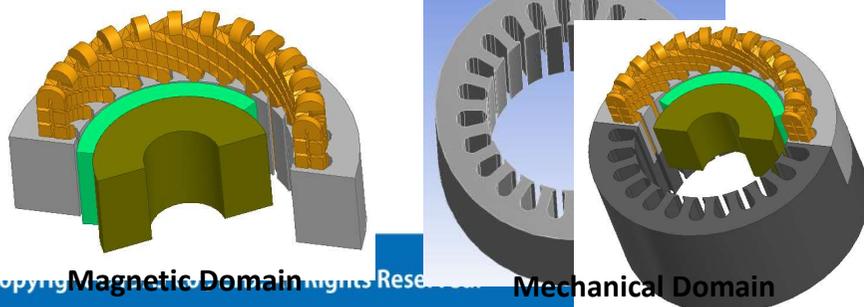
2 电磁力计算



3 依次对各个对象进行FFT计算



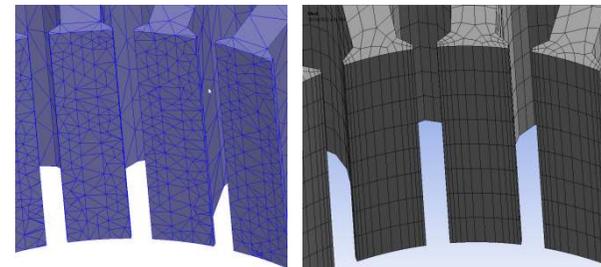
4 耦合两种几何形状(包括对称模型)



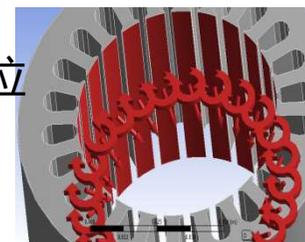
Copying Magnetic Domain

Mechanical Domain

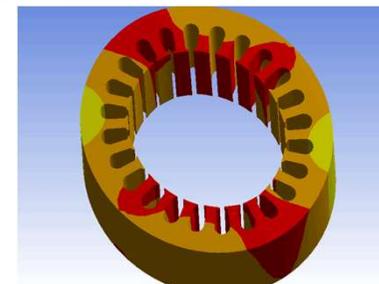
5 耦合两种网格拓扑



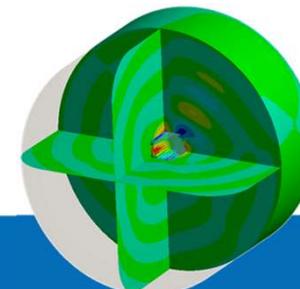
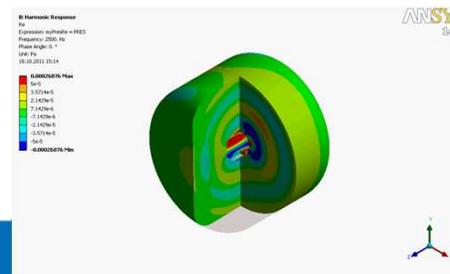
6 自动应用振幅和相位



7 获得Harmonic Response



8 计算声音传播



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## 总结及致谢

- 本报告介绍了ANSYS产品在电机仿真方面的多物理场耦合解决方案，IDAJ在CAE领域深耕多年，一直致力于为国内外客户提供相关仿真咨询服务，积累了大量经验，欢迎大家交流沟通，期待和大家的合作。
- 感谢ANSYS中国马世虎、ANSYS北美胡晓博士提供案例资料，文中Lucid案例引自《*Multiphysics Simulation Driven Design of an Induction Machine and an Inverter for Electric Vehicles*》。

感谢倾听！  
Thank You!



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