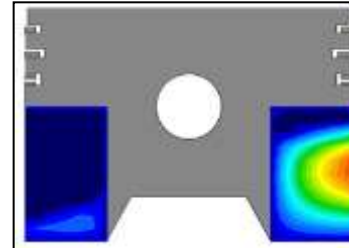
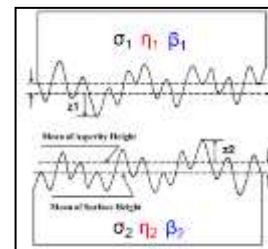
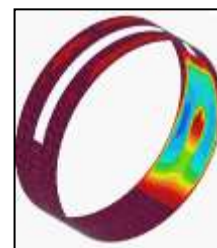
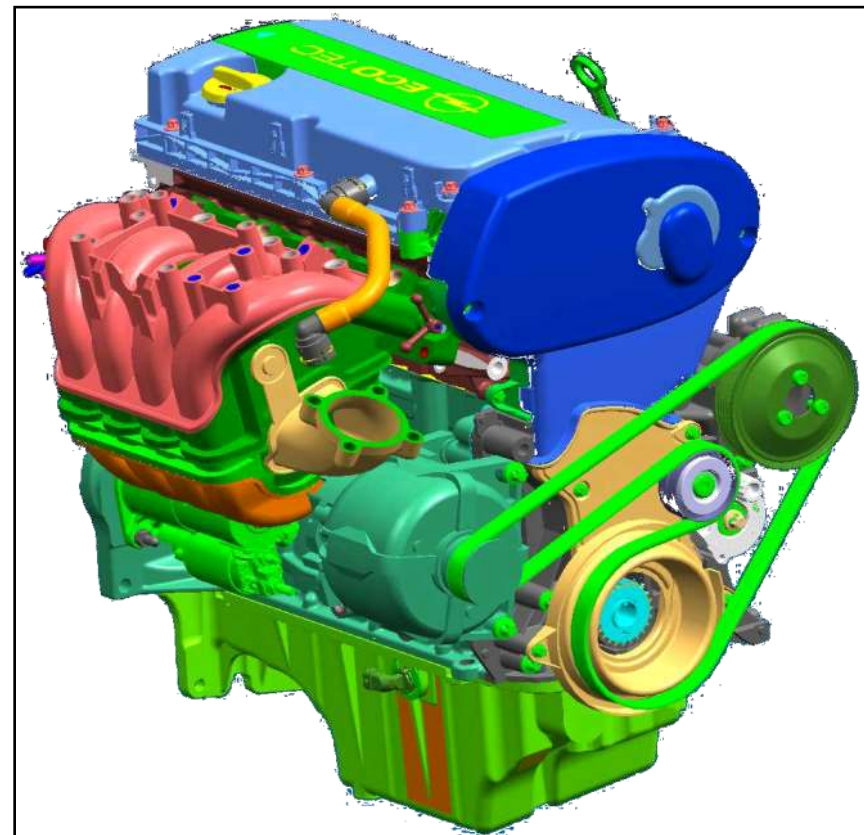


GT-SUITE

在发动机摩擦中的 分析应用



2013.12.20

主要内容

1 GT-SUITE在发动机摩擦中的预测分析与模拟

- 动机、原因和需求
- GT-SUITE能提供的关键技术
- 发动机摩擦模拟的关键模板
- 校核

2 摩擦和润滑;

3 应用分析

4 Q&A, 讨论

应用“前瞻”

- 对于发动机的轴承，什么样的间隙是合适的？什么样的入口润滑油温度是合适的？
- 在“strip-down”的测试中相关参数，怎么关联到运行中的发动机摩擦？
- 在发动机的停-起过程中，发动机的摩擦副是什么样的运行状态？

主要内容

1 GT-SUITE在发动机摩擦中的预测分析与模拟

- 动机、原因和需求
- GT-SUITE能提供的关键技术
- 发动机摩擦模拟的关键模板
- 校核

2 摩擦和润滑; v7.5新功能和开发进展

3 应用分析

4 Q&A, 讨论

发动机摩擦的预测模拟: 动机

工业界的应用和需求:

- 1 在概念设计阶段预测设计和运行的条件的的影响，在各运行条件下减少摩擦，考虑设计的最优化，使得发动机的摩擦最小
- 2 在GT-SUITE 发动机动力学模型中，仿真瞬态的缸内摩擦，对于瞬态或停-起状态中的混合动力车来说非常重要 (starting, HEV)
- 3 对于VTM来说，评估摩擦副的热产生状态

发动机摩擦的预测模拟: 动机

预测 vs. 关联或经验

- 1 物理模型, 与基本的摩擦原理一致
- 2 单独模拟发动机的每一个摩擦副
- 3 瞬态模拟 (与曲轴转角相关)
- 4 相对于表面、摩擦系数和润滑参数的敏感性分析

困难: 模型必须有以下特点:

- 高精度, 预测必须准确
- 运算快速、使用简便, 适合日常应用

主要内容

1 GT-SUITE在发动机摩擦中的预测分析与模拟

- 动机、原因和需求
- GT-SUITE能提供的关键技术
- 发动机摩擦模拟的关键模板
- 校核

2 摩擦和润滑; v7.5新功能和开发进展

3 应用分析

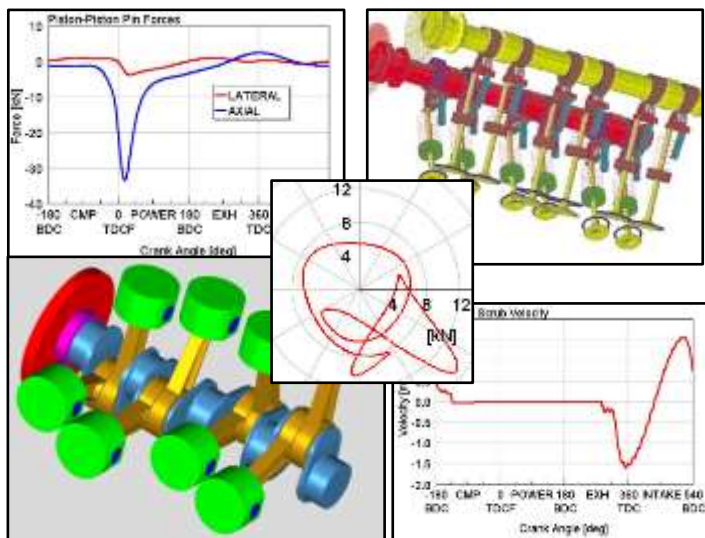
4 Q&A, 讨论

GT-SUITE提供的关键技术 1



Mechanics

Mechanical Modeling/MBD:
Speeds/Loads

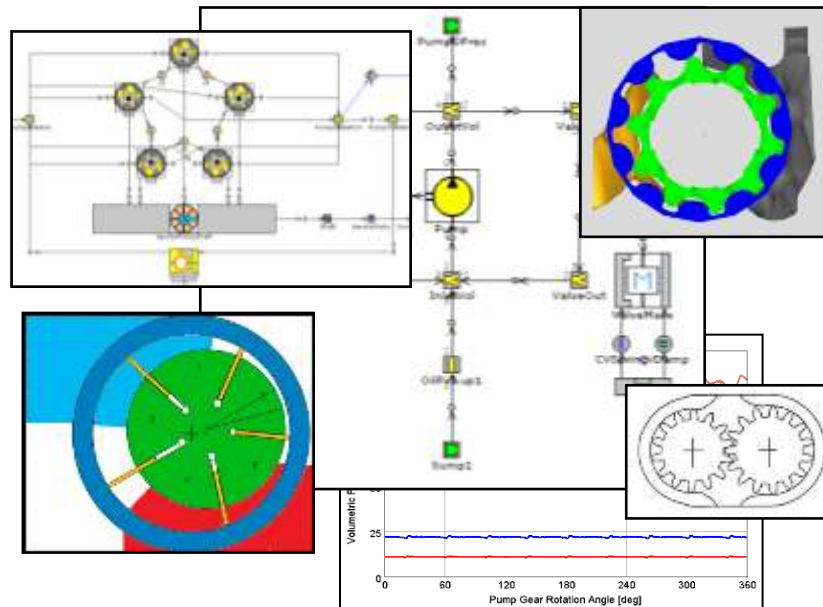


- ✓ Primary & secondary motions shear/scrub speeds
- ✓ Pressure, inertia, spring loads on piston/rings, at bearings, contacts, joints, guides etc.



