



IDAJ公司

GT-SUITE拟三维电机热管理分析

IDAJ中国
GT小组

目录

1. 电机热管理仿真分析方法及应用
2. 拟三维电机热管理仿真分析方法
3. 拟三维电机热管理仿真分析在开发流程的应用

■ 不断提高的整车“燃油”经济性

- 纯电动、混合动力
- 整车效率：三电、传动系统

■ 不断压缩的前舱空间

- 发动机、电机

■ 电机热管理难度增加

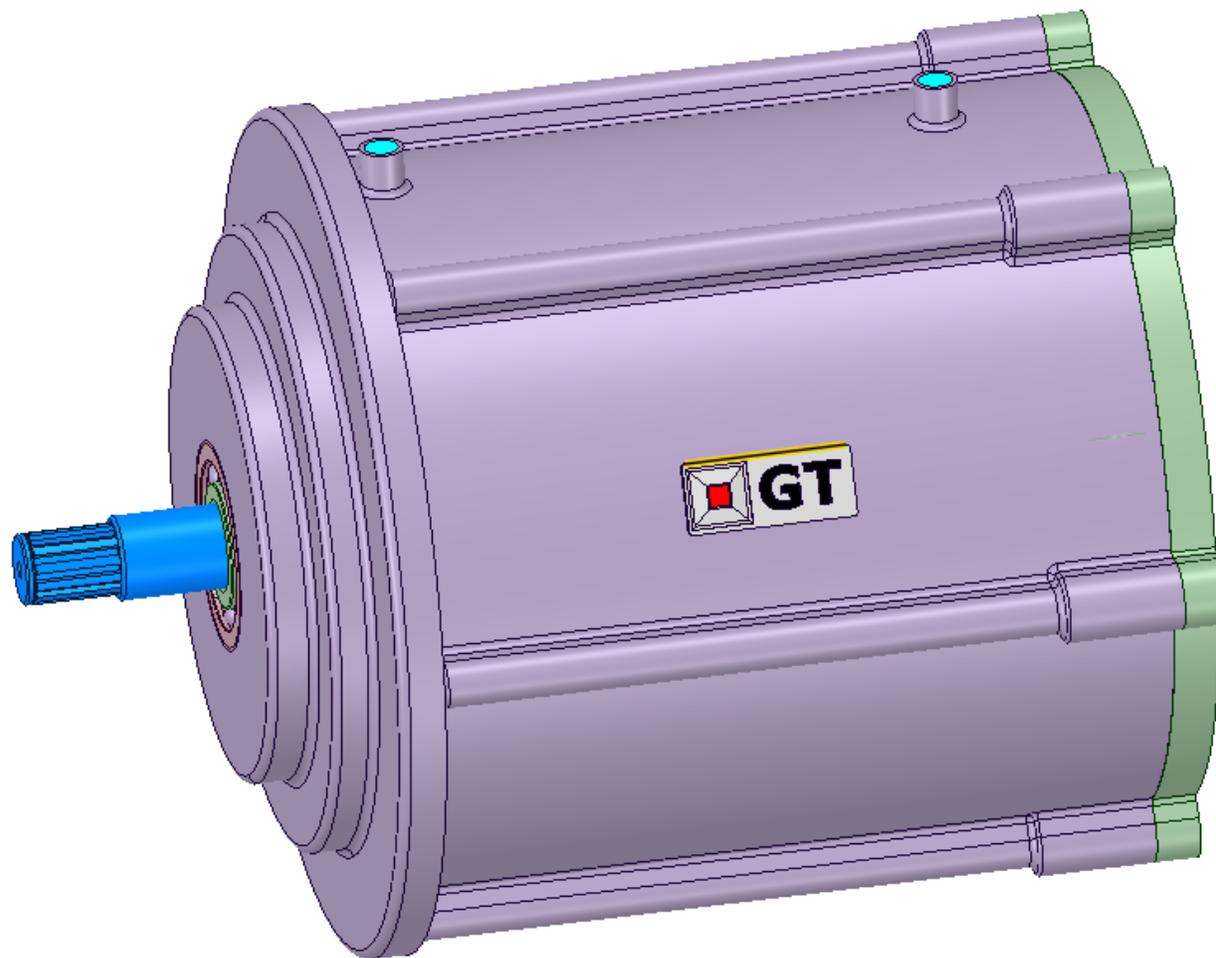
- 散热量
- 集成冷却的应用

■ 不断压缩的产品设计周期

- 长周期试验、CFD

■ 电机热管理如何设计

- 规格：水泵、换热器、风扇
- 控制：水泵、阀、风扇



■ 电机发热原因

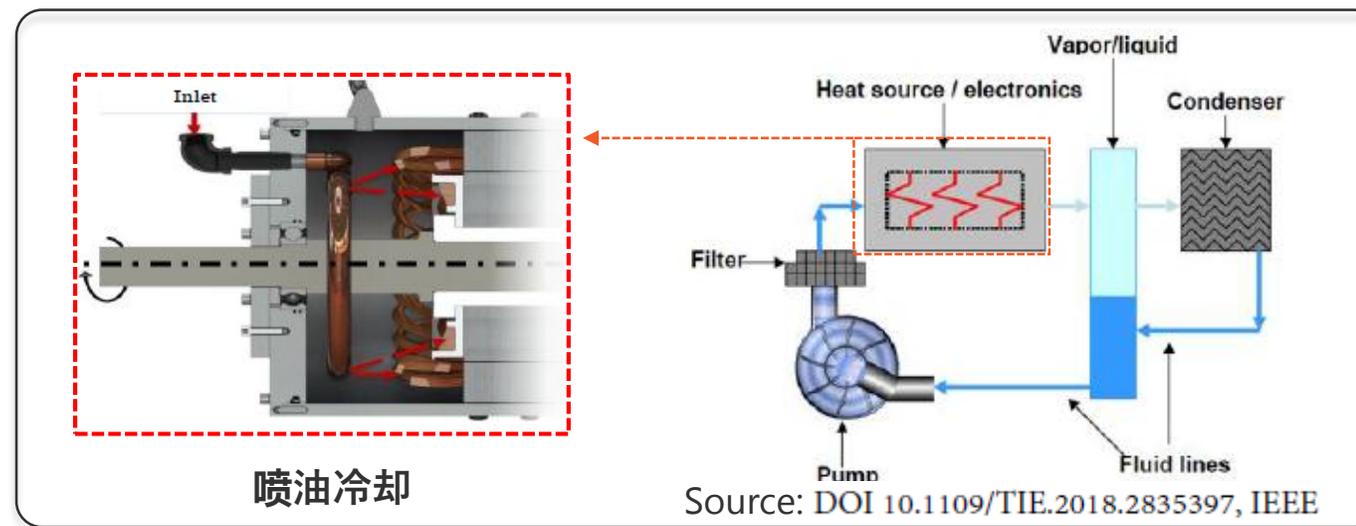
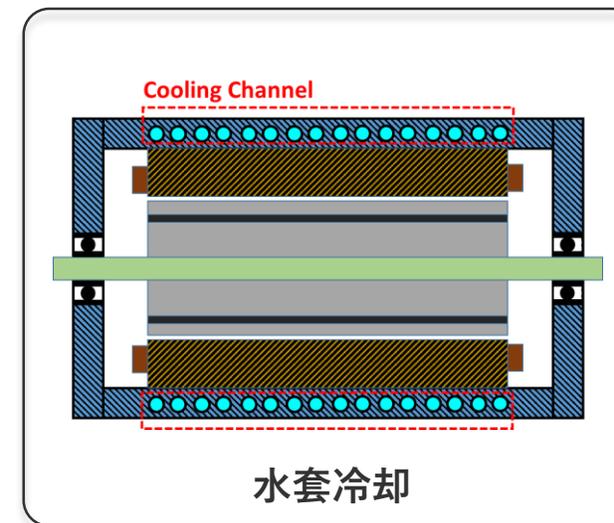
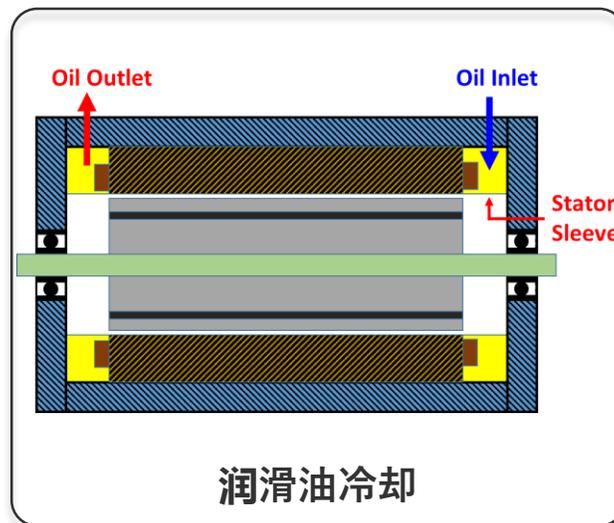
- 铜损：线圈内阻产生的损耗
- 铁损：磁滞损耗、涡流损耗
- 摩擦损失：轴承

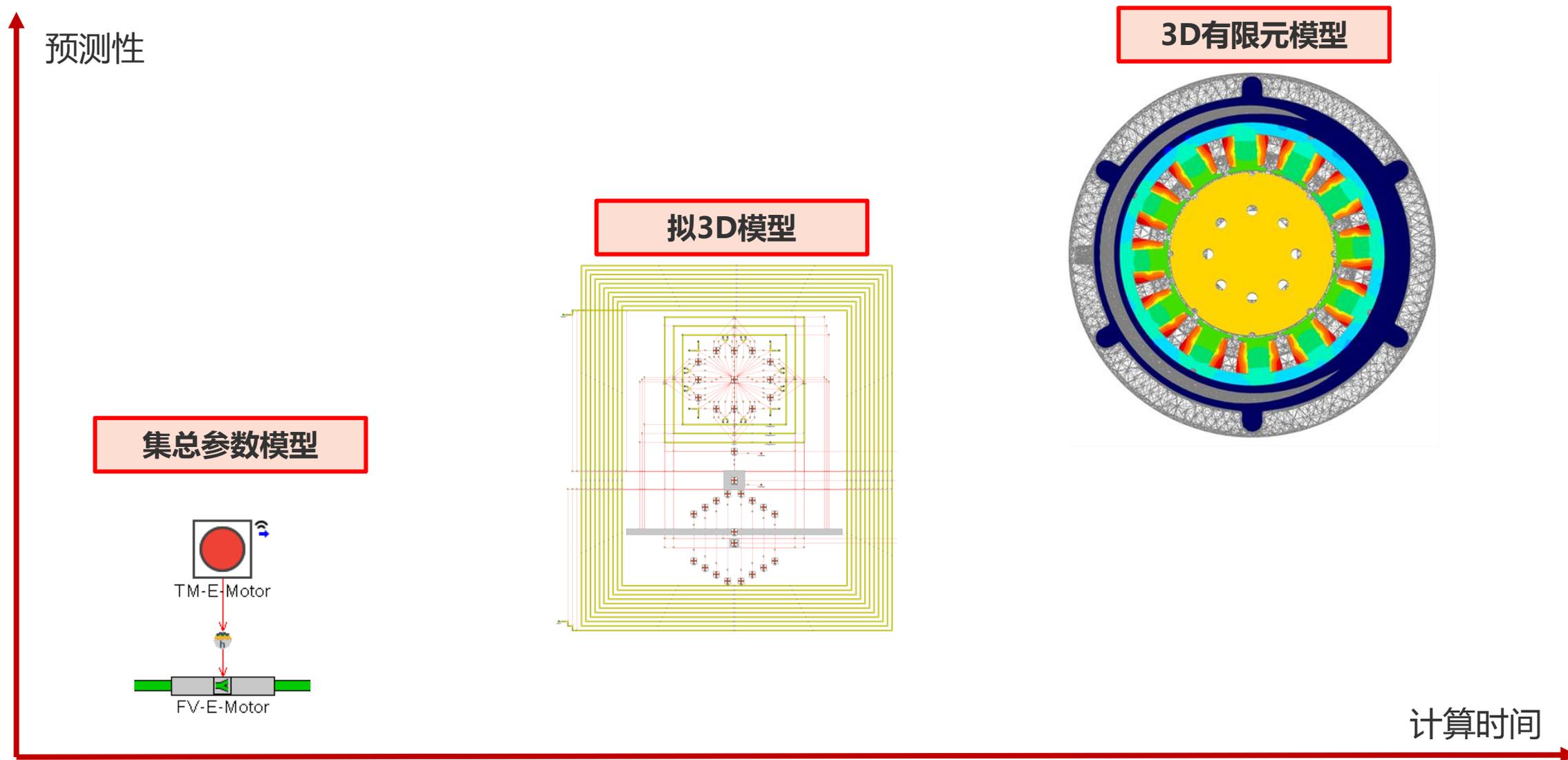
■ 电机温度过高的危害

- 磁钢退磁
- 线圈发热导致铜损增加

■ 电机冷却类型

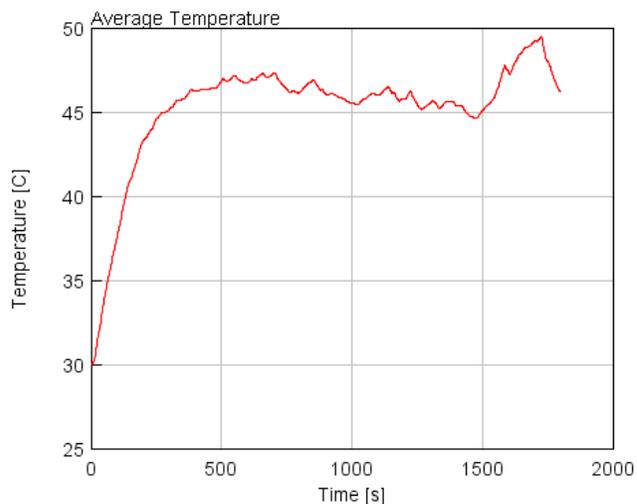
- 风冷
- 水冷
- 油冷



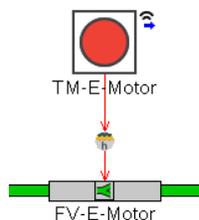


预测性

电机平均温度



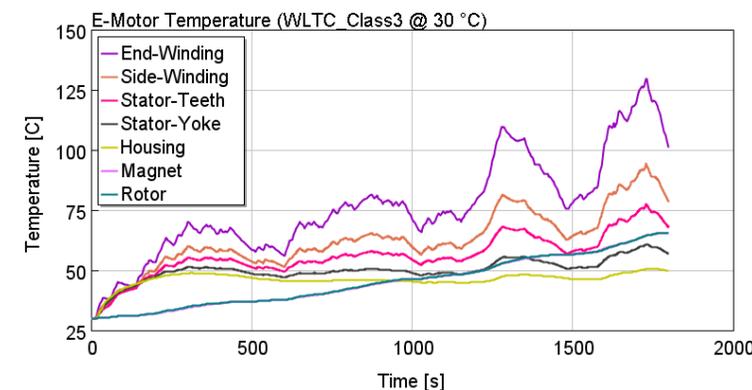
集总参数模型



| 技术方案 | 将电机视为一个整体，不考虑具体结构及参数，通过2~3个简单系数标定电机与冷却系统及环境的换热系数 |
|----------|--|
| 输入数据 | 电机发热量、水套流阻、水套换热系数、电机导热系数 |
| 温度场预测能力 | 无，主要输出电机出口水温、电机本体只能输出“平均温度” |
| 水套流阻预测能力 | 无，需要输入 |
| 外部环境的影响 | 只能粗略考虑 |
| 网格数量 | <5 |
| 计算速度 | 非常快 |
| 适用场景 | 概念设计阶段、系统回路仿真、整车能量管理系统集成 |

计算时间

3D有限元模型



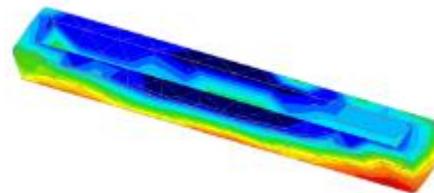
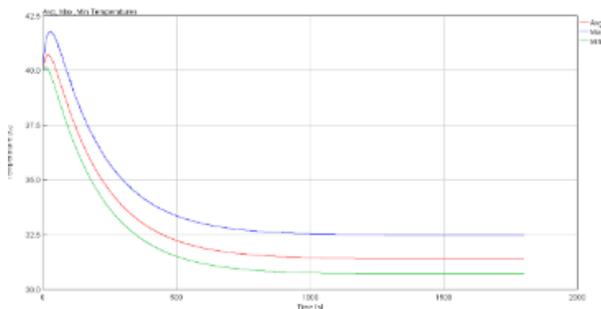
计算时间