ThermoFluids

Modeling of Thermal and Fluid Systems,
Pressures & Pumping Losses



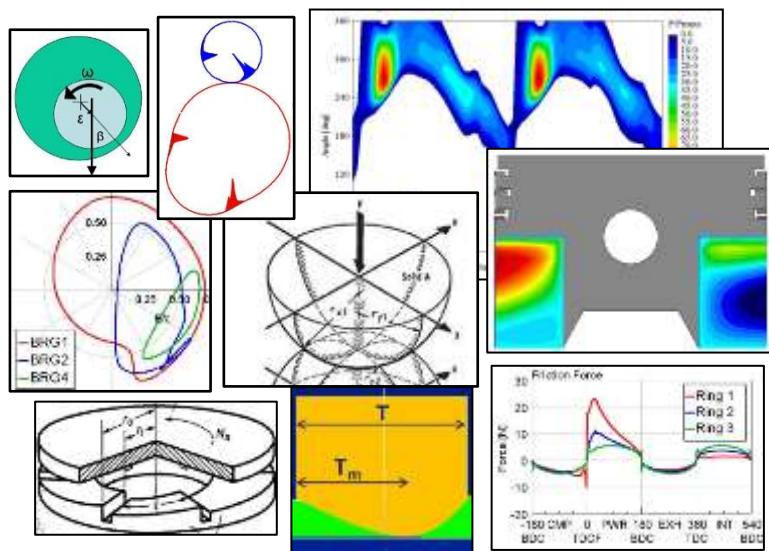
- ✓ Coolant, oil, gas pressures, flow rates, component temperatures
- ✓ Pump PdV work, leakage, friction etc. losses
- ✓ Fluid pressure BCs

GT-SUITE提供的关键技术 2



Tribology: Models

Modeling of Oil Film HD, Surface Roughness Interactions

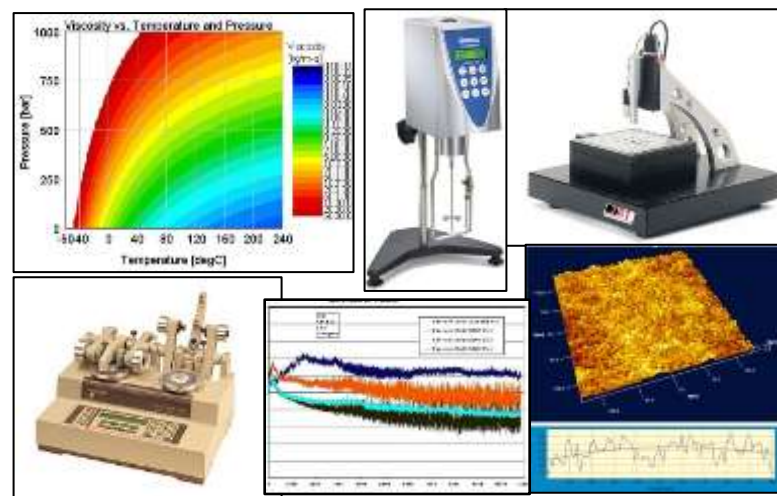


- ✓ OFT, Oil pressure, shear stress distributions
- ✓ Asperity contact pressures
- ✓ Oil temperature, thermal effects



Tribology: Properties

Inputs for/Sensitivity to Laboratory Measurements:
Oil, Surface, Friction

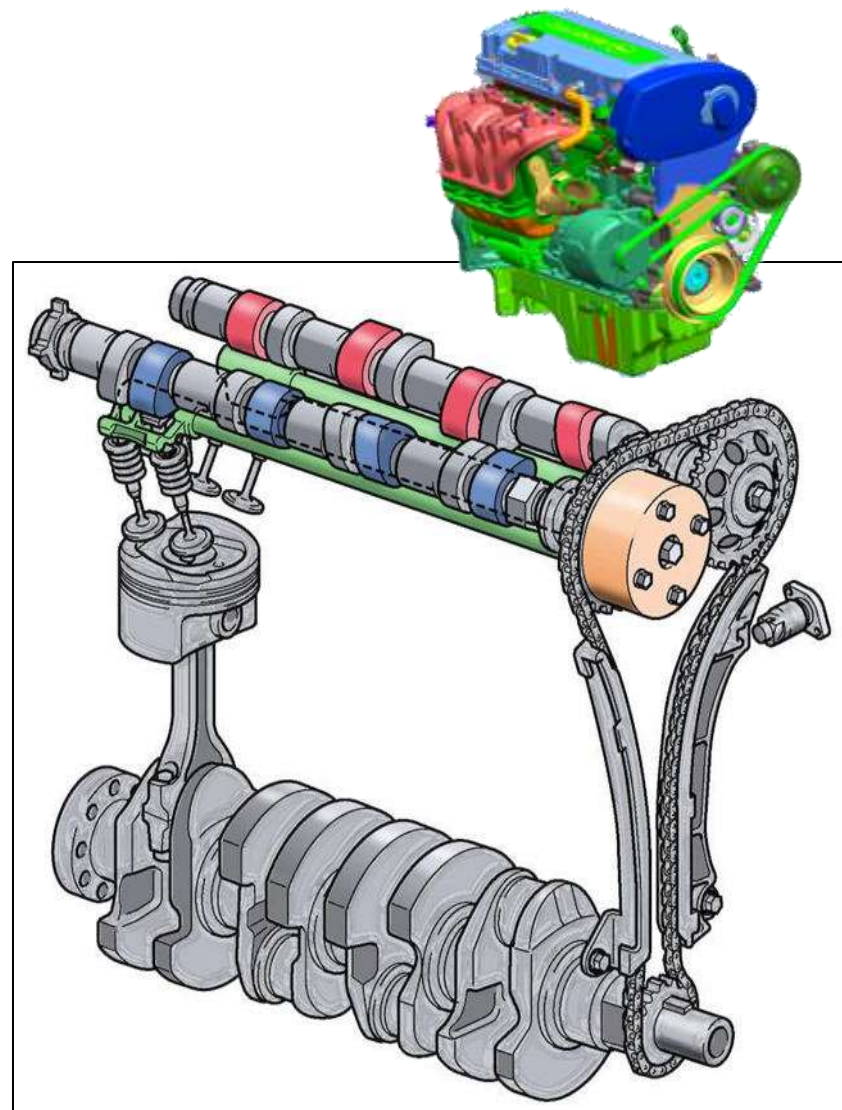


- ✓ Oil viscosity vs. T,P, shear rate
- ✓ Surface roughness
- ✓ Friction and wear coeff. for friction surface matl. pairs