预测性

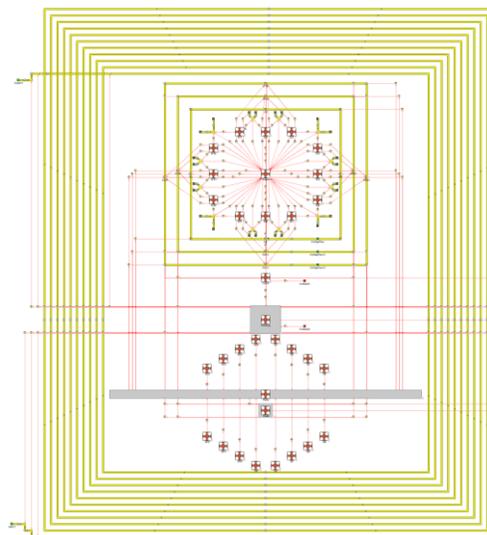
| 技术方案 | 基于详细几何数模划分网格、输入全部物性参数计算电机温度场 |
|----------|------------------------------|
| 输入数据 | 电机发热量、几何数模、全部零件材料属性 |
| 温度场预测能力 | 强 |
| 水套流阻预测能力 | 强 |
| 外部环境影响 | 可考虑 |
| 网格数量 | $10^5 \sim 10^6$ |
| 计算速度 | 慢，需要并行计算 |
| 适用场景 | 详细设计阶段、单一工况模拟，设计方案确认 |

预测性

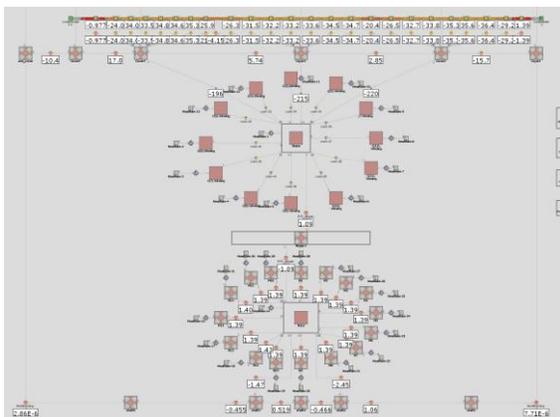
温度分布及变化



拟3D模型



换热量分布



| | |
|----------|---|
| 技术方案 | 根据几何数模将电机结构离散为1D传热计算单元，结合材料属性计算传热计算单元温度分布 |
| 输入数据 | 发热量、几何数模、全部零件材料属性 |
| 温度场预测能力 | 有，可预测局部温度 |
| 水套流阻预测能力 | 有 |
| 外部环境的影响 | 可考虑 |
| 网格数量 | $10^1 \sim 10^2$ |
| 计算速度 | 快，满足实时仿真需求 |
| 适用场景 | 电机冷却布置方案优化、系统方案验证、控制系统开发、长周期瞬态模拟 |

计算时间

■ 使用基本传热单元和流动单元来描述电机传热网络

● 基本传热单元：

- 外壳、定子、线圈、转子、磁钢
- Thermal mass、ThermalFiniteElement、ThermalNode

● 流动单元：

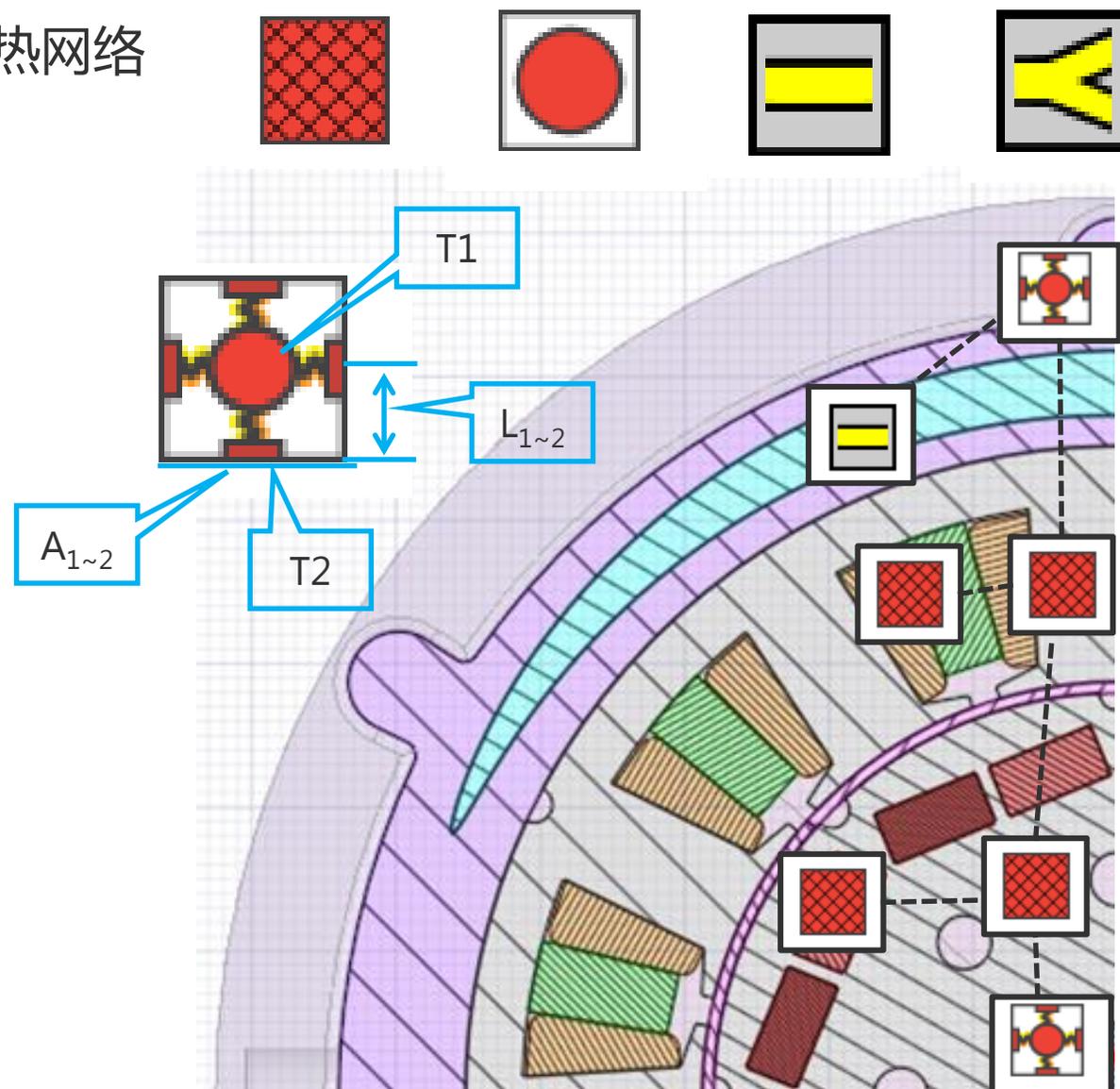
- 管路、腔体
- Pipe、FlowSplit

● 电机内传热网络：

- 冷却液对流换热、固体之间导热、环境辐射
- ConvectionConn、ConductanceConn、RadiationConn、ResistanceConn

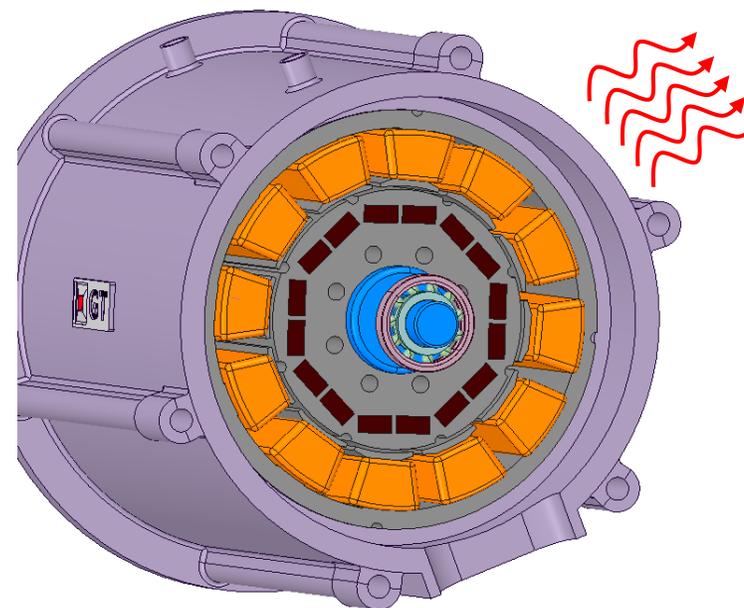
$$Q = \frac{T_1 - T_2}{R}$$

$$R = \frac{L}{kA}$$



■ 拟3D建模面临的问题

- 复杂的几何形状如何建模
- 复杂的传热结构如何体现
- 复杂的换热边界如何给出



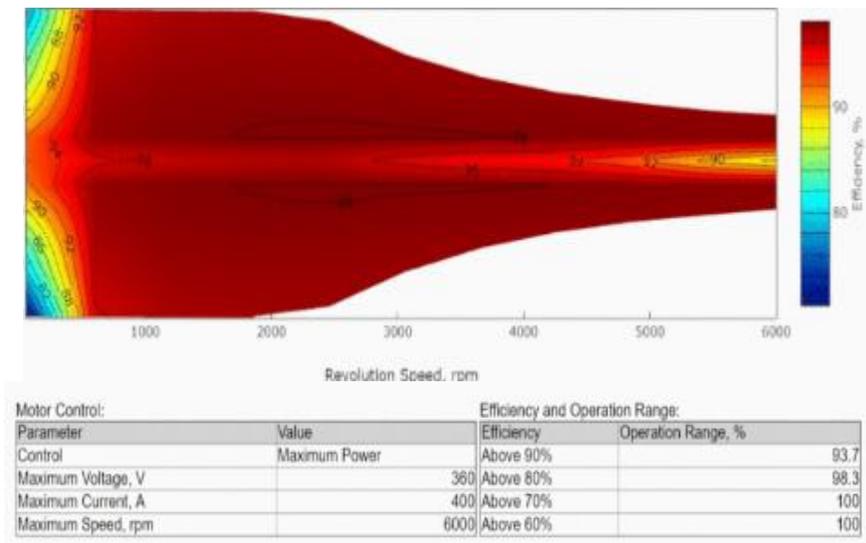
■ GT-SUITE解决方案

- GT-SPACECLAIM数模前处理：数模修整、水套抽取
- GEM3D数模转换：**将复杂几何形状自动转换为1D模型，包括固体、流体、自动识别换热边界、预留换热边界**
- GTISE整机模型：分块建模、通用端口



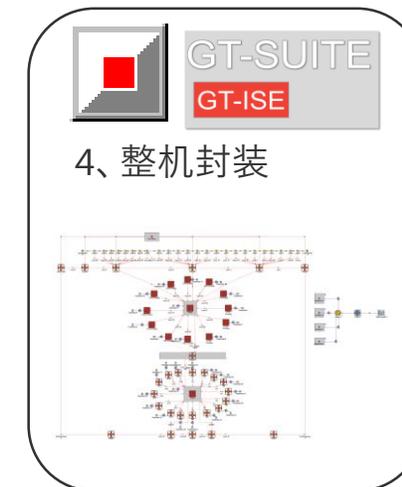
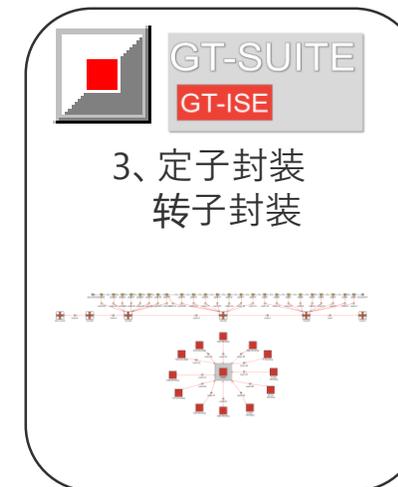
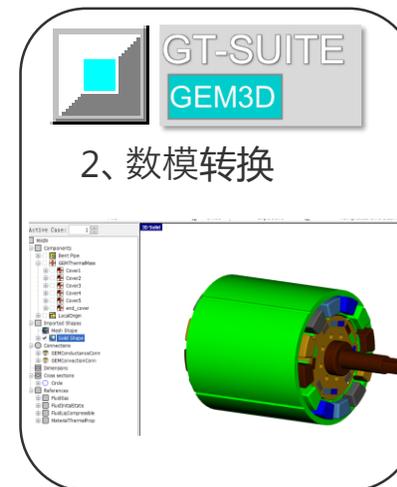
■ 数据准备

- 几何数模
- 材料属性：密度、比热容、导热系数
 - 定子、转子、线圈、磁钢
- 热源
 - 发热量
 - 电机效率+工况
 - JMAG Express online+ 工况

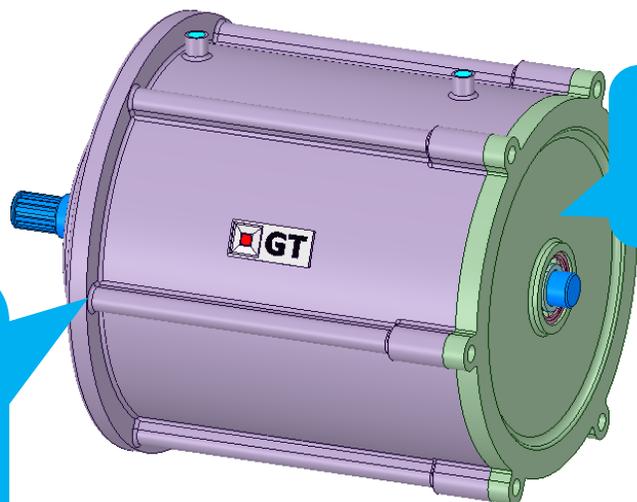


■ 工作流程

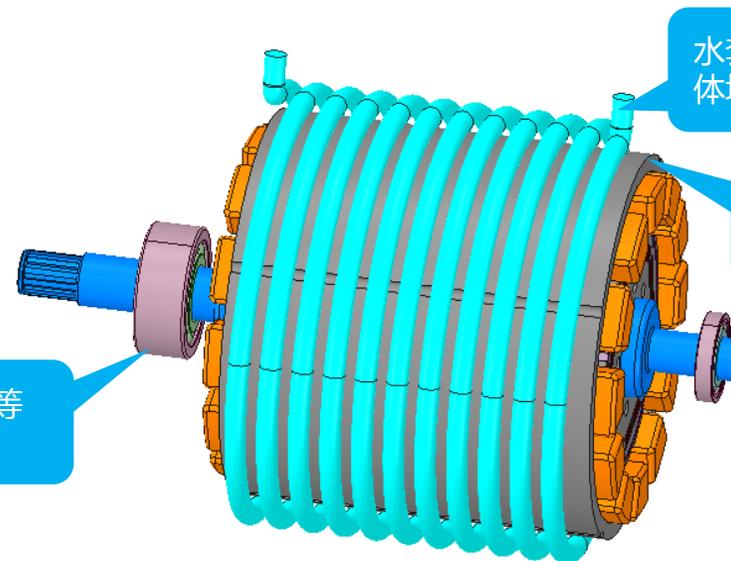
1. 数模整理：SpaceClaim
2. 数模转换：GEM3D
3. 模组模型：GTISE
4. 整包封装：GTISE



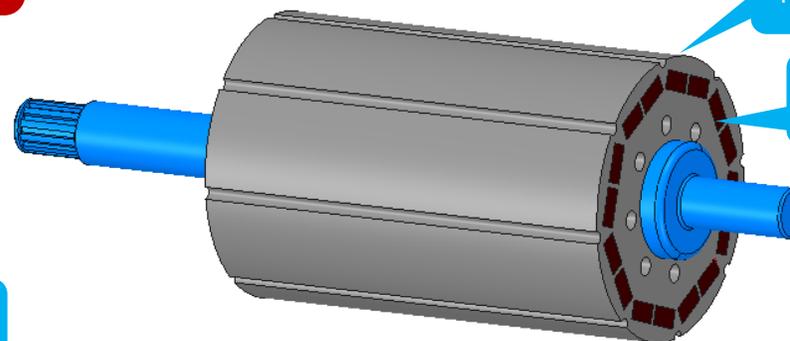
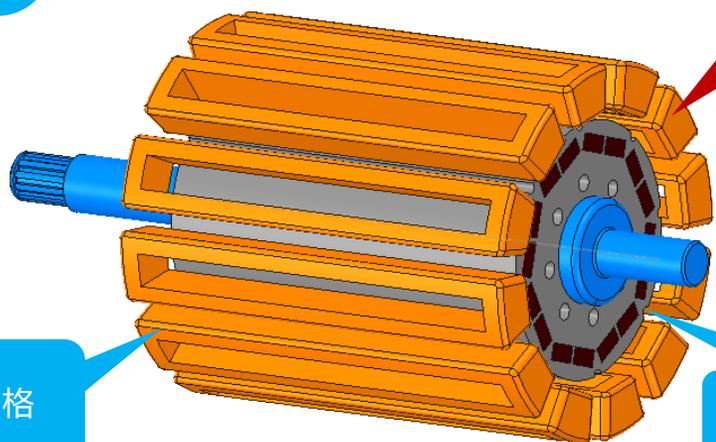
■ 电机内主要元件处理方法：1D + 有限元