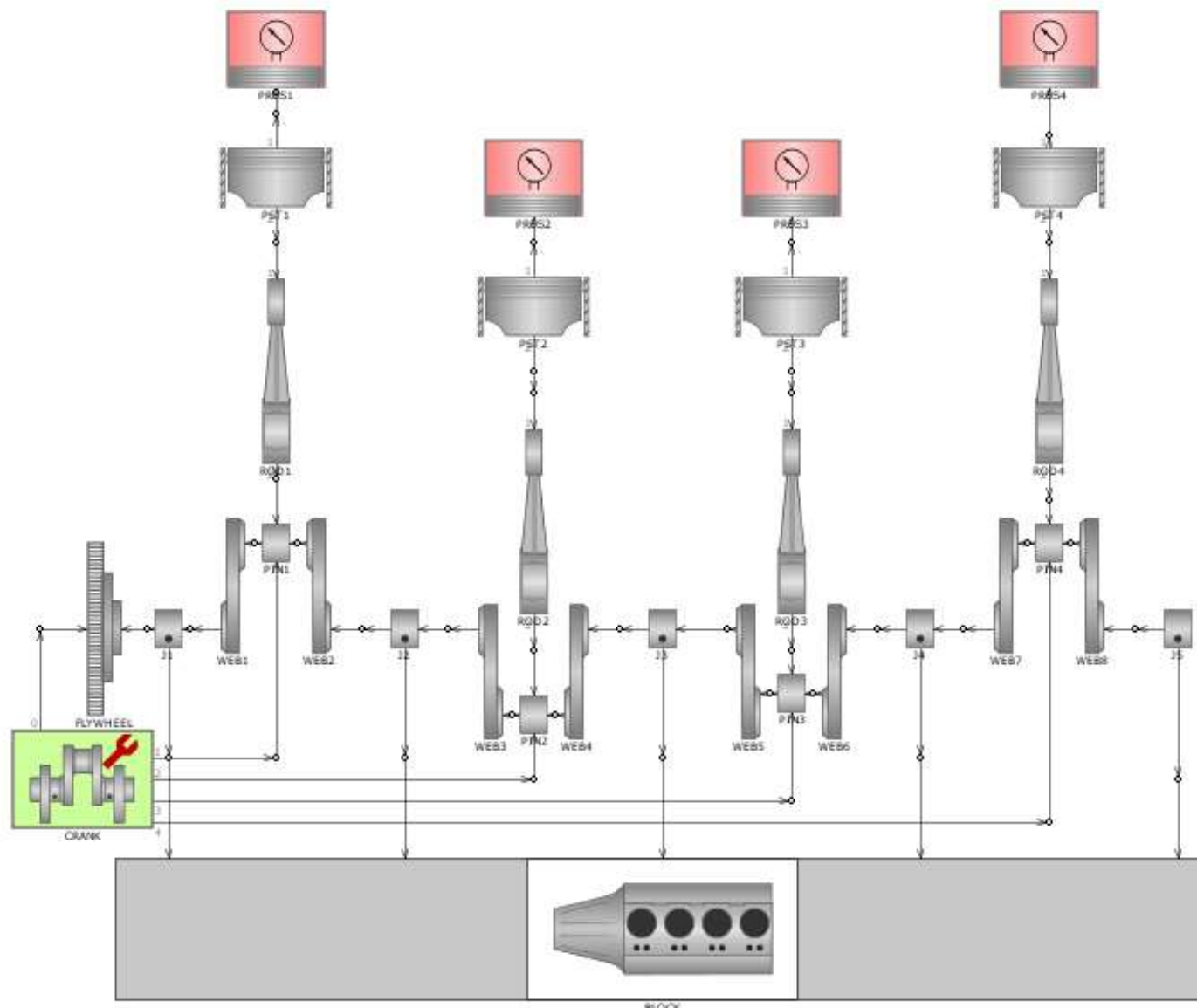
关键的仿真技术- 机械/MBD

速度, 负荷

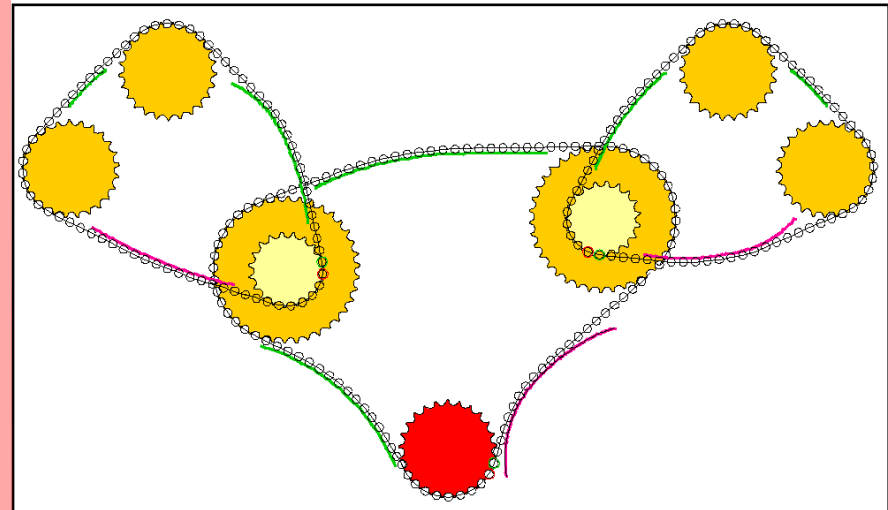
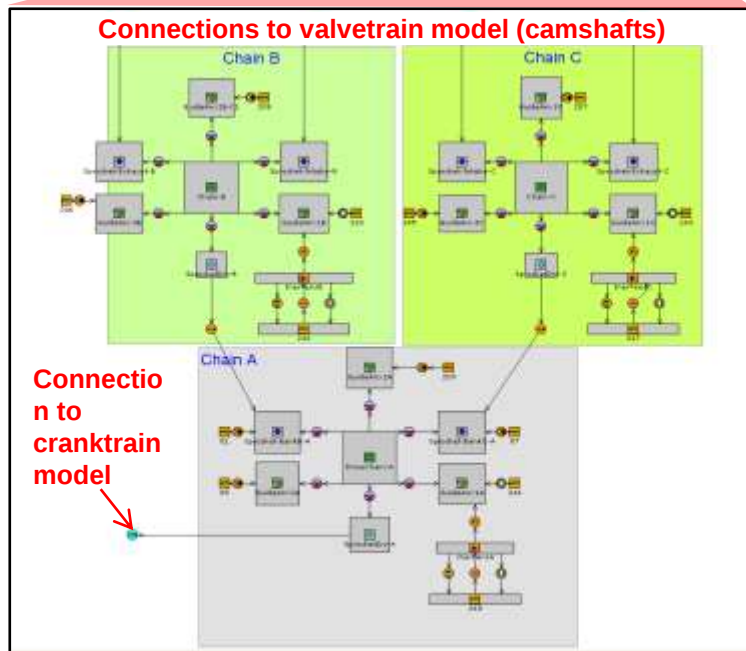
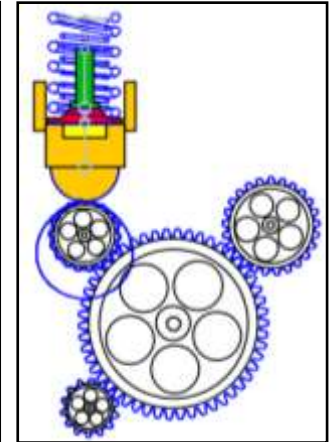
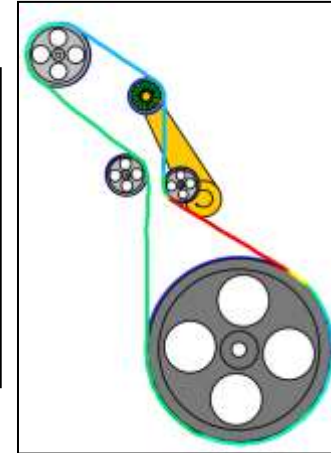
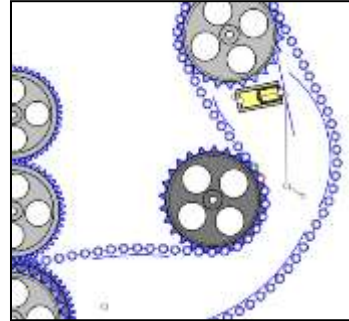
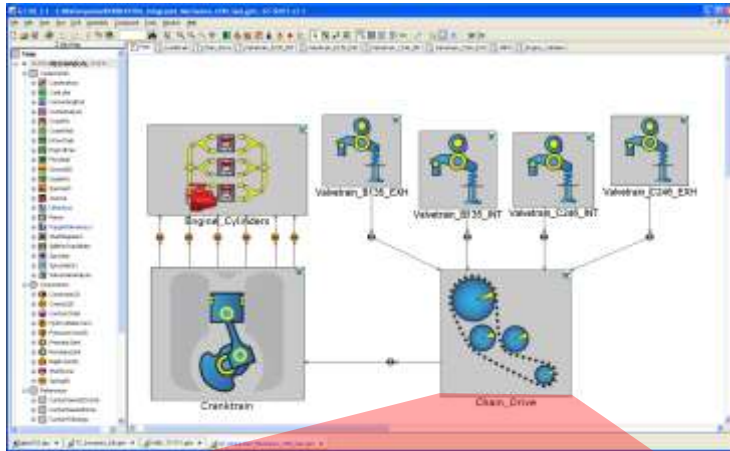
- 曲柄连杆机构, 平衡轴
- 配气机构, 凸轮轴
- 齿轮、链条、和带传动
- 增压器和各种泵
- 基于最通用的2-D/3-D (rigid/flex) MBD
- 通过高水平的部件系统联合仿真完整的发动机的机械系统
- 与发动机 (GT-POWER) 和/或润滑系统无缝的耦合



GT-SUITE 发动机机械仿真(Cranktrain)

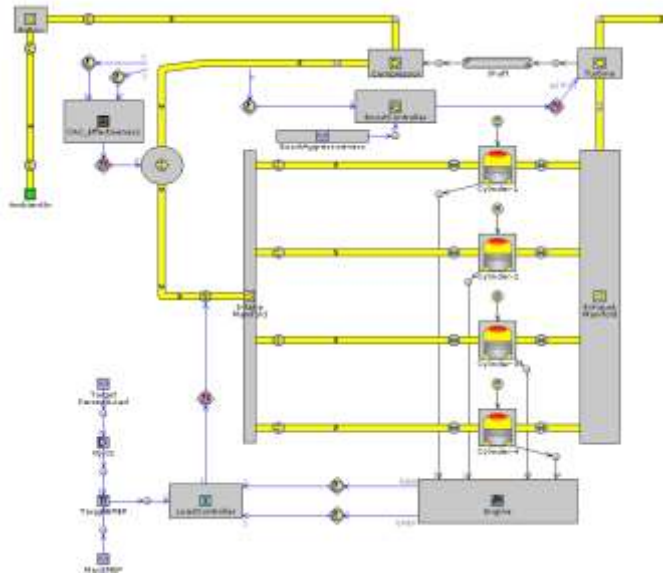


GT-SUITE 发动机机械仿真(Timing Drives)

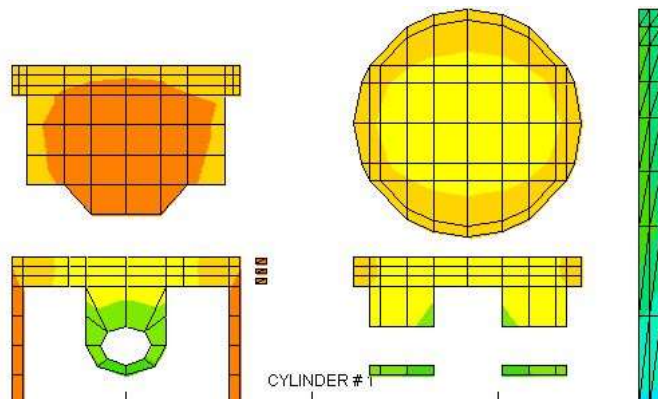
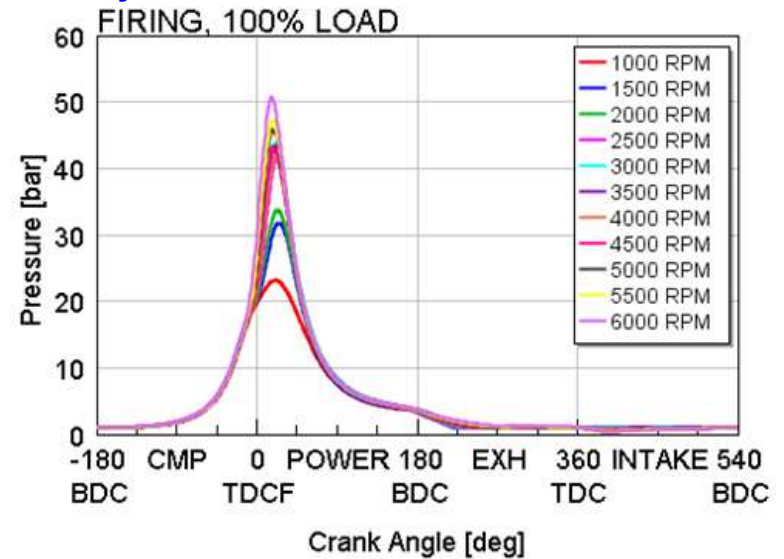


关键的仿真技术- 热流体技术

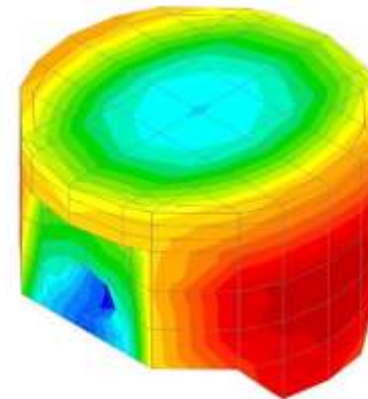
GT-POWER model



Cylinder Pressures



Piston, ring, liner
Temperatures



RPM	ΔT
250	0.2
500	0.6
750	1.1
1000	2.0
1250	2.5
1500	3.5

摩擦模拟在GT-SUITE中的应用

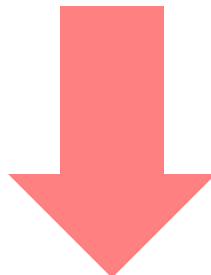
在机构中的摩擦模拟连接:

less predictive:
basic geom
user imposed



1 机械连接(运动学的限制1D,2D,3D)

2 滑动摩擦连接(typically 1D)

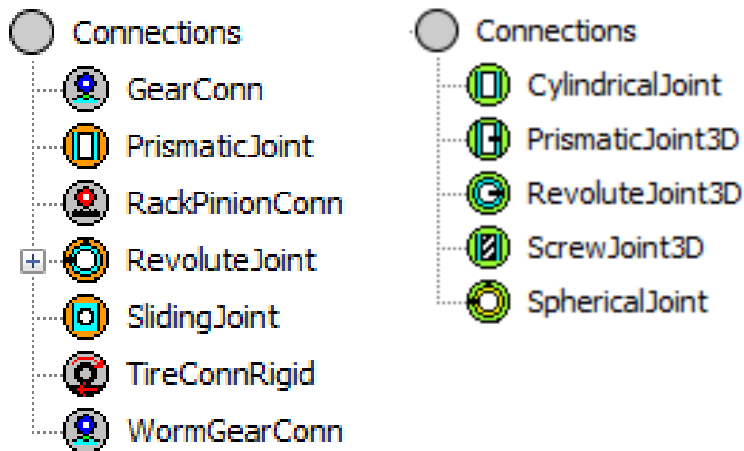


3 接触副 (between 2D, 3D bodies)

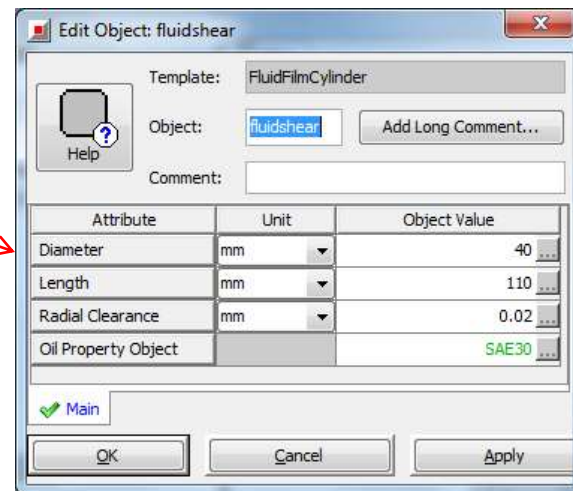
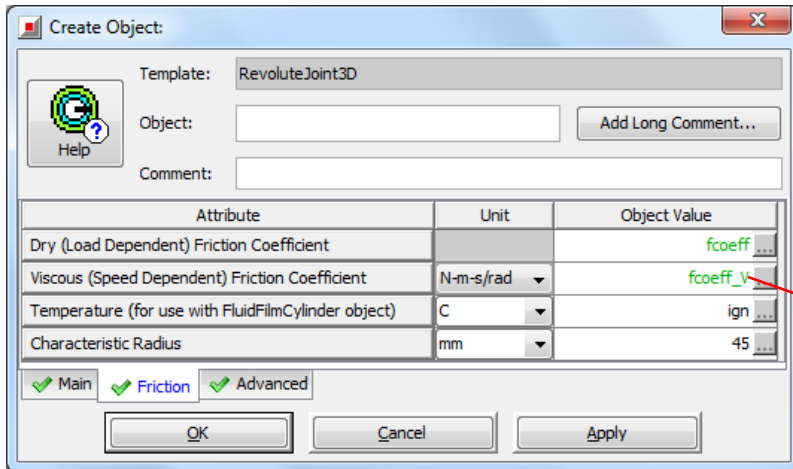
4 HD的油膜连接, 与润滑系统相互作用(1D,2D,3D)

more predictive:
detailed geom
physical model

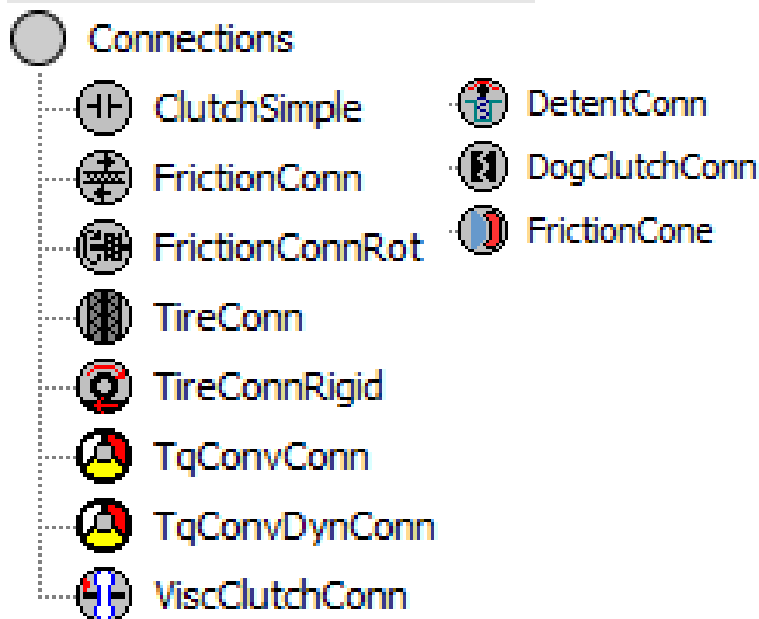
机械连接中的摩擦



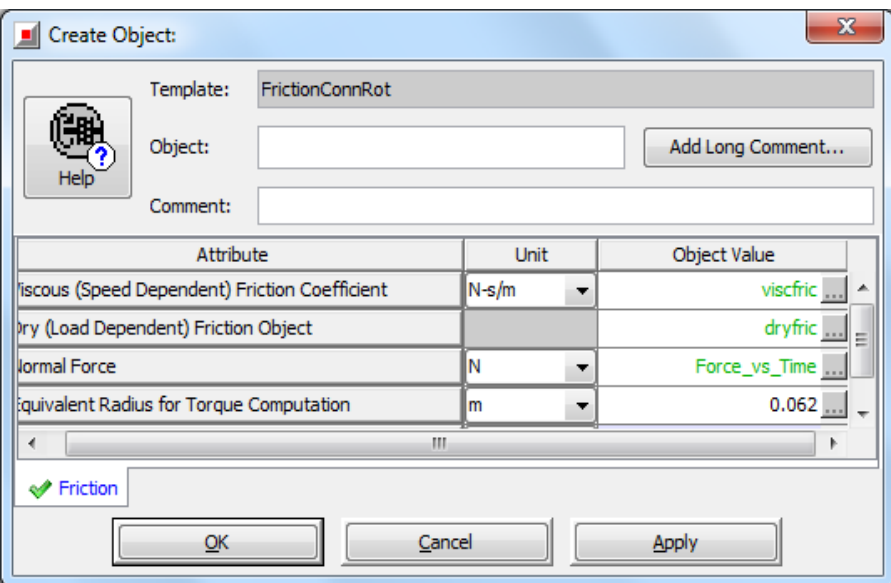
- 2D 或 3D的基本元件
- 运动学或动力学的连接，提供速度、载荷
- 摩擦系数（效率）与速度和载荷相关
- 一定程度上的准物理现象：基于油粘性剪力,油的属性



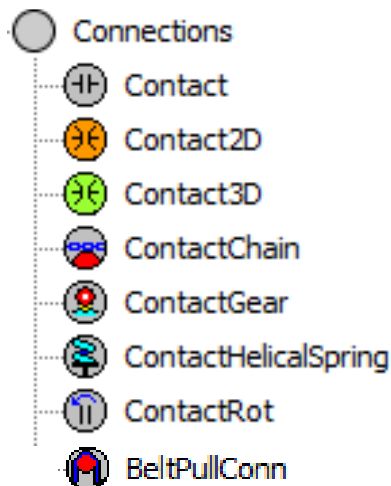
在滑动连接中的摩擦



- 1D/1D基本旋转元件
- 正交的负载: 用记定义或外部输入 (离合器的执行力, 轮胎负载等.)
- 滑移速度: 根据模型的状态(发动机、变速箱、增压器轴转速、同步器等)
- 图或表的摩擦系数. vs. speed, load
- 特定的准物理模型: 基于粘性剪切应力, 润滑油的属性, LuGre 模型, 液力变矩器MAP图, 等.