电机端盖：1个1D网格
预留与环境空气换热边界

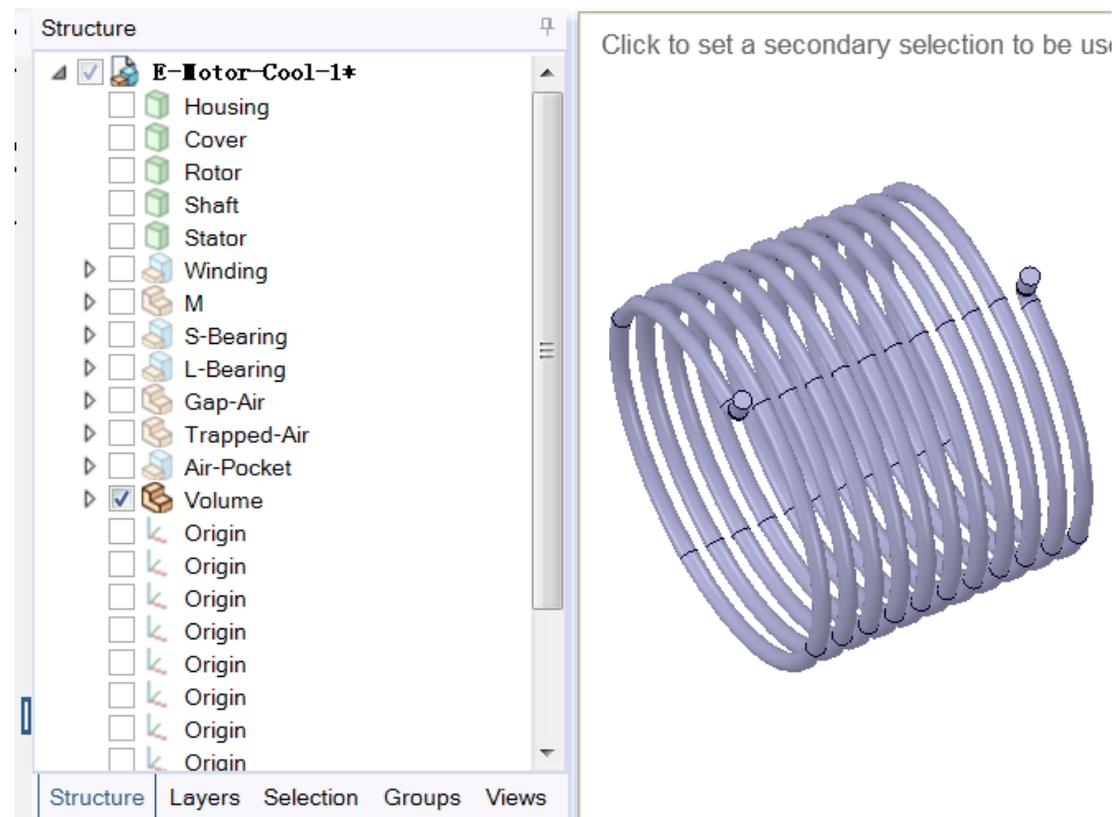
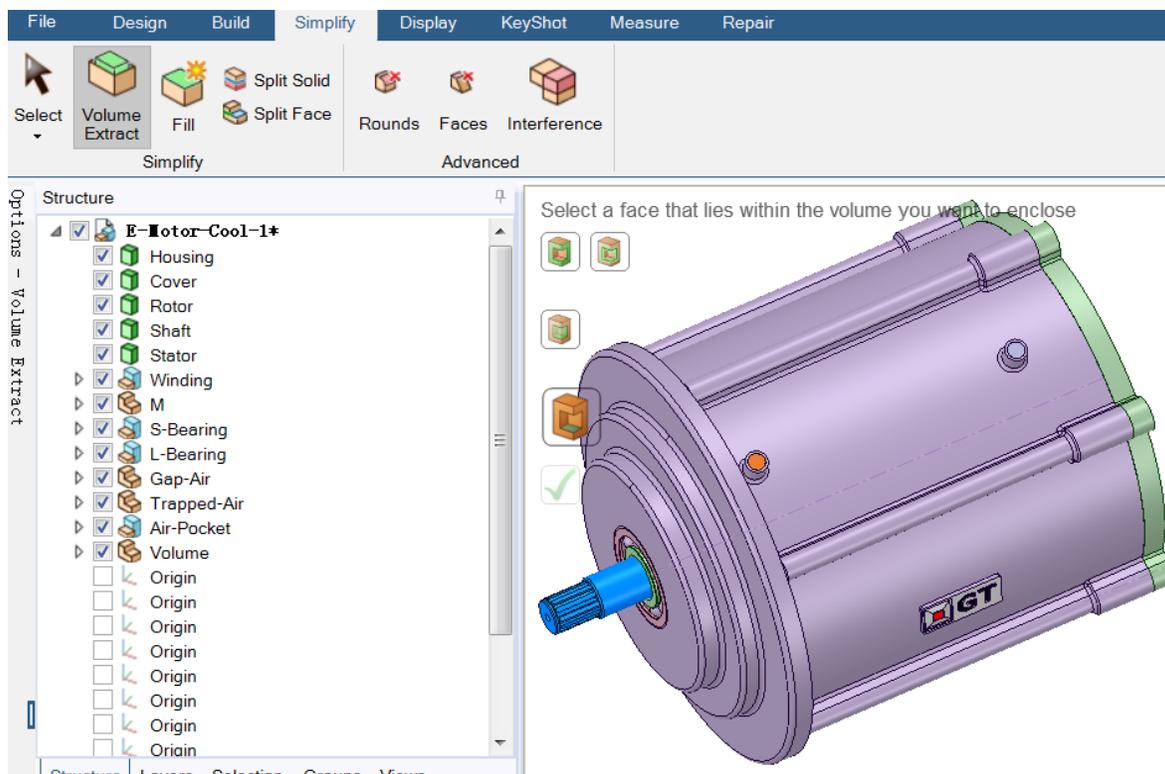


轴承：使用热阻等效或者忽略



■ 目的：水套抽取

- 支持绝大部分CAD数模格式



■ 固体域：



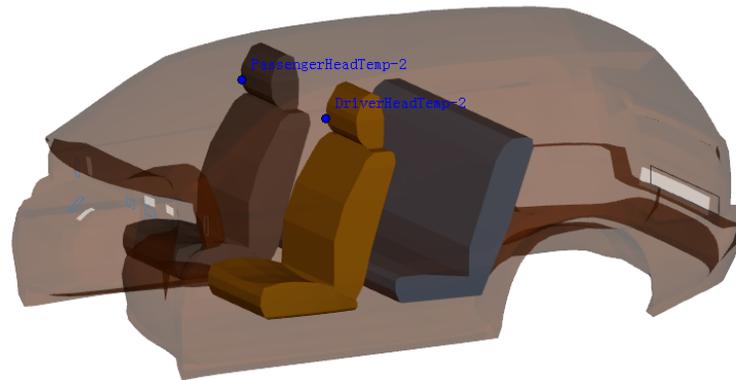
■ 流体域：



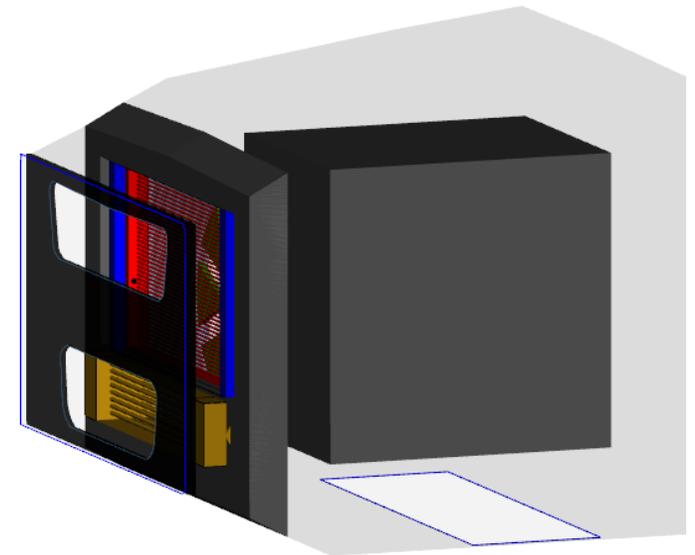
■ 机械域



■ 乘员舱

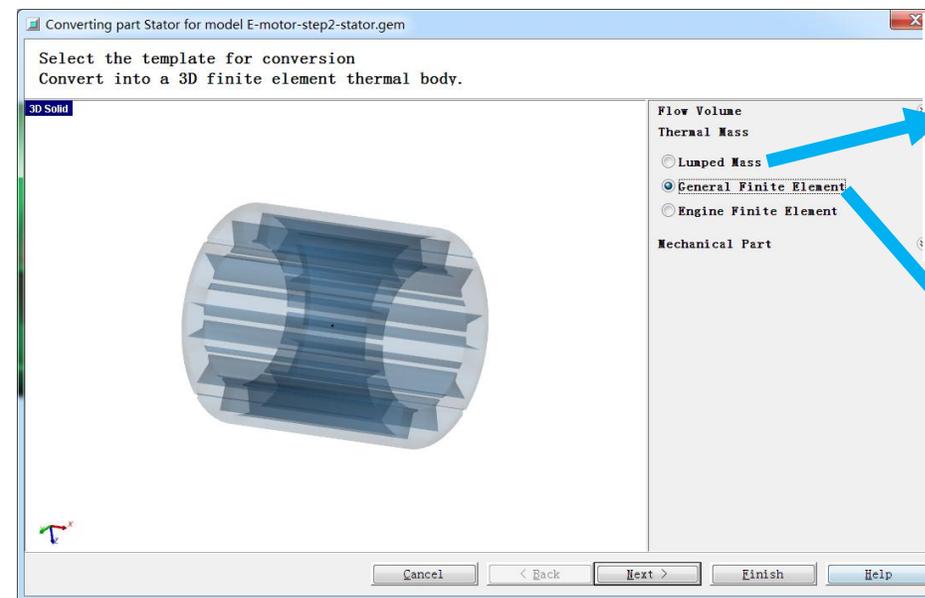


■ 动力舱



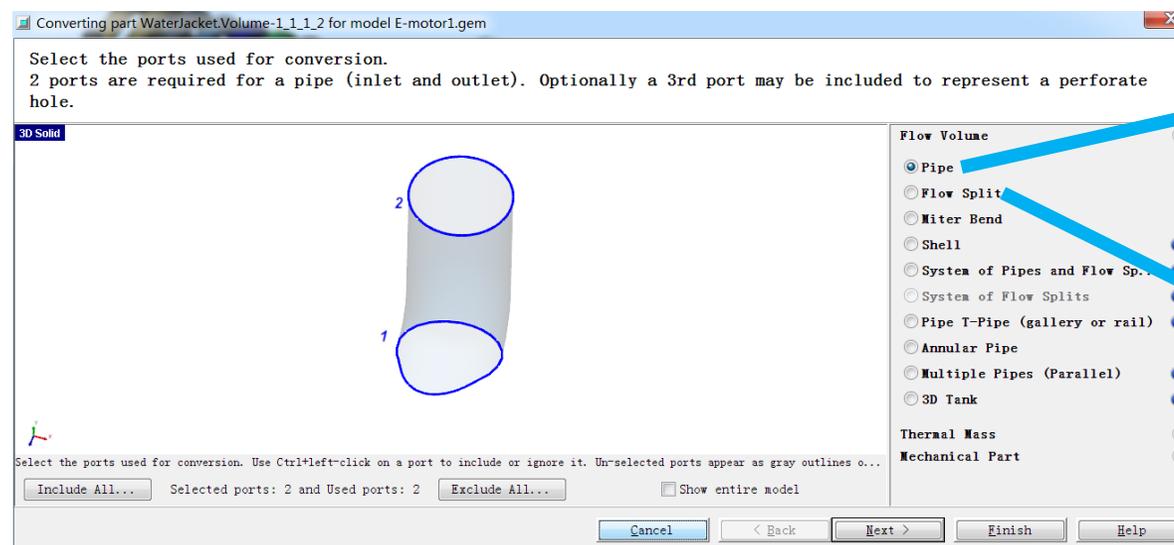
■ 固体域：

- Lump Mass：适用于形状规则、不考虑温度分布的零件，如外壳、磁钢、转轴
- General Finite Element：适用于形状不规则、考虑温度分布、难以手动切割的零件，如定子、转子、线圈



■ 流体域：

- Pipe：管路
- Flow Split：腔体

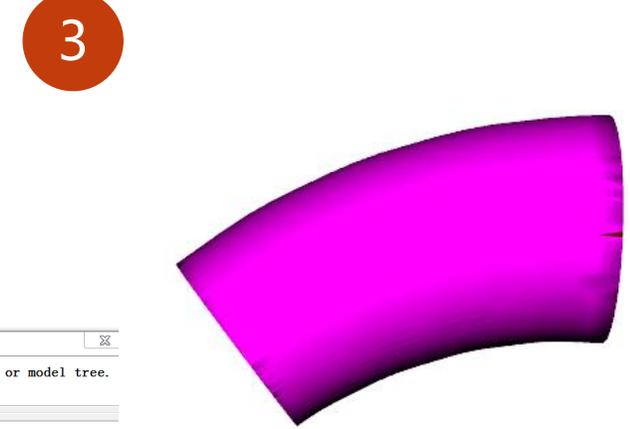
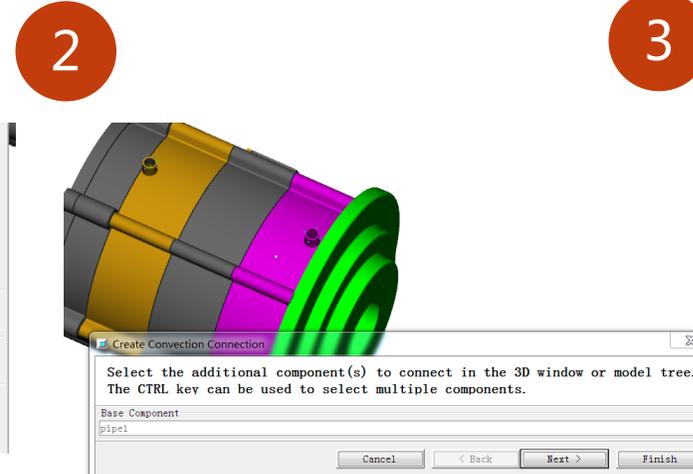
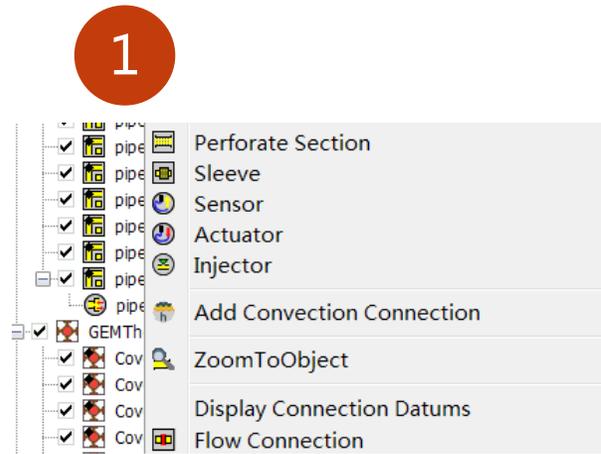


■ 零部件之间换热

- 自动识别换热面

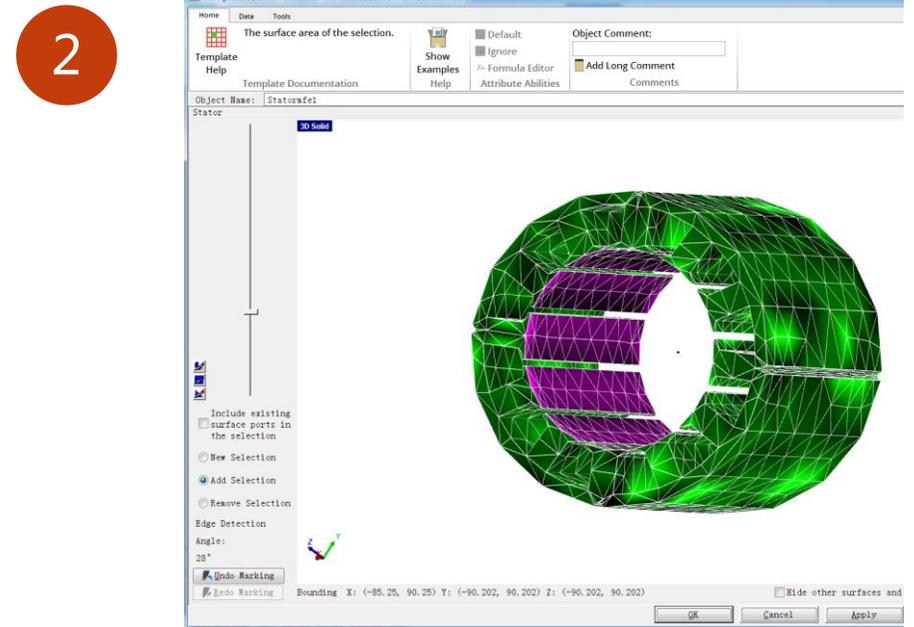
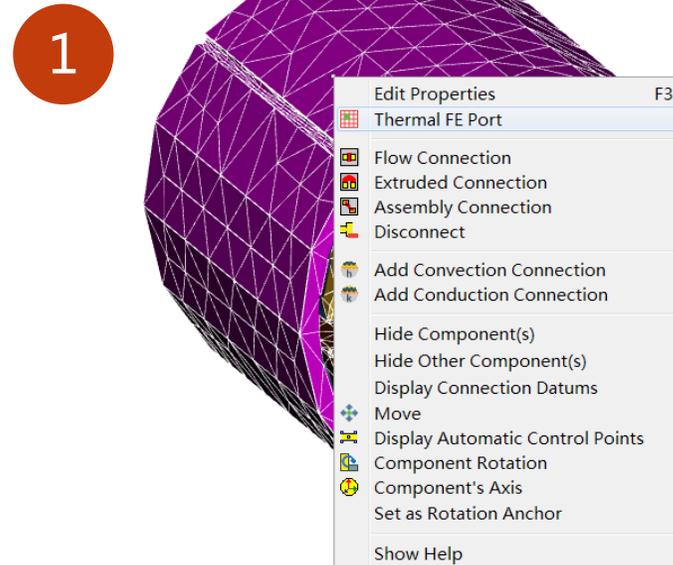
- 手动添加换热面