接觸摩擦



Create Object:

Template: Contact2D

Object: Add Long Comment...

Comment:

Attribute	Unit	Object Value
Contact Stiffness Input Method		calculation
Contact Stiffness	N/m	ign
Contact Tribology Reference Object		trib

☒ Main
 ☒ Advanced

Edit Object: trib

Template: ContactTribology

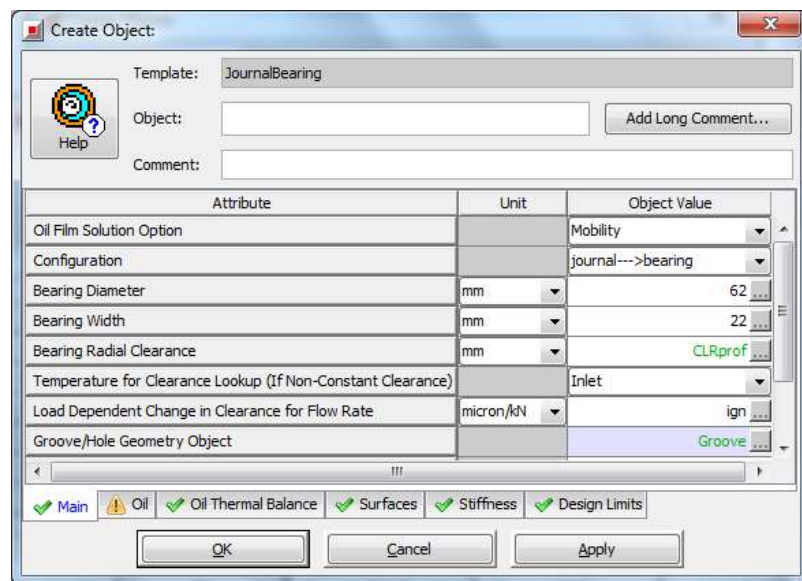
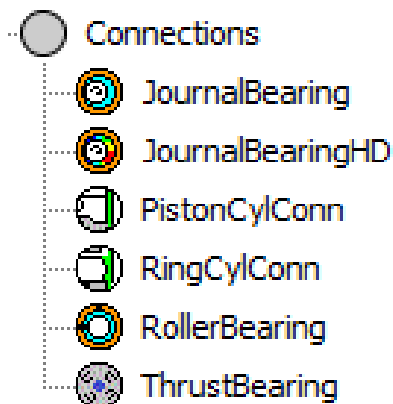
Object: trib Add Long Comment...

Comment:

Attribute	Unit	Object Value
Model Option		ehd
Oil Property Object		5W30
Oil Temperature	C	112
Surface 1 Material Object		Steel
Surface 1 Roughness	mm	def (=0.02 microns)
Surface 1 Width	mm	12
Surface 1 Crown Radius	mm	450
Surface 2 Material Object		Steel
Surface 2 Roughness	mm	def (=0.02 microns)
Surface 2 Width	mm	9
Surface 2 Crown Radius	mm	ign

☒ Main
 ☒ Advanced
 ☒ Output

油膜连接的摩擦模拟



- 适形的润滑界面
- 1D,2D, 3D 机械部件 (2+ dofs)
- 专业化的 拓扑几何/运动, 如: 平面, 圆柱形油膜, 旋转和/或平移的二阶运动
- 表面粗糙度 (粗糙度) 交界面, 混合润滑
- 模型进行HD和接触摩擦混合计算, 而非输入
- 真实的物理现象, **预测**

油膜连接— 常规输入

- 不同的几何参数, 用到以下参数:
 - 油压和温度等边界条件 (或者通过计算得到温度边界)
 - 润滑油的属性: [OilPropData*](#), [FluidLiq*](#)
 - 表面粗糙度的数据: [SurfaceRoughness](#)
 - 表面材料属性: [MaterialMechanical](#)

Template: JournalBearing

Object: CRS

Comment:

Attribute	Unit	Object Value
Oil Film Solution Option		Mobility
Configuration		journal--->bearing
Bearing Diameter	mm	23
Bearing Width	mm	22
Bearing Radial Clearance	See Cas...	[SE_CLR]
Temperature for Clearance Lookup (If Non-Constant Clearance)		Inlet
Load Dependent Change in Clearance for Flow Rate	micron/kN	ign
Groove/Hole Geometry Object		ign
Mobility (or Impedance) Map Plots?		☐
Velocity Constraint Stabilization Factor	1/s	def
Displacement Constraint Stabilization Factor	1/s	def

✓ Main ✓ Oil ✓ Oil Thermal Balance ✓ Surfaces ✓ Stiffness ✓ Design Limits

OK Cancel Apply

Template: RingCylConn

Object: topface

Comment:

Attribute	Unit	Object Value
Ring Face Thickness	See Cas...	[RING1_THK]
Number of Rails (e.g. 2 for Oil Ring)		1
Ring Face Profile Specification Option		
Split Standard Profile Types (Top/Bottom)		
Normalized Axial Position of Zero Height (MOFT Location)		def (=0.5)
Profile Type (Top)		Parabolic
Maximum Height of Profile (Top)	See Cas...	[RING1_HGT]
Profile Type (Bottom)		Parabolic
Maximum Height of Profile (Bottom)	See Cas...	[RING1_HGT]
External Ring Face Profile		
Ring Face Profile	micron	ign
Ring Profile Plot		☒

✓ Ring Face ✓ Oil ✓ Ring-Cylinder Contact ✓ Advanced

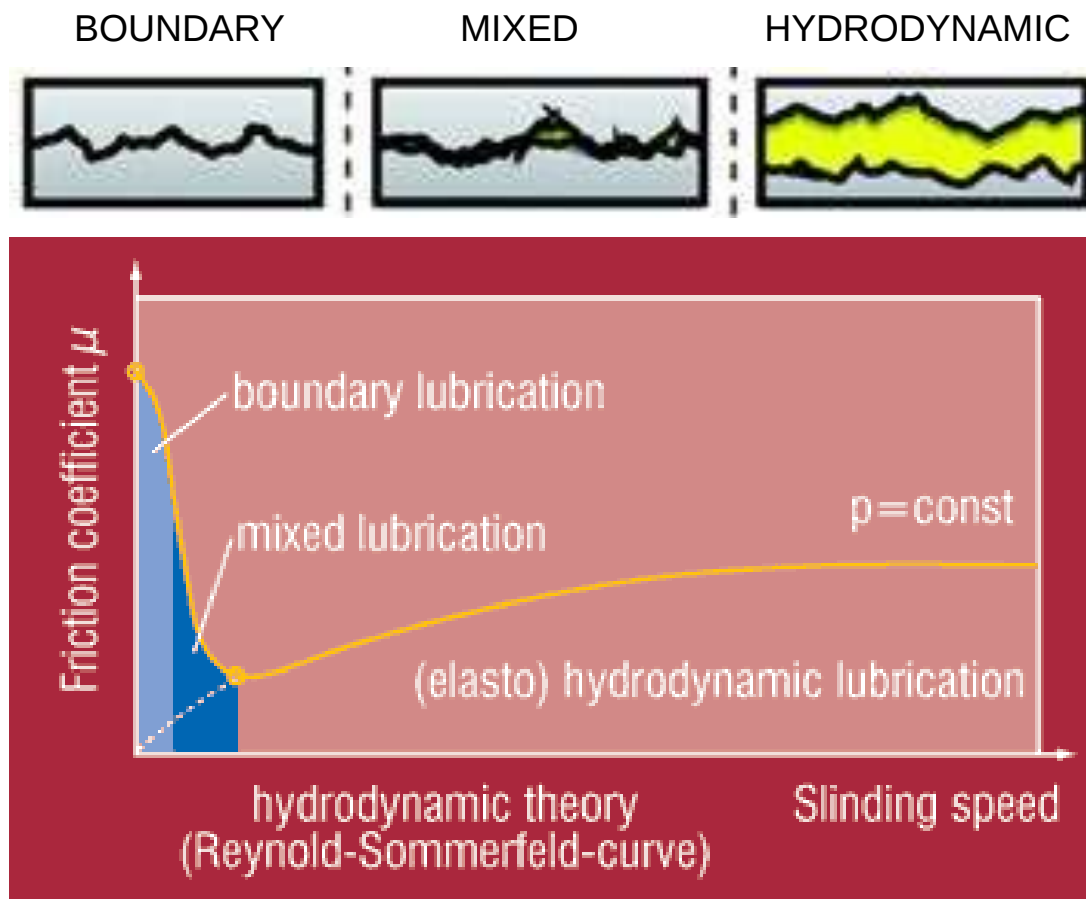
OK Cancel Apply

关键的仿真技术— 摩擦学

关键目标:

准确预测：摩擦交界面的状态,是流体润滑、,边界润滑和混合润滑, 必须与以下一致:

- Speeds
- Load
- Geometry
- Lubricant properties
- Surface material properties
- Surface roughness
- Component temperatures



关键的仿真技术– 摩擦学

- 1 油膜的 HD求解 (Reynolds Eq.) 求解(FD)
 - 气缸几何(journal bearings, piston skirt)
 - 平面几何(slider bearing, e.g. rings)
 - 圆盘/圆环向何(止推轴承)
- 2 通用的油膜拓扑HD 求解 (FE, mass-conserving, v74)
- 3 Greenwood-Tripp 粗糙度 (asperity) 接触模型
- 4 Patir-Cheng corrections for roughness effect on film HD
- 5 Dawson-Hamrock EHD 模型或线/点的接触
 - Valvetrain contacts, ball/needle bearings
- 6 油膜的热模拟

关键的摩擦学数据- 油的属性

- 油度的粘度, 影响因子:
 - 温度
 - 压力
 - 剪切速率 (Carreau Eq.)
- 油的密度, 比热等

Edit Object: 15W40

Template: OilPropDataSAE

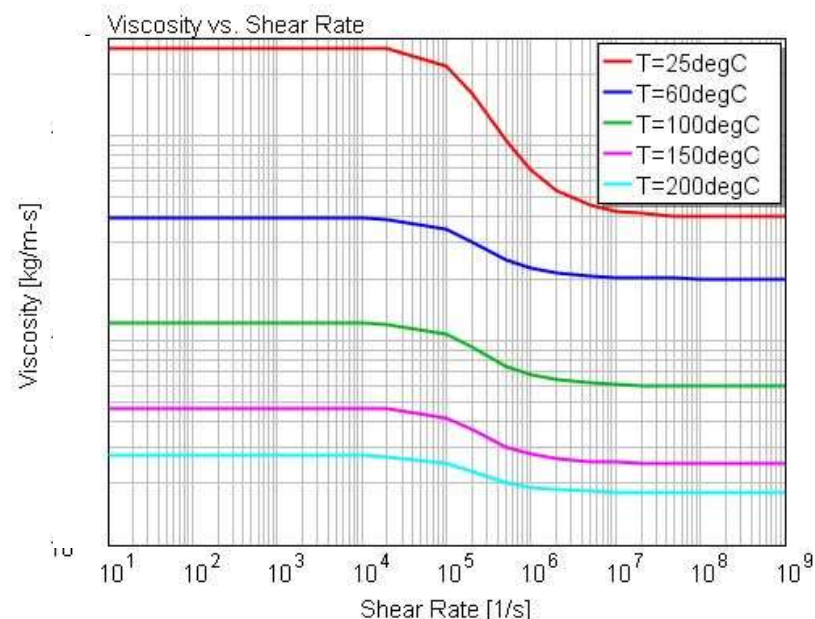
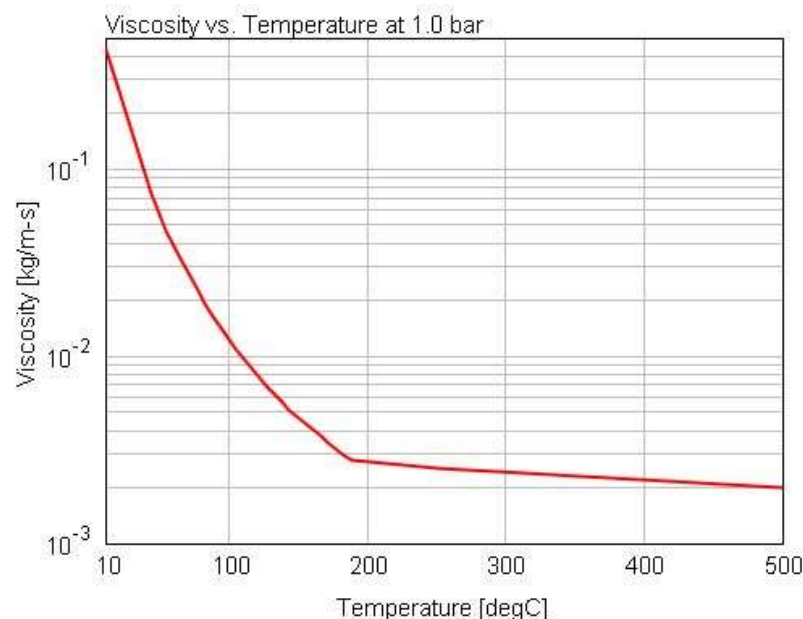
Object: 15W40

Comments:

Attribute	Unit	Object Value
SAE Oil Name		sae 15w40
Density	kg/m ³	804.5
Specific Heat	J/kg K	1960
Bulk Modulus	Pa	1E9
Vapor Pressure	Pa	100
Volume Fraction of Air		0
Plot of Viscosity vs. Temperature & Pressure		☒
Reference Minimum Viscosity (for Shear Thinning)	See Cas...	[VISC_MIN]
Shear Thinning (Carreau) Model Multiplier		[CARREAU_MULT]
Shear Thinning (Carreau) Model Exponent		[CARREAU_EXP]

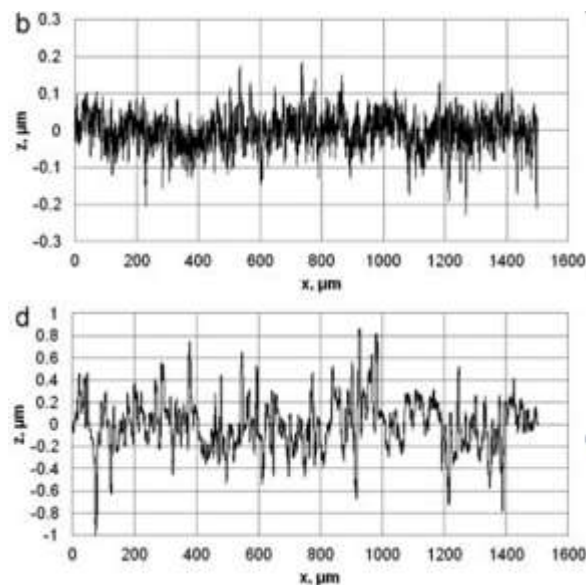
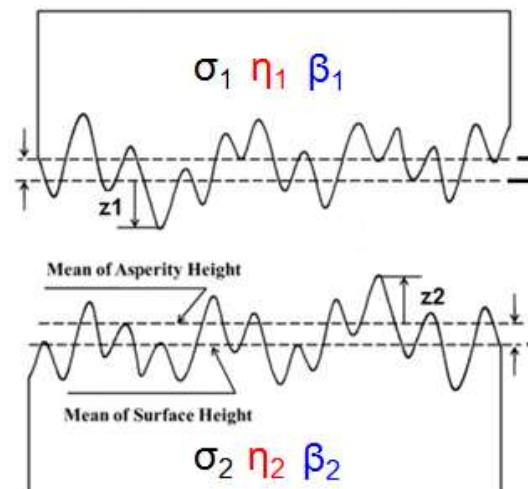
Main

OK Cancel Apply



关键的摩擦学数据— 表面粗糙度

- Greenwood 模型参数
 - σ asperity height standard deviation
 - β asperity peak radius of curvature
 - η asperity density (area⁻¹)
- Data available:
 - Raw profilometer measurements
 - Rq , Δq etc.
- σ, β, η have to be calculated from this data



自动抽取粗糙度参数 σ, β, η

SurfaceRoughness object

Edit Object: SRF_liner

Template: SurfaceRoughness

Object: SRF_liner

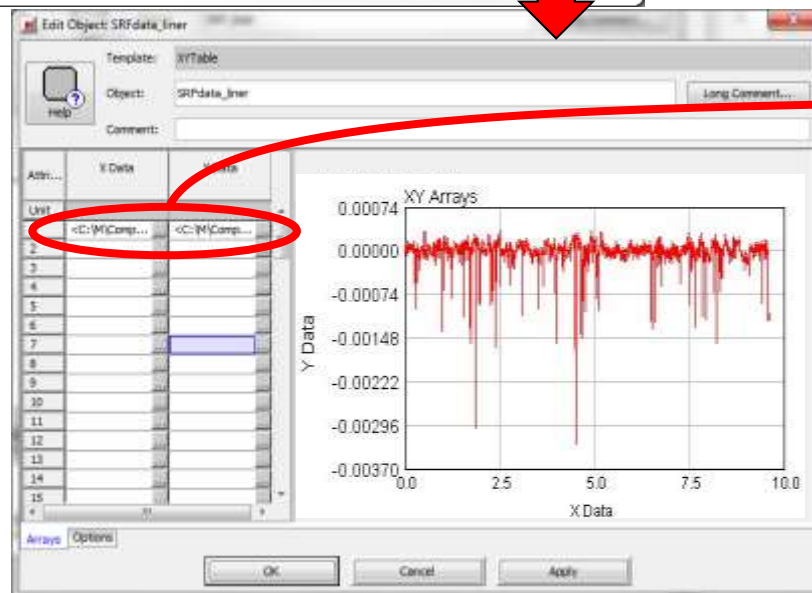
Comment:

Attribute	Unit	Object Value
Asperity Peak Height Standard Deviation (Sigma)	mm	def ...
Asperity Density (Eta)	1/m^2	def ...
Asperity Radius of Curvature (Beta)	mm	def ...
Profilometer Data (XYTable) Object	mm	SRFdata_liner ...
Method for Extracting Sigma, Eta, Beta		Tomanik
Asperity Peak Data Plots (Profilometer Data)		☒

Main

OK Cancel Apply

XYTable object



C:\M\Companies\FORD\FORD_ENGINE_...