1. 添加换热端口
2. 选择换热部件
3. 确认换热面

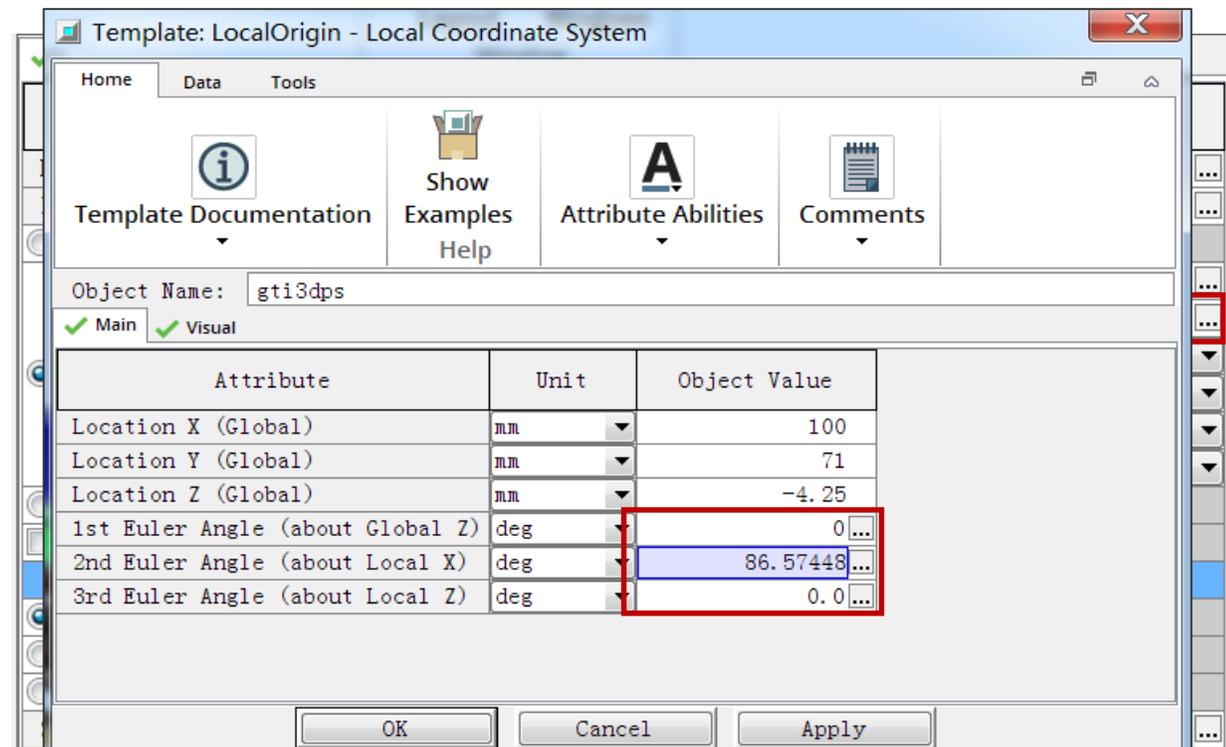
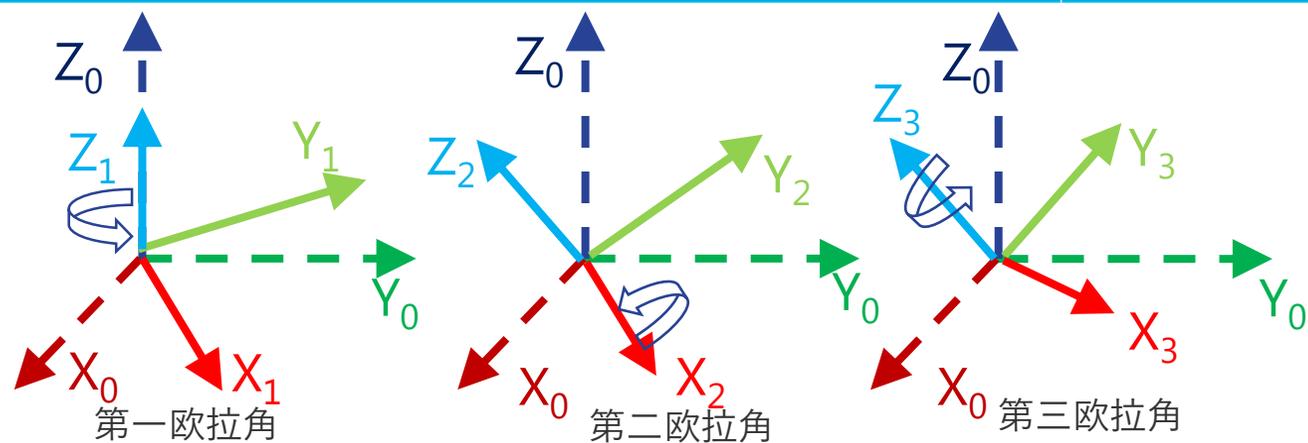
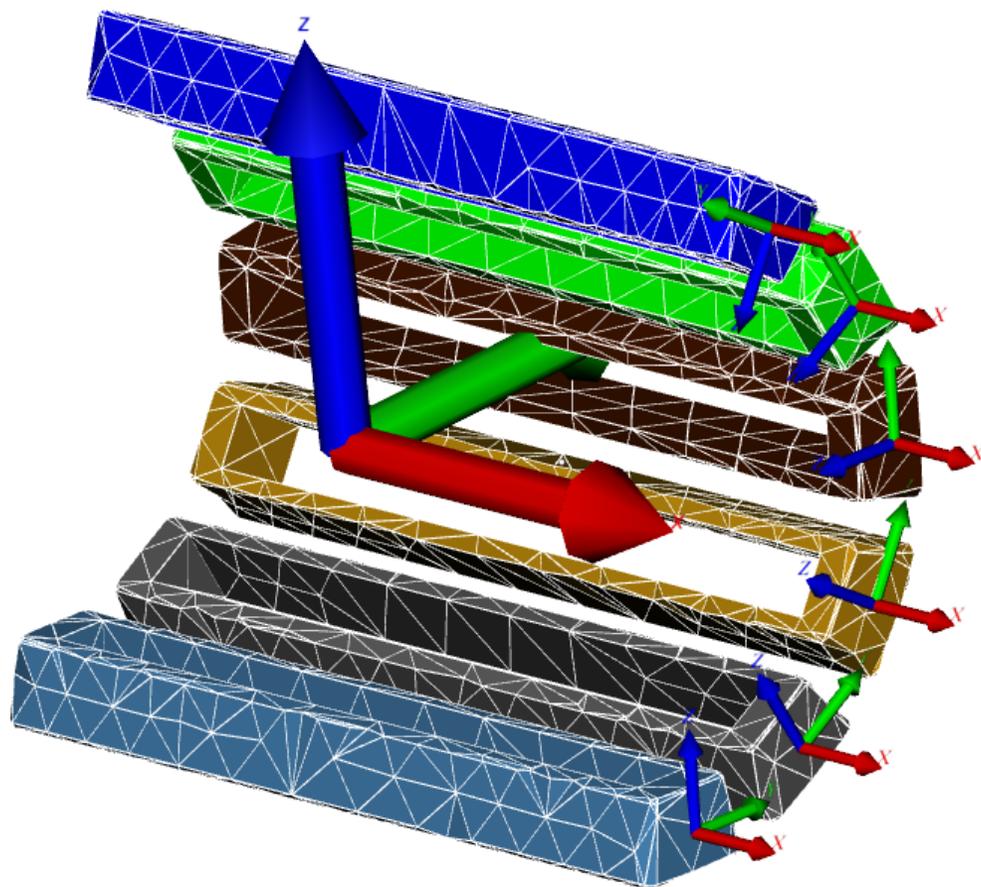


■ 预留换热面

1. 选择零件
2. 换热面选择



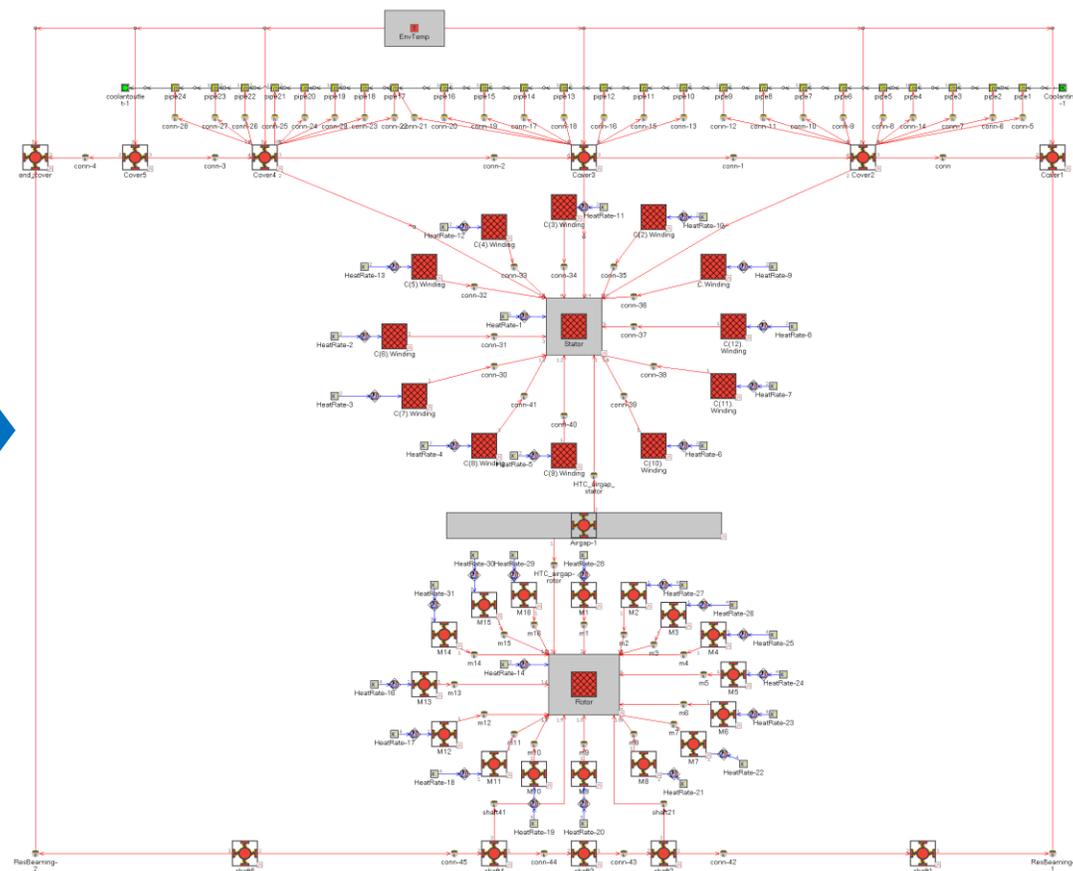
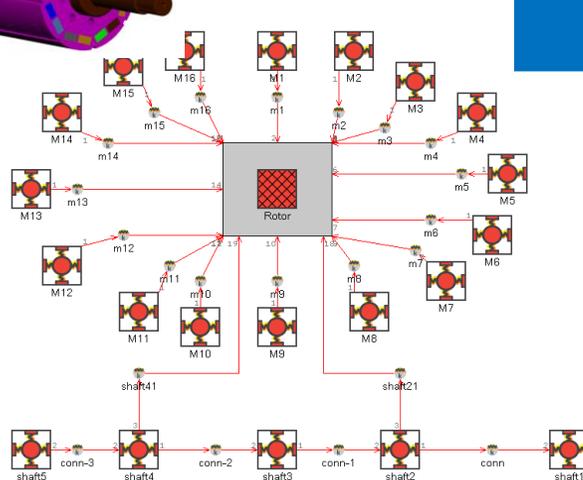
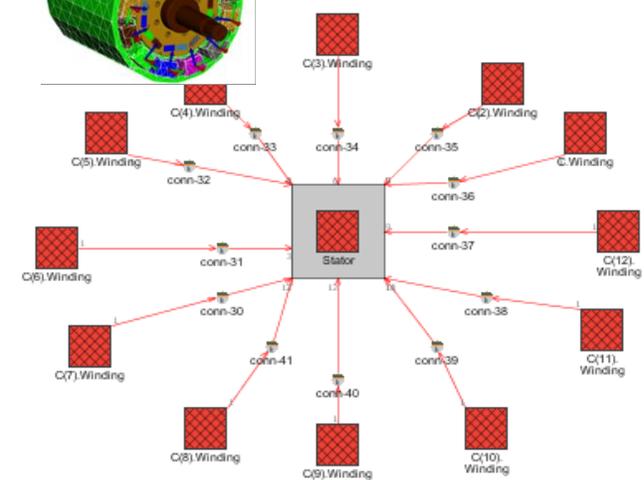
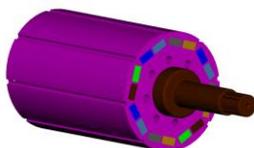
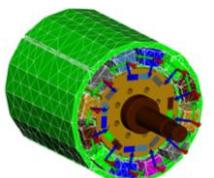
■ 各向异性导热材料：局部坐标系



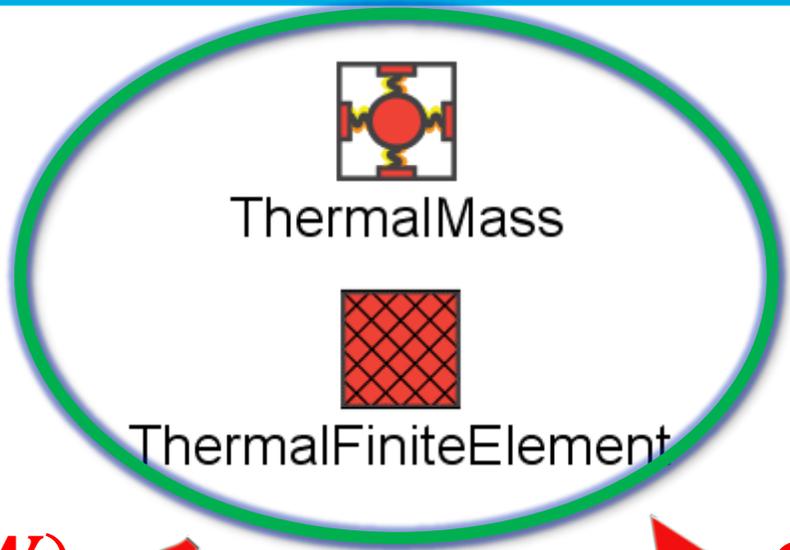
■ 问题：由几何数模转换后的计算单元、边界很多，模型面板的整理花费很长世间

■ 解决方案：分块建模、预留端口

● 外壳->定子->转子->整机



- ① 热量
- ② 电机效率模型
- ③ JMAG Express Online



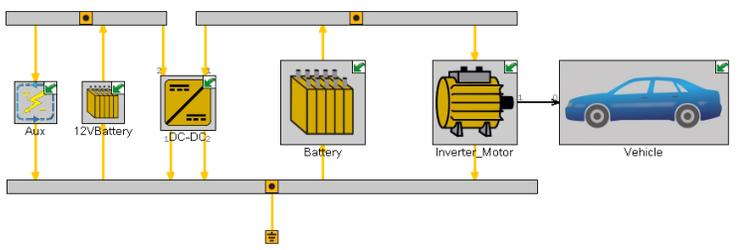
$\dot{Q} (W)$

Thermal

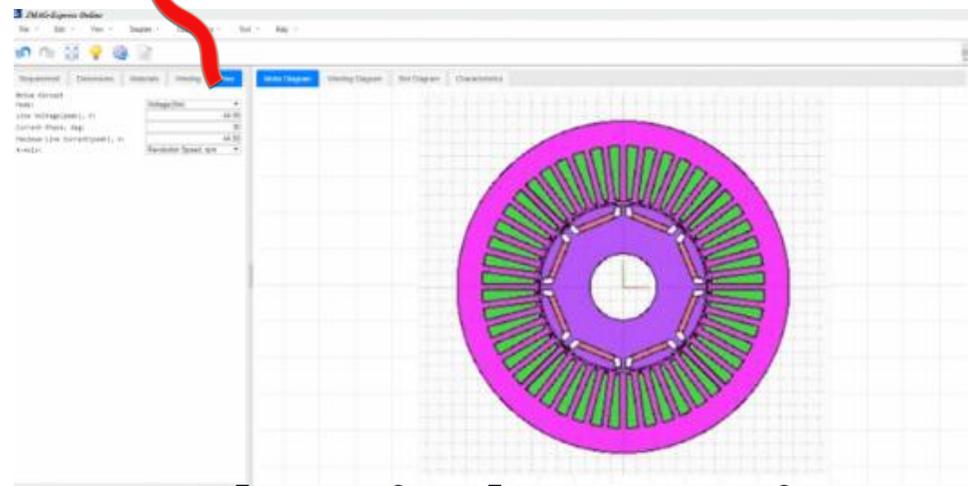
$\dot{Q} (W)$

$\dot{Q} (W)$
 $T (^\circ C)$

$eff (%)$



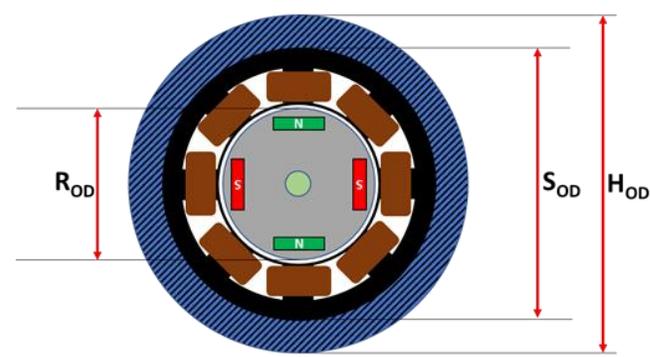
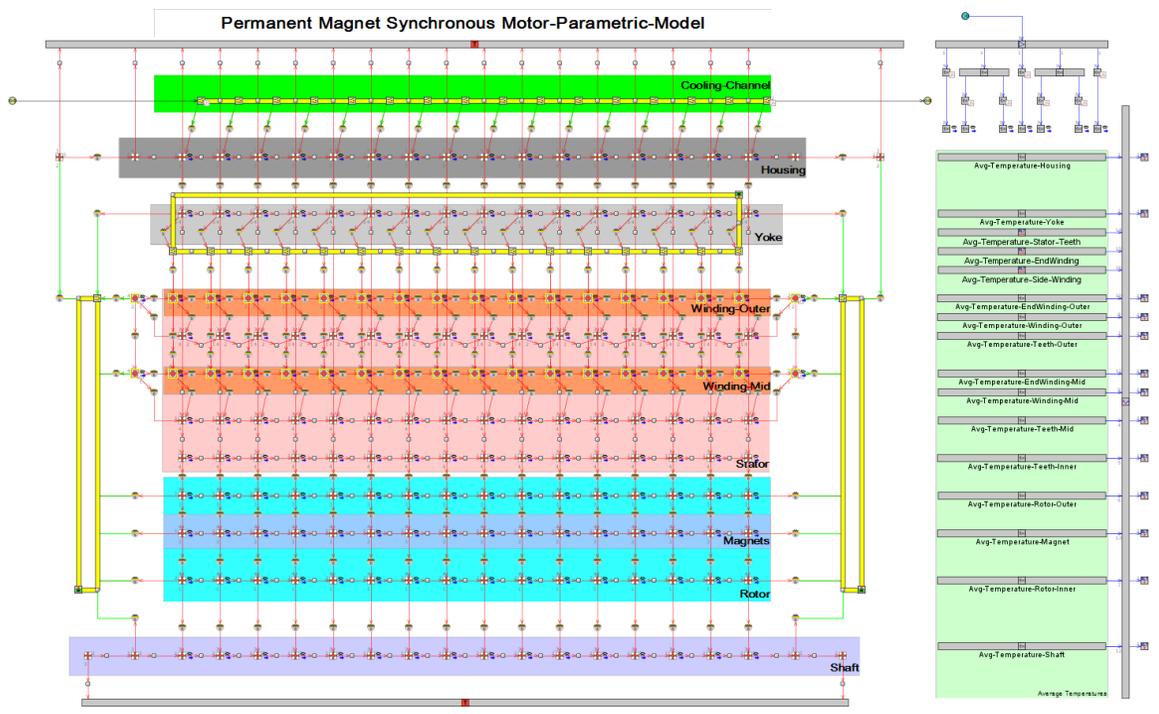
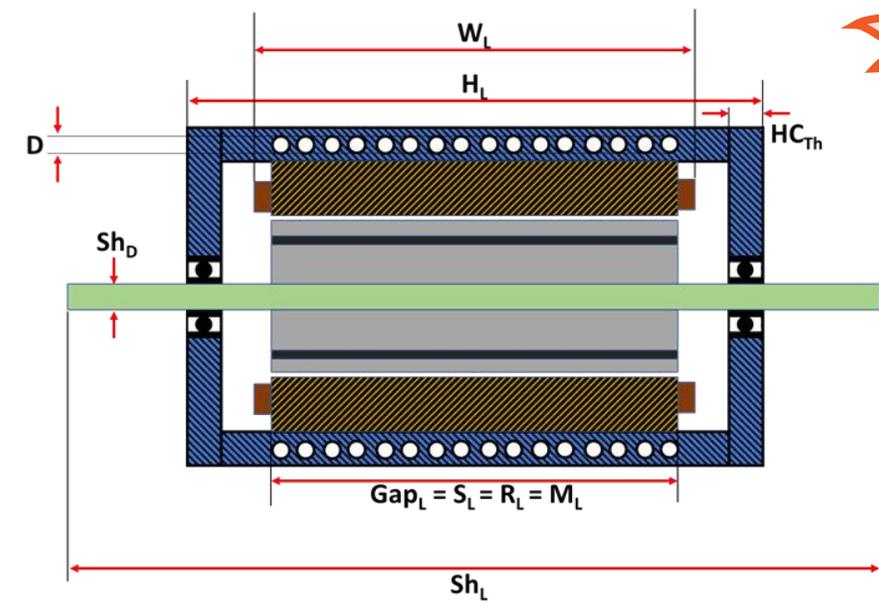
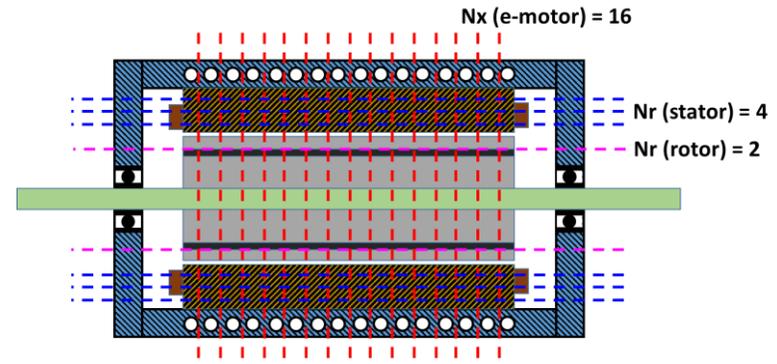
Electrical



Electricalmagnetic



ACMachinePM
SynchThermal



- H_L - Housing Outer Length
- H_{OD} - Housing Outer Diameter
- HC_{Th} - Housing Cover Thickness
- S_L - Stator Length
- S_{OD} - Stator Outer Diameter
- W_L - Winding Axial Length
- R_{OD} - Rotor Outer Diameter
- R_L - Rotor Length
- M_L - Magnet Length
- Sh_L - Shaft Length
- Sh_D - Shaft Diameter
- D - Channel Diameter
- GAP_L - Air Gap Length

外壳长度、直径、厚度

| Attribute | Unit | Object Value |
|-----------------------------|------|--------------|
| Housing Material Properties | | |
| Housing Outer Length | mm | 250 |
| Housing Outer Diameter | mm | 216 |
| Housing Cover Thickness | mm | 10.1 |

定子长度、外径、
线圈体积、长度、数量

| Attribute | Unit | Object Value |
|--------------------------------|----------|--------------|
| Stator | | |
| Stator Material Properties | | |
| Stator Length | mm | 175.5 |
| Stator Outer Diameter | mm | 180.7 |
| Slot Filling Ratio | fraction | 0.8623 |
| Winding to Stator Volume Ratio | fraction | 0.31 |
| Windings | | |
| Winding Material Properties | | |
| Winding Axial Length | mm | 195 |
| Number of Winding Slots | | 12 |

转子外径、磁钢体积、转轴长度、直径

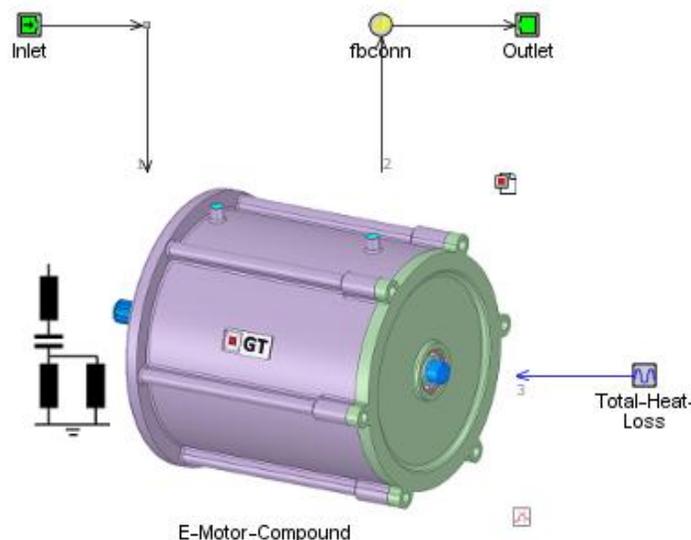
| Attribute | Unit | Object Value |
|------------------------------|----------|--------------|
| Rotor | | |
| Rotor Material Properties | | |
| Rotor Outer Diameter | mm | 112 |
| Magnets | | |
| Magnet Material Properties | | |
| Magnet to Rotor Volume Ratio | fraction | 0.19 |
| Shaft | | |
| Shaft Material Properties | | |
| Shaft Length | mm | 343 |
| Shaft Diameter | mm | 22 |

热阻

| Attribute | Unit | Object Value |
|--|-----------------|--------------|
| Thermal Resistance: Housing to Cover | $m^2 \cdot K/W$ | def (=1E-8) |
| Thermal Resistance: Housing to Stator-Yoke | $m^2 \cdot K/W$ | def (=1E-8) |
| Thermal Resistance: Stator-Teeth to Rotor | $m^2 \cdot K/W$ | def (=1E-8) |
| Thermal Resistance: Rotor to Magnet | $m^2 \cdot K/W$ | def (=1E-8) |
| Thermal Resistance: Rotor to Shaft | $m^2 \cdot K/W$ | def (=1E-8) |
| Thermal Resistance: Winding (Axial) | $m^2 \cdot K/W$ | def (=1E-8) |
| Thermal Resistance: Winding (Radial) | $m^2 \cdot K/W$ | def (=1E-8) |
| Thermal Resistance: Winding (Angular) | $m^2 \cdot K/W$ | def (=1E-8) |

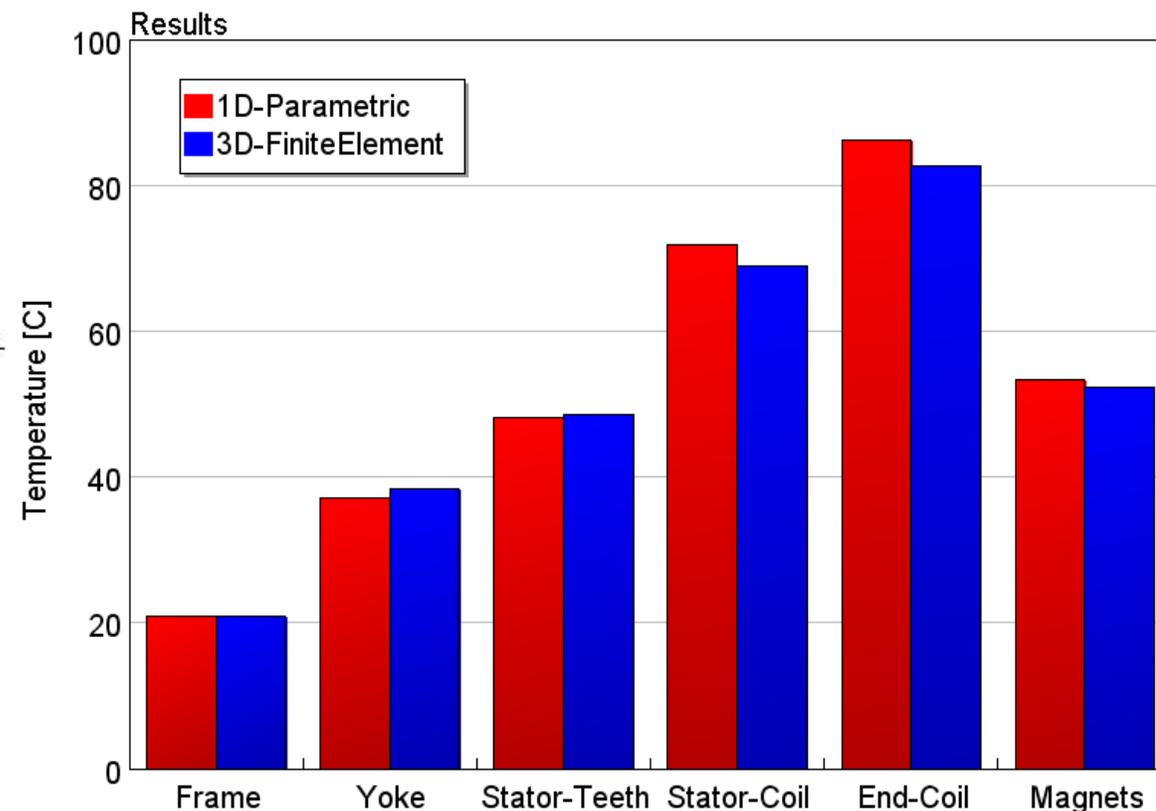
优化变量:

1. R_{th} Rotor-to-Stator
2. R_{th} Rotor-to-Magnet
3. R_{th} Winding-Axial
4. R_{th} Winding-Radial
5. R_{th} Winding-Angular
6. R_{th} Housing-to-Stator
7. HTM (Coolant)

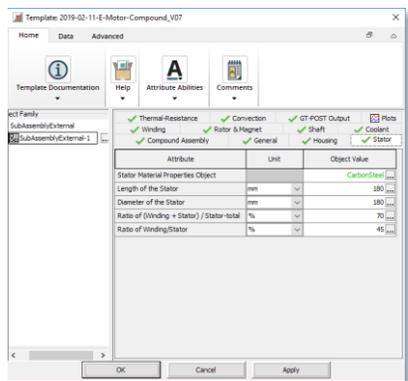


优化目标:

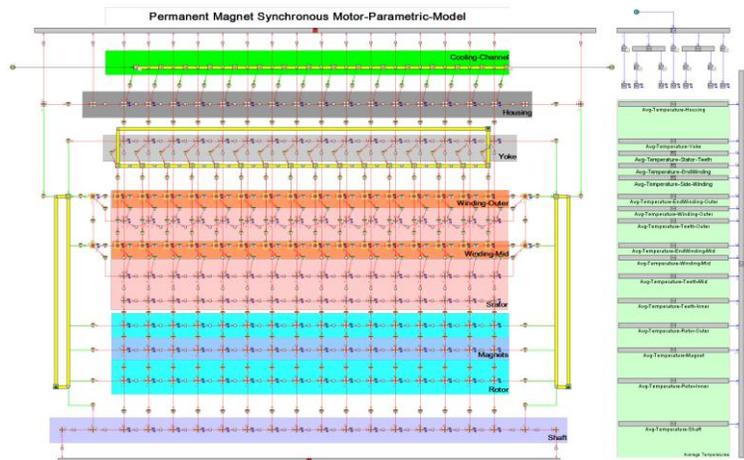
1. 线圈端部温度
2. 线圈边温度
3. 定子齿温度
4. 磁钢温度



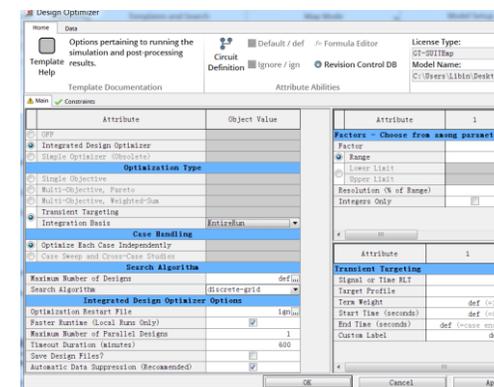
Load Torque = 80 Nm; Motor Speed = 6000 RPM
Coolant VFR = 8 L/min