File Edit Search View Encoding Language Settings
Macro Run Plugins Window ?

ch6.mp GTsuite.mpp Crankshaft_LowerMB1-usec

```
1 1 2
2 Liner_ 0.000000000000e+000 MOD
3 CX A 3.840100000000e+004 MM 1.00000
4 CZ A 3.840100000000e+004 MM 1.00000
5 EOR
6 FILTER_MODE ROUGHNESS
7 FILTER_TYPE GAUSSIAN
8 FORM LS_ARC
9 CUTOFF 2.500000000000e-003 MM 3840
10 BANDWIDTH 3.000000000000e+002
11 ASSESSMENT_LENGTH 9.600000000000e+0
12 NUMBER_MOD_POINTS 3.840100000000e+0
13 EOR
14 0.000000000000e+000
15 2.500000000000e-004
16 5.000000000000e-004
17 7.500000000000e-004
18 1.000000000000e-003
19 1.250000000000e-003
20 1.500000000000e-003
21 1.750000000000e-003
22 2.000000000000e-003
```

Ln: 1 Col: Dos\Windows ANSI INS

主要内容

1 GT-SUITE在发动机摩擦中的预测分析与模拟

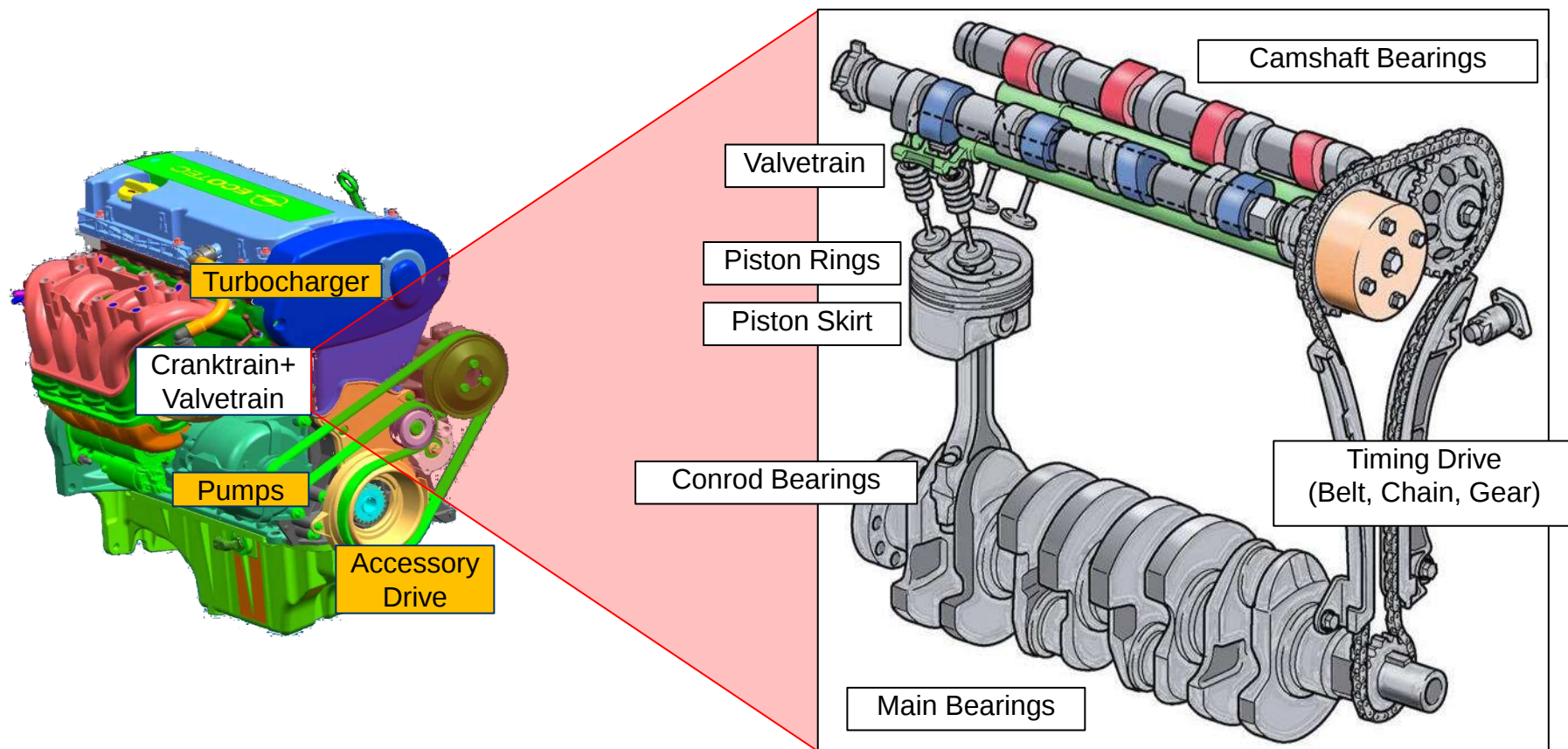
- 动机、原因和需求
- GT-SUITE能提供的关键技术
- 发动机摩擦模拟的关键模板
- 校核