参数定义



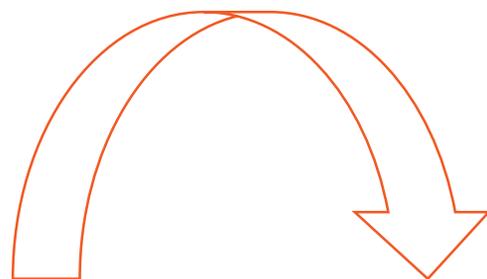
定义优化



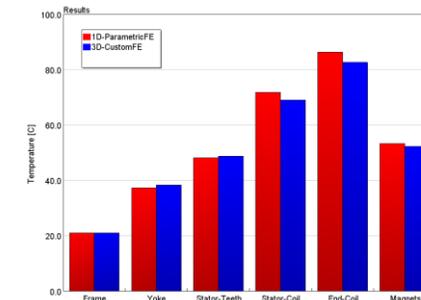
尺寸测量

E-Motor Data Sheet

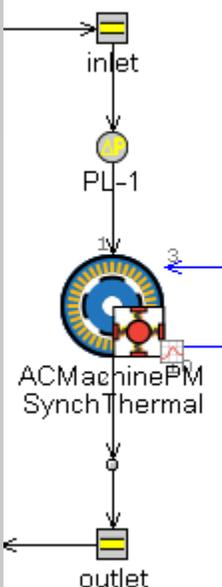
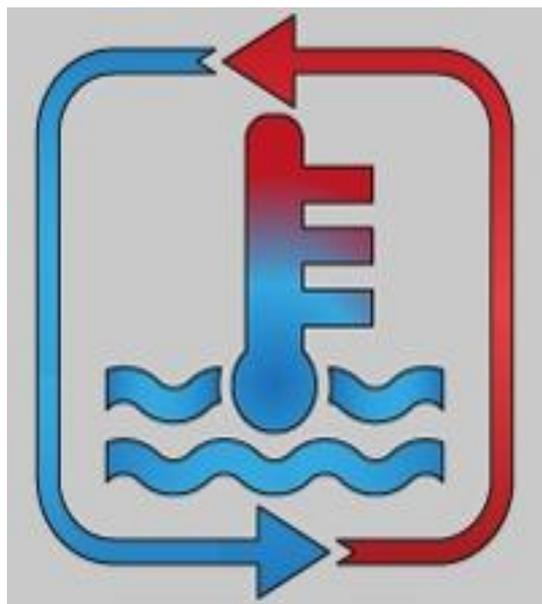
| General | Input | Example |
|---|-------|-------------|
| Number of Winding Slots (N _s) | | 12 |
| Number of Poles (P _s) | | 8 |
| Overall Stator Mass (M _s) | | 31 kg |
| Housing Outer Length (L _h) | | 228 mm |
| Housing Outer Diameter (D _h) | | 218 mm |
| Air Gap Thickness (G _{ag}) | | 1 mm |
| Housing | | |
| Housing Material Properties | | Aluminum |
| Housing Cover Thickness (H _{cc}) | | 12 mm |
| Stator | | |
| Stator Material Properties | | CarbonSteel |
| Stator Length (L _s) | | 180 mm |
| Stator Outer Diameter (D _{so}) | | 180 mm |
| Slot Filing Ratio (R _{sf}) | | 70% |
| Winding to Stator Volume Ratio (R _{vs}) | | 45% |
| Winding | | |
| Winding Material Properties | | Copper |
| Winding Axial Length (W _a) | | 200 mm |
| Rotor | | |
| Rotor Material Properties | | CarbonSteel |
| Rotor Outer Diameter (R _o) | | 112 mm |
| Magnet to Rotor Volume Ratio (R _{vr}) | | 25% |
| Magnet | | |
| Magnet Material Properties | | N42F48 |
| Magnet to Rotor Volume Ratio (R _{vr}) | | 25% |
| Shaft | | |
| Shaft Material Properties | | 304 |
| Shaft Diameter (D _{sh}) | | 28 mm |
| Shaft Length (L _{sh}) | | 340 mm |
| Cooling Channel | | |
| Flow Inlet Diameter (C) | | 10 mm |
| Number of Convolute (N _c) | | 11 |



计算结果

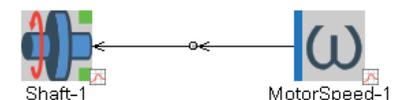
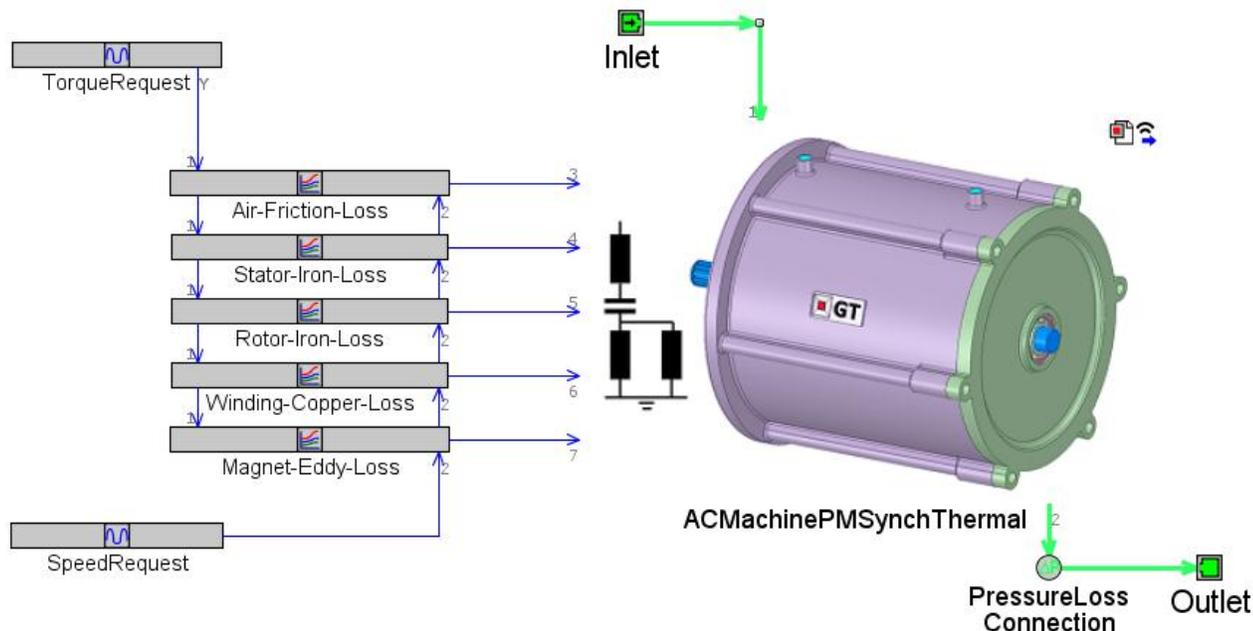


- 单一工况模拟
- 与电机联动
- 热源：总损失/损失分布



$\dot{Q} (W)$

$T (^{\circ}C)$



Template: MotorGeneratorMapJMAG - Mapped Electromechanical Motor/Generator using JMAG Express Online

Home Data Tools

This template is used to model an electro-mechanical motor/generator with...

Connectivity Information Help

Show Examples

Default Formula Editor

Ignore Create Parameter

Object Comment:

Part Comment:

Add Long Comment

Attribute Abilities

Comments

Object Family

JMAGmotor

JMAGmotor

| Attribute | Unit | Object Value |
|--|------|-------------------|
| Machine Efficiency/Power Loss | | |
| JMAG Exported Map | | <PM_I_D_I.csv>... |
| <input type="checkbox"/> Include Inverter Losses | | |
| Machine | | |
| Control Mode | | |
| Brake Torque | N | |

Map

Data Type:

- Copper Loss
- Efficiency
- Power
- Total Loss
- Copper Loss
- Iron Loss
- Copper Loss + Iron Loss
- Mechanical Loss
- Id
- Iq
- Iam
- Ld
- Lq
- Voltage

Torque, Nm

0 1000 2000 4000 6000 8000 10,000 12,000

Efficiency, %

94 96 98 100

Mutual Inductance, H -4.787e-04

mm

Inside Diameter.

OK Cancel Apply

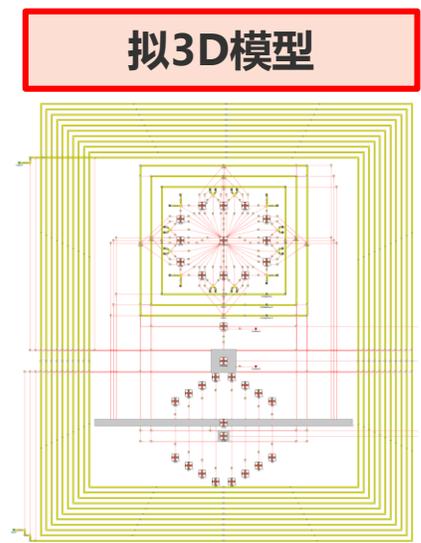
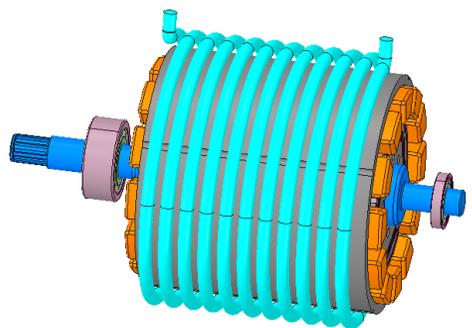
预测性

3D有限元模型

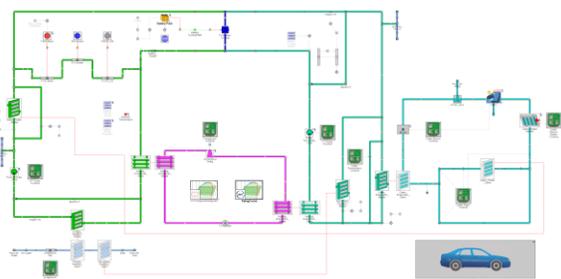
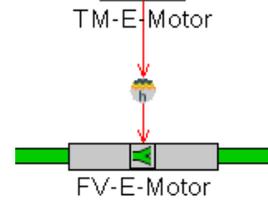
拟3D模型

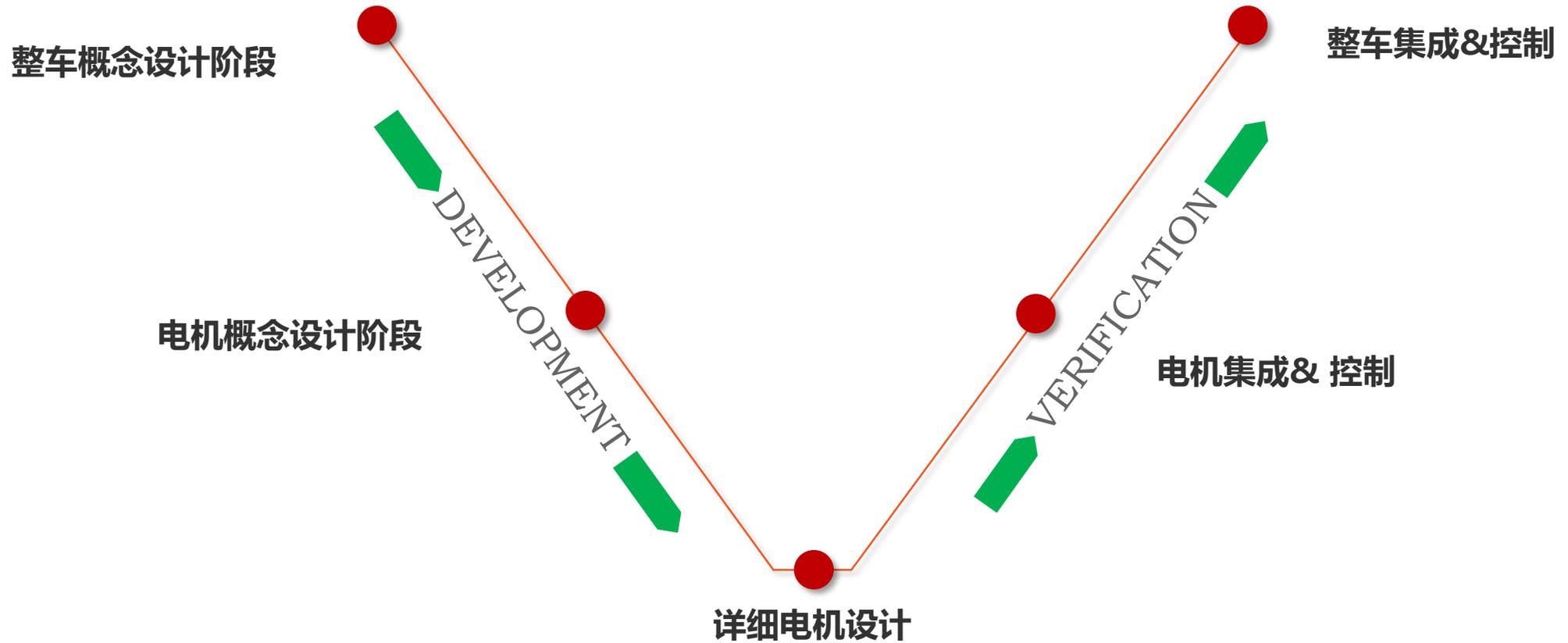
集总参数模型

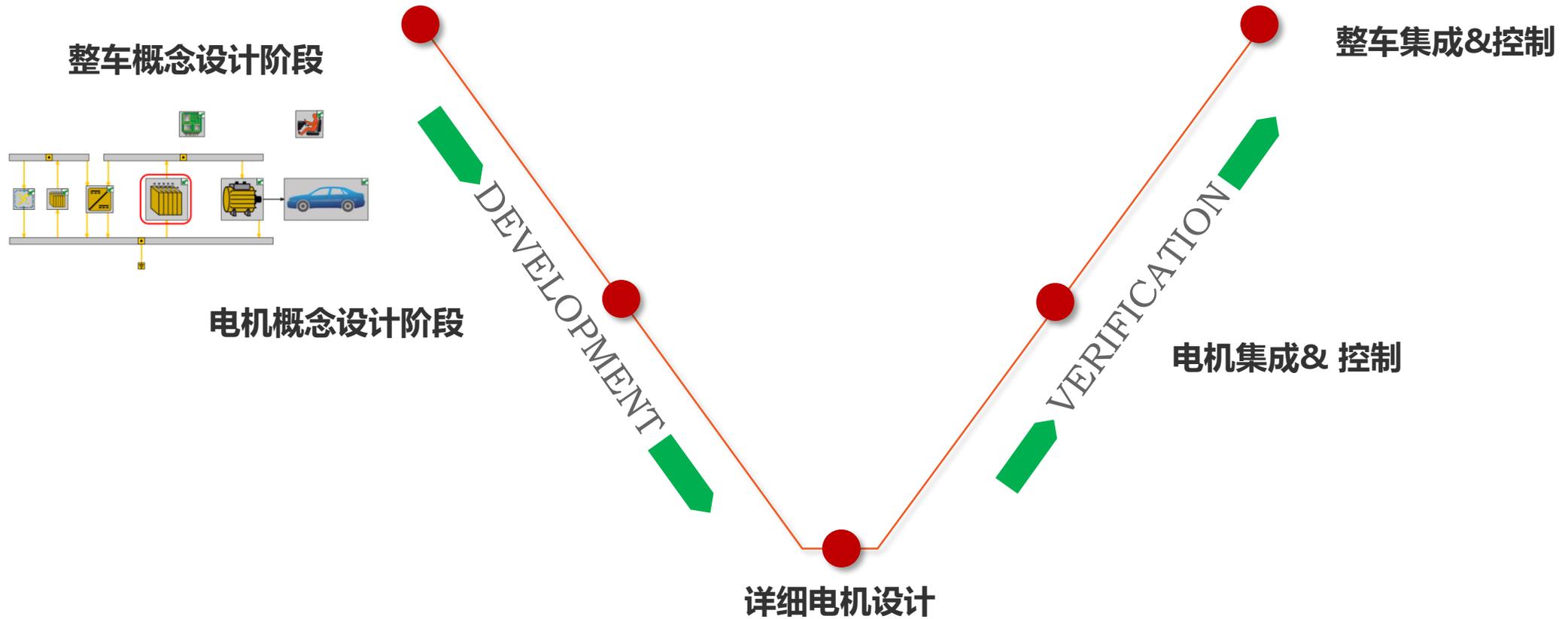
计算时间

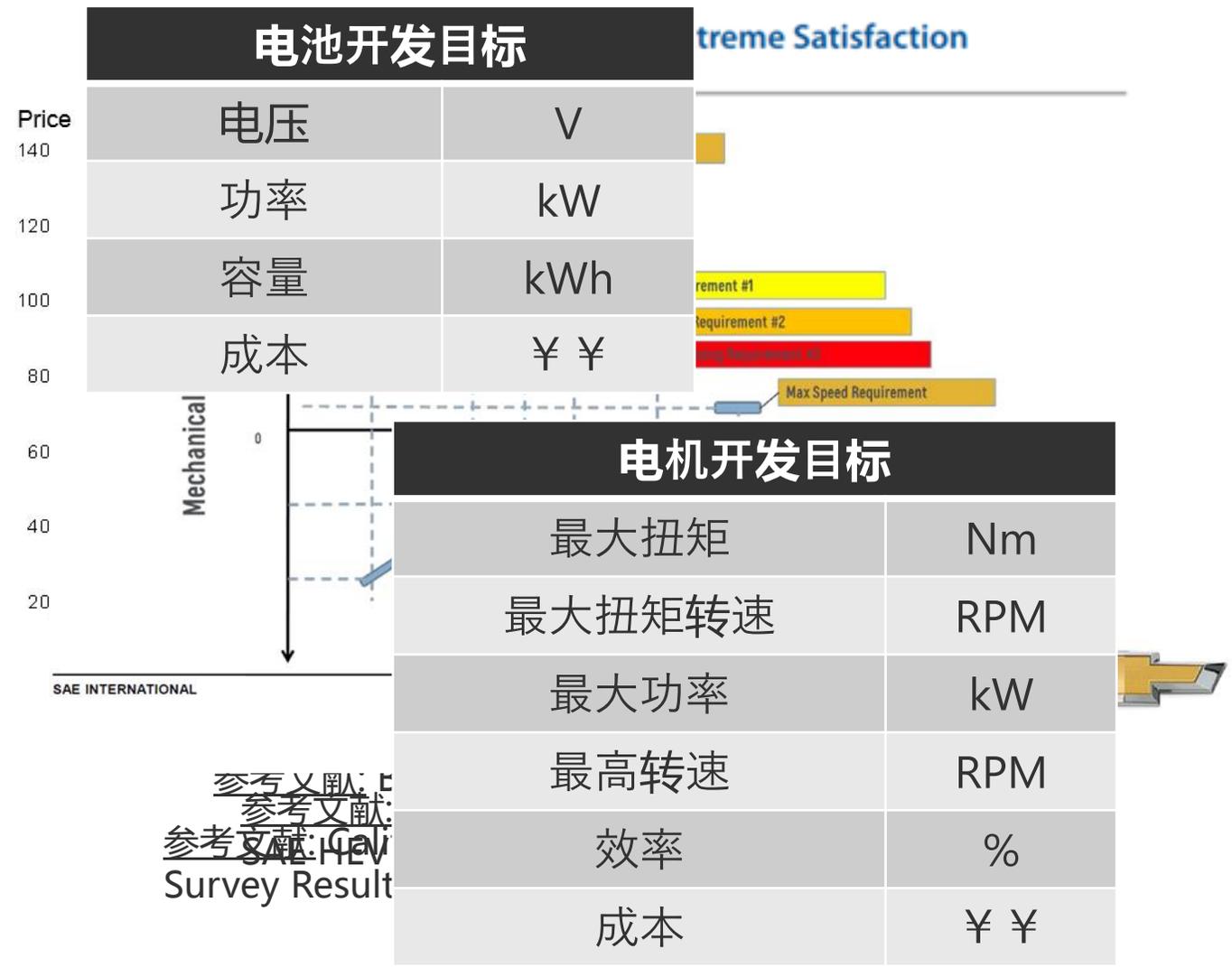


TM-E-Motor









GT-ISE v2018 - C:\Users\gtlap\Desktop\Joe\HEV Marketing\Electric_Vehicle.gtm : GT-SUITE v2018 *

File Home View Data Tools INHOUSE

Undo Redo Cut Copy Paste Find Template Find Value Select Link Edit Parts in Spreadsheet Flow Scale View Case Setup Run Setup Advanced Setup Optimization Run View Results Preprocess Stop Distributed Queue

1 Main 2 Battery 2 Inverter_Motor 2 Vehicle 2 DC-DC 2 12VBattery 2 Aux 2 DRIVER 2 Supervisory_Controller

Electric Vehicle

Vehicle Builder

Architecture Type

Choose a Vehicle Configuration

- Battery Electric Vehicle
- P0 Mild Hybrid Electric Vehicle
- P2 Hybrid Electric Vehicle
- P0/P4 Hybrid Electric Vehicle
- P4 Hybrid Electric Vehicle

The Battery Electric Vehicle Builder

This builder will allow you to create a new battery electric motor, battery, transmission, and driveline transmission + FWD vehicle, CVT + 4WD vehicle, detailed model, subsystems may be omitted.

For each subsystem of the vehicle model, (motor pre-existing objects can be used (100kW machine transmission, mid-sized FWD car). These objects GTO file; GT-SUITE also provides some pre-built which will be opened upon the start of the wizard.

Once the model is built, pre-defined vehicle tests (d acceleration performance tests) can be run.

基于MAP 电机&控制器

电机 & 电机转换器
效率Map

DC-DC转换器:
效率Map

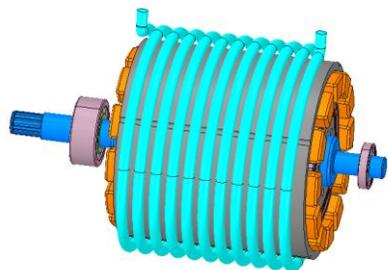
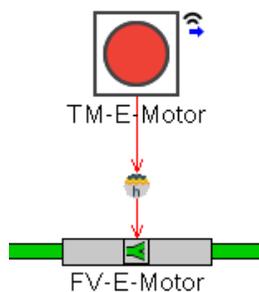
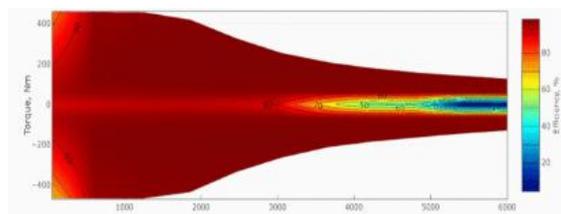
Libraries Mild_Hybrid.gtm x P2_Hybrid.gtm x Series_Hybrid.gtm x TTR_Hybrid.gtm x Electric_Vehicle.gtm x

整车概念设计阶段

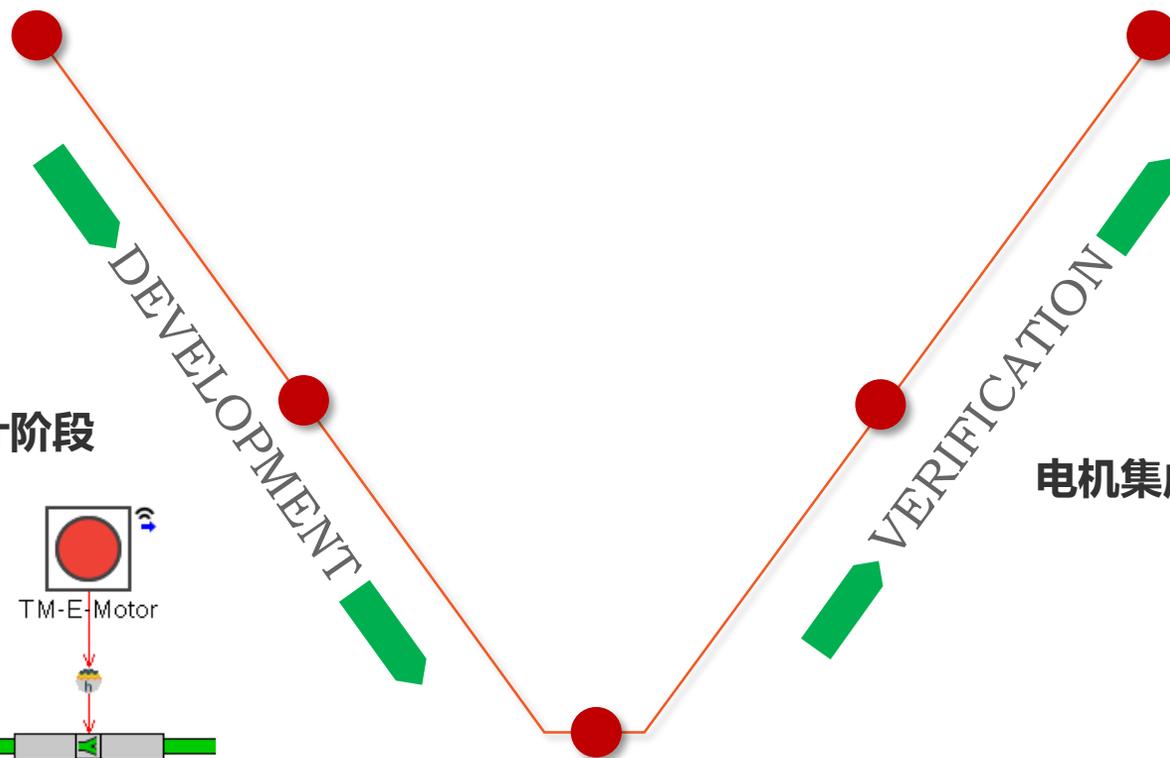
整车集成&控制

电机概念设计阶段

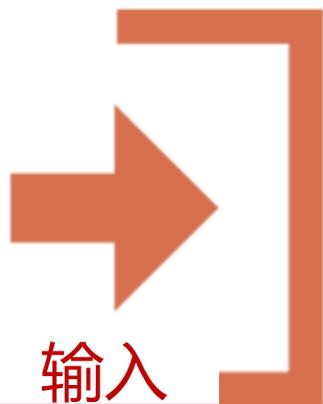
电机集成&控制



AC Machine PM
Synch Thermal

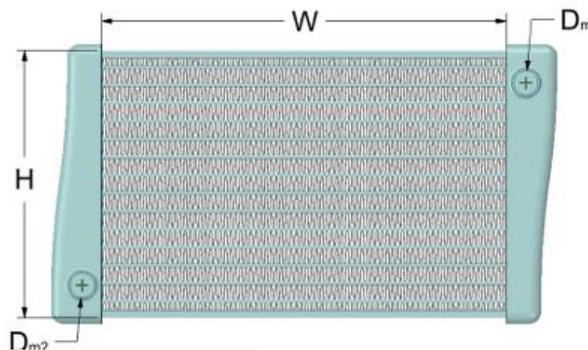


详细电机设计

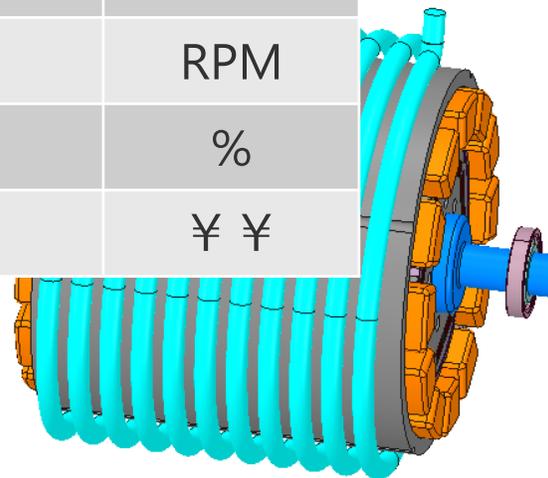


输入

电机设计要求
功率需求
温度要求



| 电机开发目标 | |
|--------|-----|
| 最大扭矩 | |
| 最大扭矩转速 | RPM |
| 最大功率 | kW |
| 最高转速 | RPM |
| 效率 | % |
| 成本 | ¥ ¥ |



输出

电机几何尺寸
电机效率
电机散热量
水泵流量

JMAG-Express Online

File Edit View Template Characteristics Tool Help

Requirement Dimensions **Materials** Motor Diagram Winding Diagram Slot Diagram **Characteristics**

Winding Drive

Parts:
Coil
Stator Core
Rotor Core
Rotor Magnet

Material
Category: Copper
Electric Conductivity, S/m: 64500000
Density, kg/m³: 8960

Correction Factor
Base Temperature, deg C: 20
Temperature Correction Factor, ppm/K: 3810

Map

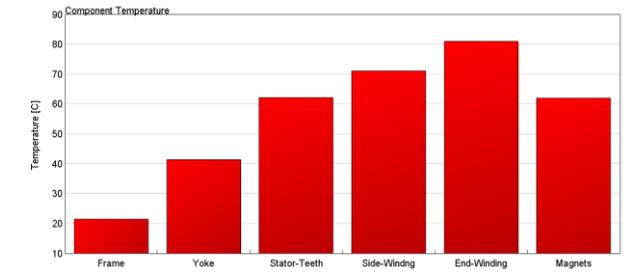
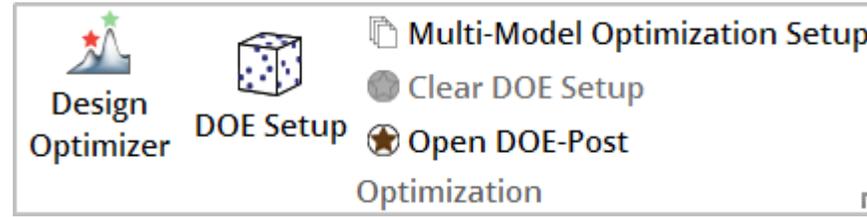
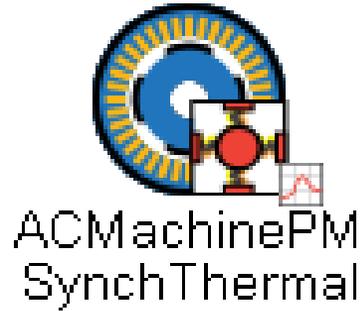
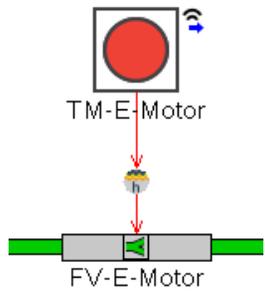
Data Type: Copper Loss

Torque, Nm

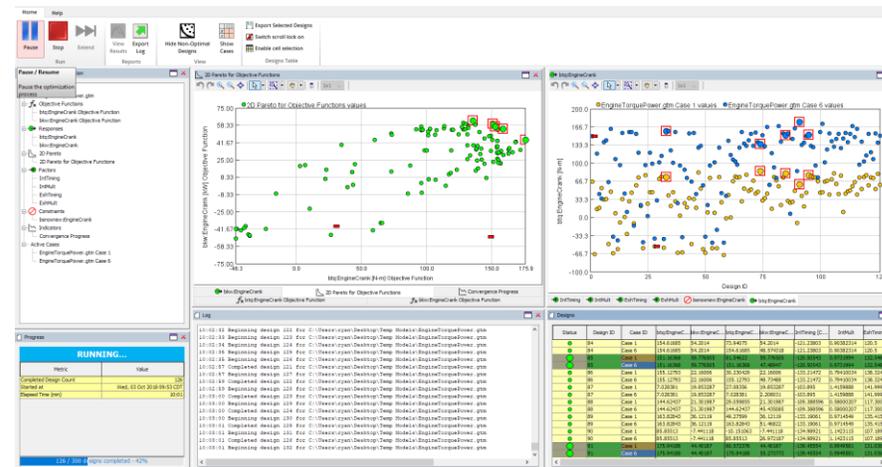
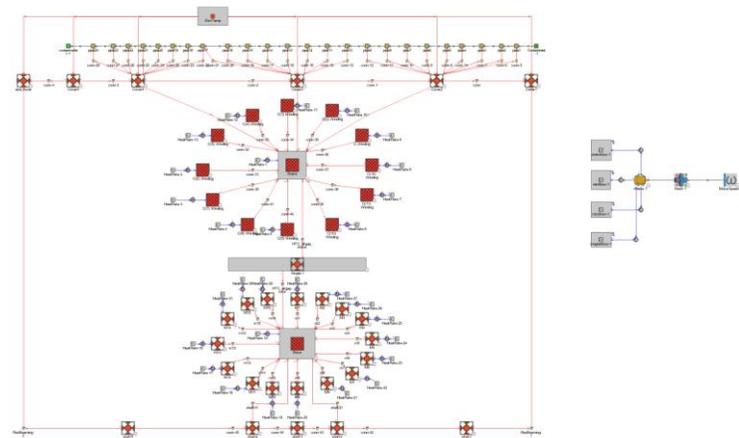
0 2000 4000 6000 8000 10,000 12,000

100
70
90
110
120
20
30
40
50
60
70
80
90
100
110
120

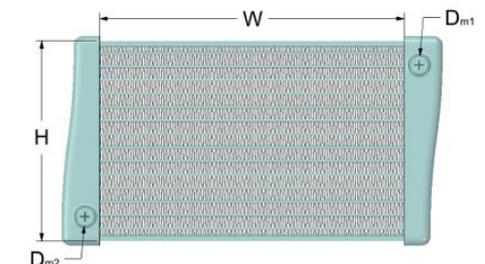
40
20
Copp



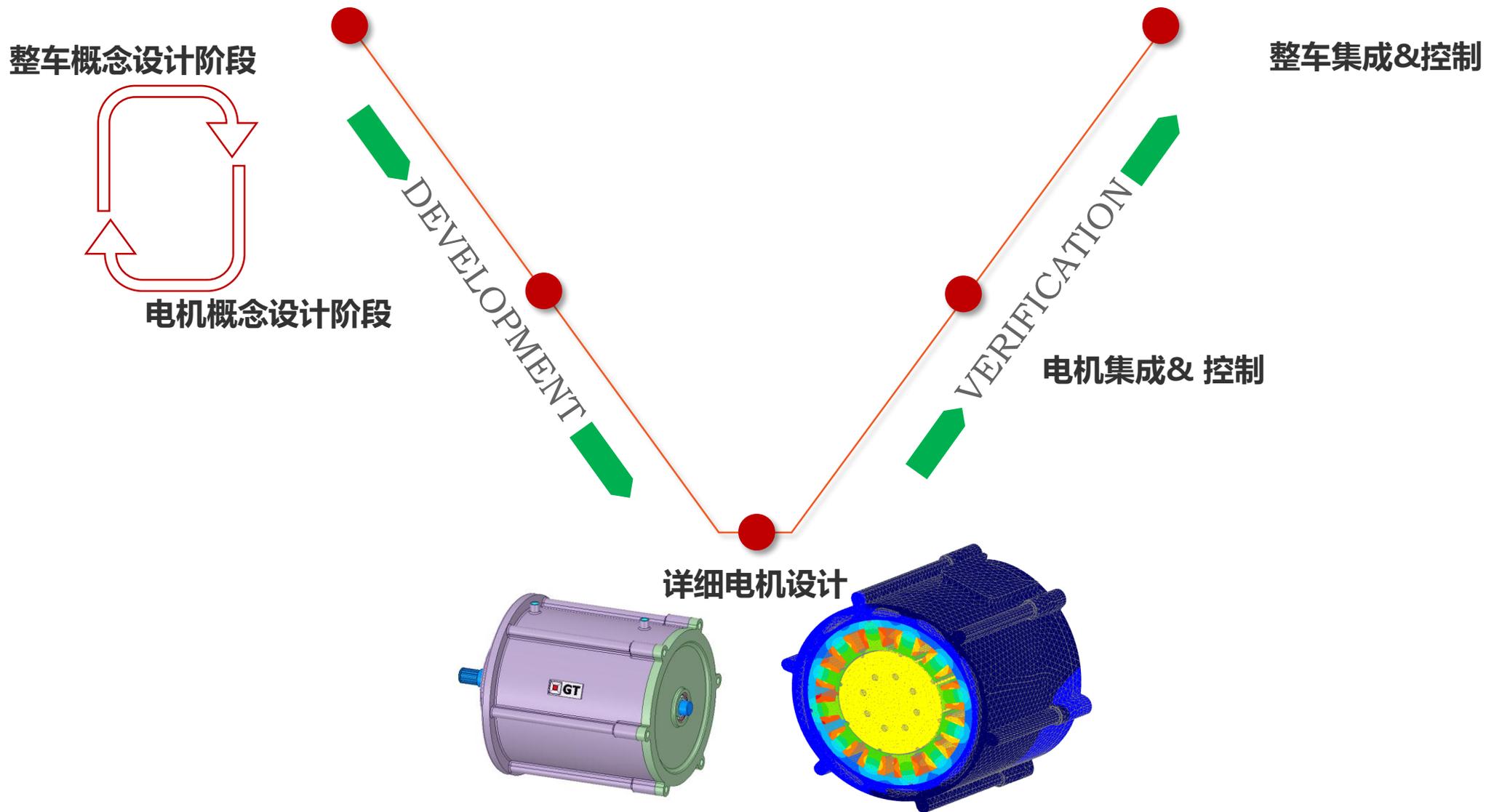
概念温度场

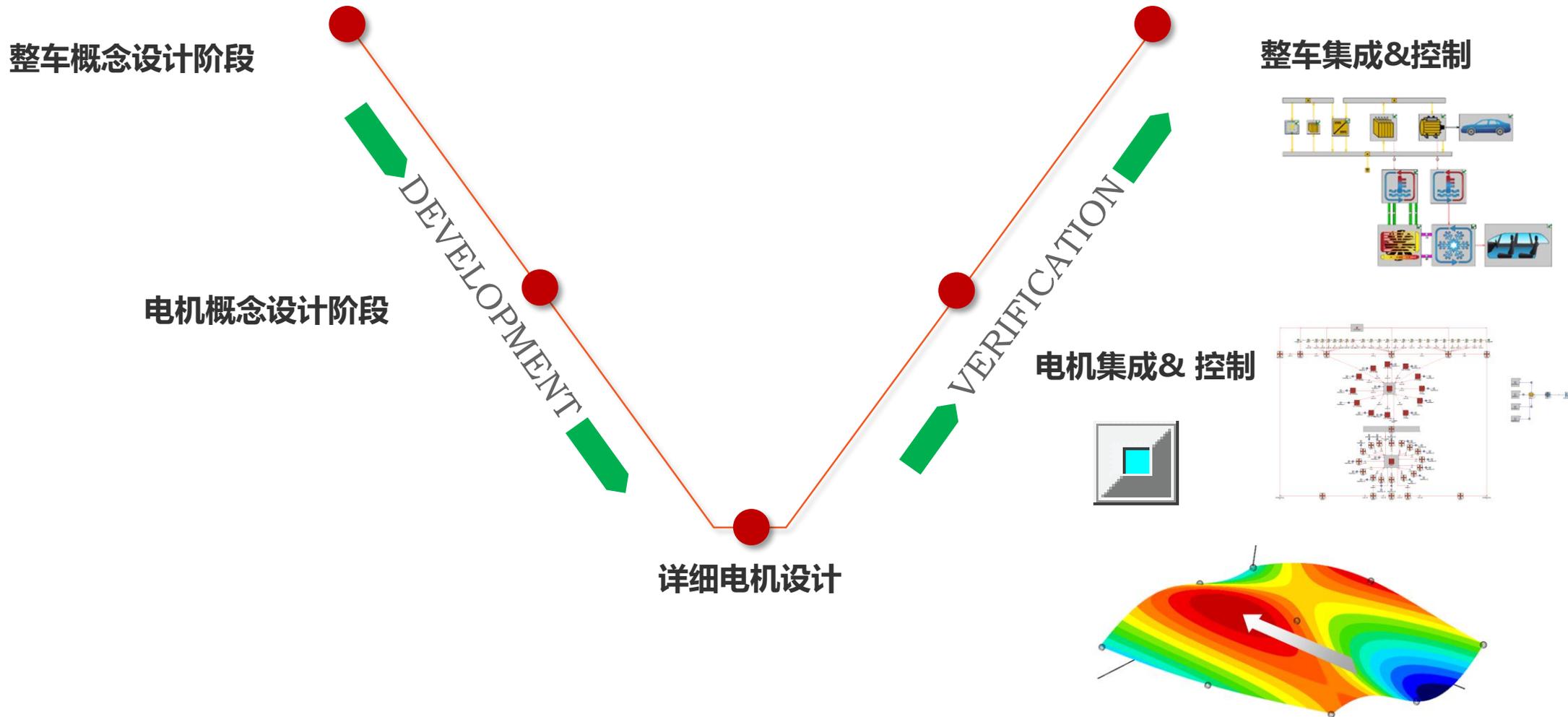


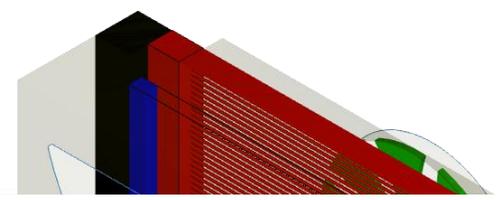
水泵规格



散热量



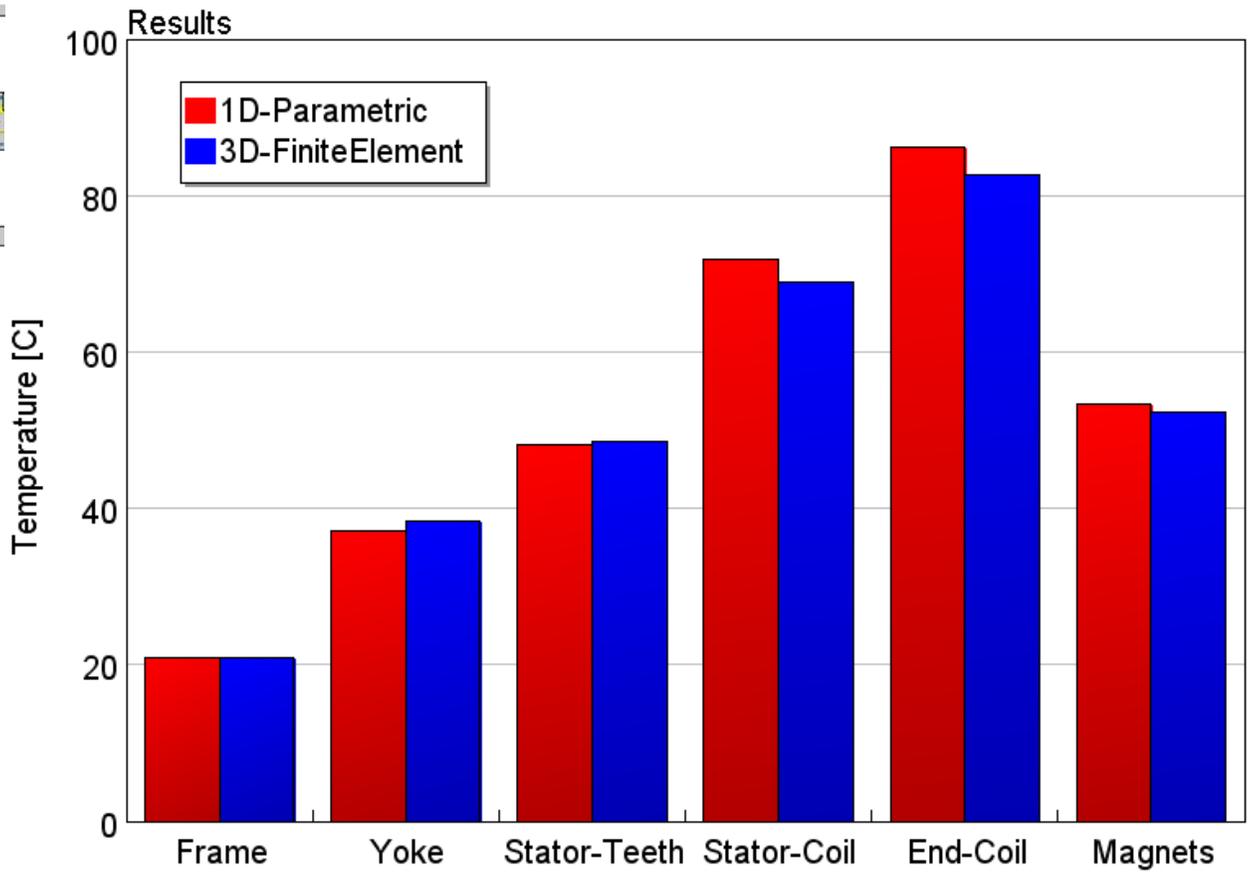




输入

快速计算3D/1D 模型

- 电池
- 电机
- 动力总成 & 整车
- 换热器
- 系统管路



输出

- 续航里程
- 控制策略优化
- 驾驶员舒适性
- 电机温度

GT-ISE v2018 - C:\Users\gtlap\Desktop\Joe\HEV Marketing\Electric_Vehicle-Cooling.gtm : GT-SUITE v2018 *

File Home View Data Tools INHOUSE

Undo Redo Cut Copy Paste Find Template Find Value Select Link Edit Parts in Spreadsheet Flow Scale View Case Setup Run Setup Plot Setup Output Setup Advanced Setup Optimization Run View Results Preprocess Stop Distributed Queue

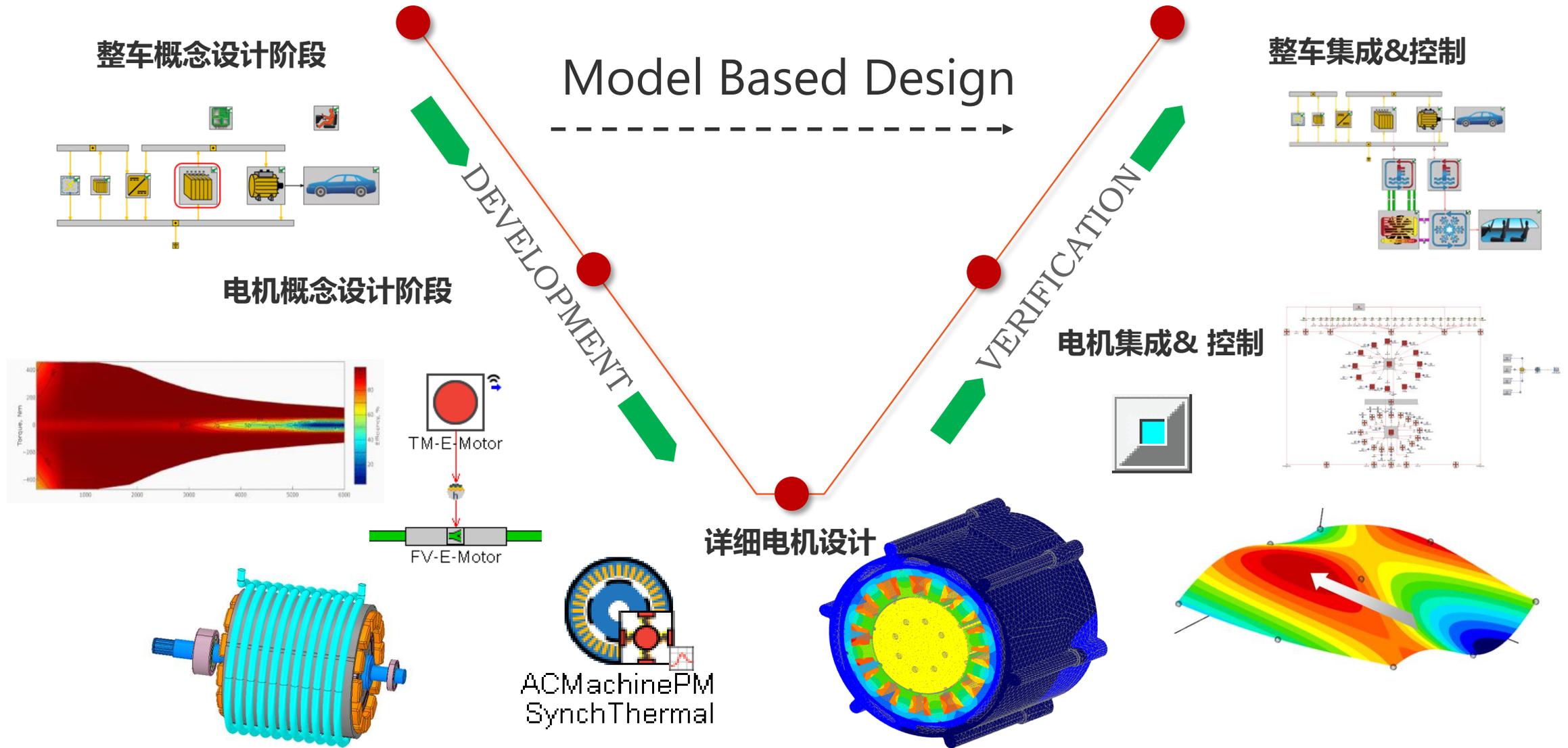
1 Main 2 Battery 2 Inverter_Motor 2 Vehicle 2 DC-DC 2 12VBattery 2 Aux 2 CabinAir 3 HVAC-Case 2 BatteryCooling 2 AC_Refrig 2 EngineCooling 2 UnderhoodAir 3 CoolingModule

Electric Vehicle

单相流和两相流 离散的电机模型

- 离散的温度场

Libraries Mild_Hybrid.gtm x P2_Hybrid.gtm x Series_Hybrid.gtm x TTR_Hybrid.gtm x Electric_Vehicle-Cooling.gtm x



要点总结

- 电机热管理系统在新能源汽车开发过程中尤为重要
- 针对不同的分析目的，需要使用不同层级的模型
- 拟3D电机热管理模型可有效应用于电机热管理系统开发
- GT-SUITE是电机-整车系统开发的理想工具
 - 具有完备的部件库
 - 快捷的前处理工具
 - 完整的整车能量管理平台
 - 优化和DOE

Tesla
Tesla Energy
Lucid Motors
Karma Automotive
Nikola Motor Co
SF Motors
Zoox
Hyllion
Exagon Motors

Chrysler
General Motors
Ford
Porsche
PSA
Renault
Daimler/AMG
Volkswagen Group
Volvo Cars
Harley Davidson

Honda
Toyota
Nissan
Hyundai
Daewoo
Isuzu
Ssangyong
Mazda
Subaru
Suzuki
Yamaha
Dalian Diesel

Audi/Lamborghini
Bentley
BMW
BOSCH
FCA/Ferrari
JLR
Delphi

GT-SUITE新能源客户



■ 超过 800 篇文章收录:

■ 网址 :

<https://www.gtisoft.com/gt-suite/publications/>

Source :

Application :

- All --
- Acoustics
- Battery
- Chain, gear, belt drives
- Cranktrain, crankshaft
- Engine
 - Boosting (Turbos, etc.)
 - CI Combustion
 - Control
 - Cylinder Pressure Analysis
 - EGR
 - Gas Exchange
 - Knock
 - SI Combustion
- Exhaust Aftertreatment
- Fuel Injection
- Hybrid Vehicles
- Hydraulics, pneumatics
- Lubrication and bearings
- SiL,HiL,real-time
- Thermal Management
 - Air Conditioning
 - Powertrain Cooling

Company :

- All --
- Aalto University
- Advanced Development, Mann+H
- AGCO
- ANSYS
- ARAI
- Aramco
- Arthur D. Little, Inc.
- AUDI
- AVL Graz, AVL Fuel Systems
- AVL Moteur Moderne
- Bangladesh Army
- Bangladesh University of Engineeri
- Beijing Automotive Powertrain Co.,
- Beijing Institute of Technology
- Beiqi Foton Motor Co., Ltd.
- Berlin TU
- Bertrandt

Industry :

- All --
- Aeronautics
- Agriculture, Construction, Off-High
- Automotive
- Large Engine (Marine, Power Gene
- Motorcycle

Year :

- All --
- 2017
- 2016
- 2015
- 2014
- 2013

Keyword(s) Filter :

Generate Publications List

感谢倾听
期待与您的进一步合作 😊



扫一扫关注官方微信
获得第一手下载资讯

联系我们

- web: <https://www.idaj.cn/>
- e-mail: support@idaj.cn
- Tel: 021-50588290 ; 010-65881497