2 摩擦和润滑; v7.5新功能和开发进展

3 应用分析

4 Q&A, 讨论

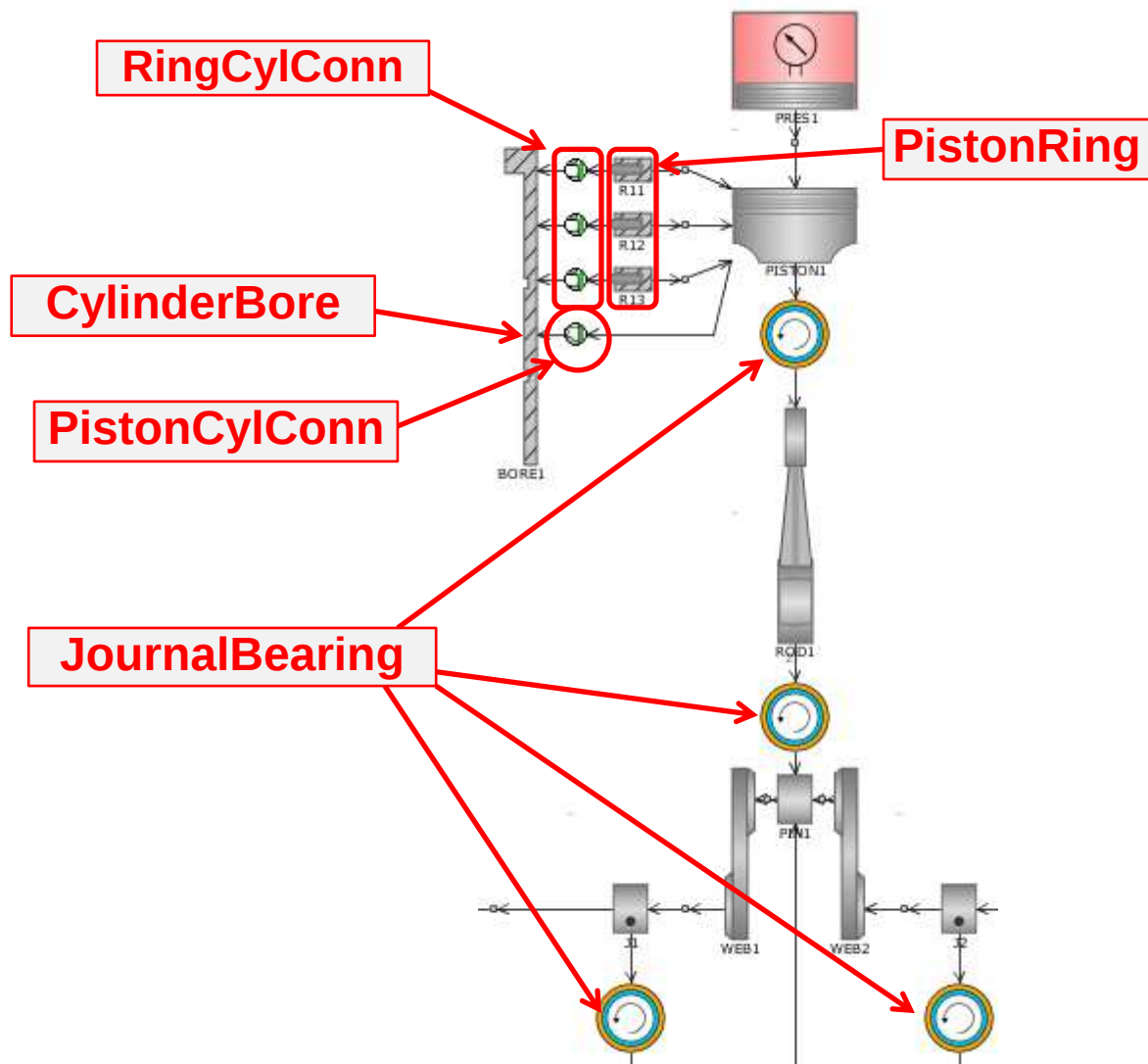
GT-SUITE 中关于发动机的摩擦部件



发动机曲柄连杆机构中关键的油膜 HD模板



BASIC CRANKTRAIN SEGMENT



WITH FRICTION MODELS

活塞环摩擦 RingCylConn: 物理, 方程式

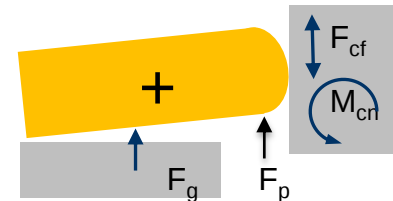
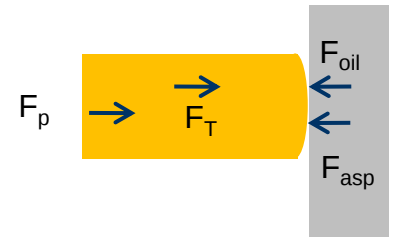
Ring Radial Force, Twist Moment Balances

(ring radial position r , toroidal tilt θ)

$$M d^2 r / dt^2 \sim 0^* = F_p + F_t - F_{crb} \{ F_{oil} (dh/dt) + F_{asp} \}$$

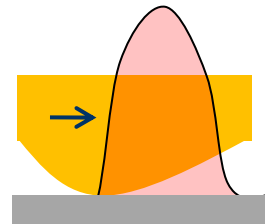
$$I_{ring} d^2 \theta / dt^2 \approx 0 =$$

$$F_g(R_g - R_r) + F_p(R_p - R_r) + F_{crb} \{ F_{cf}(R_c - R_r) + M_{cn} \} - K_T \theta$$



Ring Oil Film Hydrodynamics Oil Film Pressure $P(y)$

$$\partial / \partial x (\Phi_p h_T^3 \partial P / \partial x) = 6 U \mu (\partial h_T / \partial x + \sigma \partial \Phi_s / \partial x) + 12 \mu \partial h_T / \partial t$$

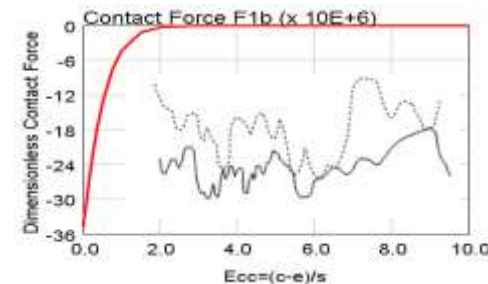


Ring-Bore Asperity Contact (Greenwood-Tripp)

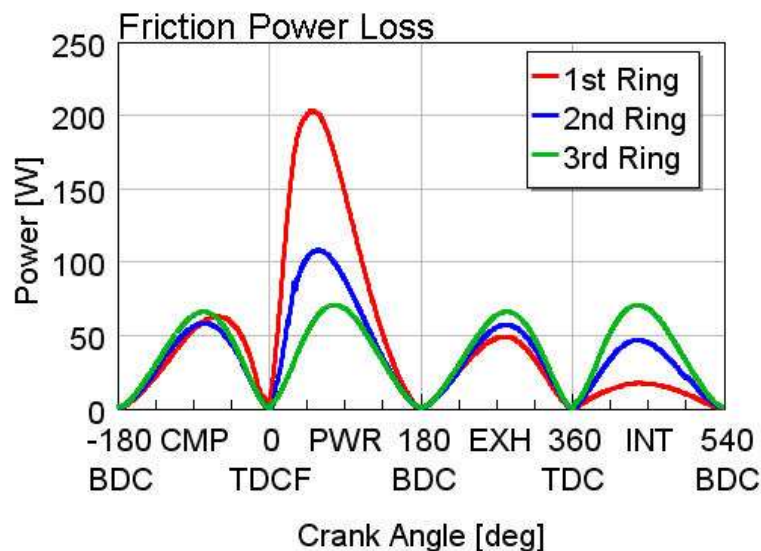
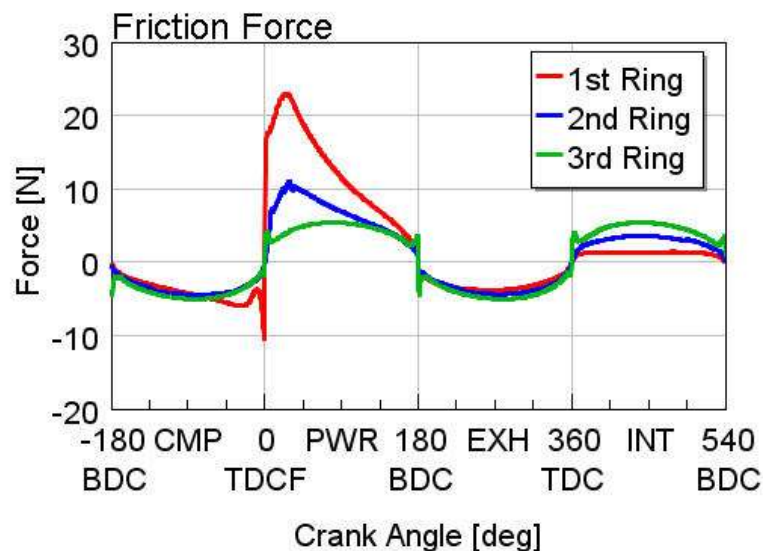
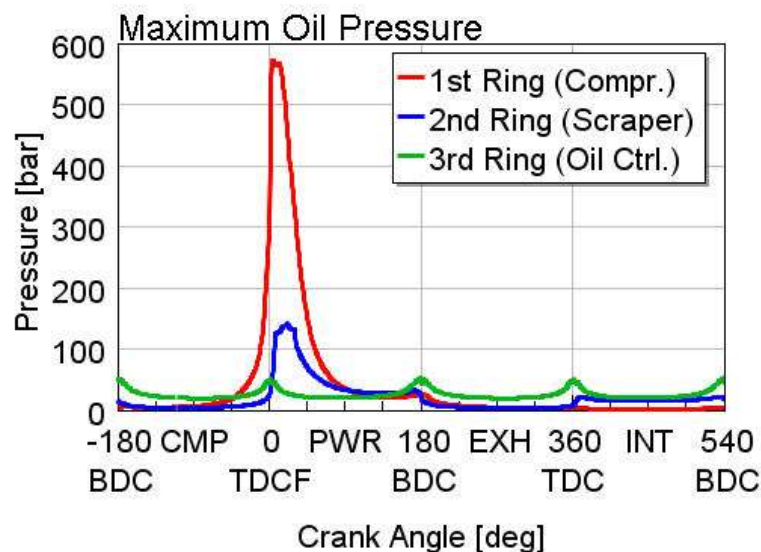
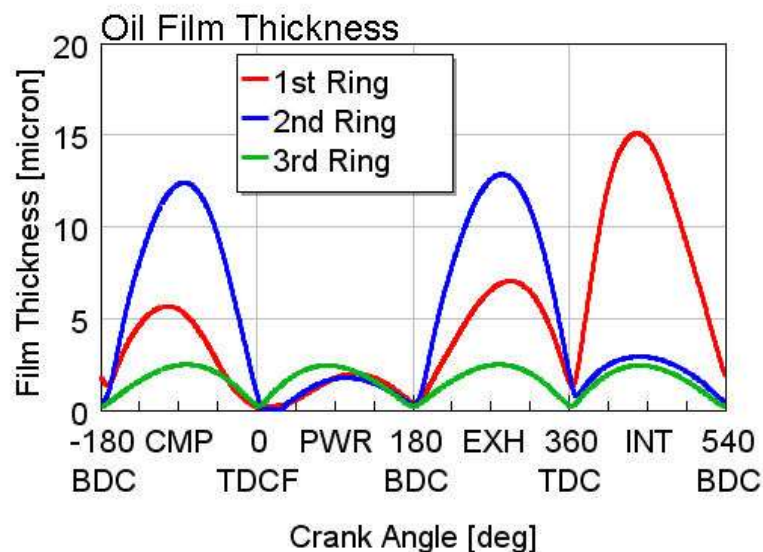
(asp. Contact pressure $P_{asp}(y)$)

$$P_{asp} = (16 \sqrt{2/15}) \pi (\sigma \beta \eta)^2 E \sqrt{\sigma / \beta} F_2(h / \sigma)$$

* Inertia may be ignored for a quasi-static force balance solved with little or no loss of accuracy, gain in CPU speed



RingCylConn模板：预测三个活塞环 - 3000 RPM



活塞裙部摩擦 **PistonCylConn** – 物理学,方程式

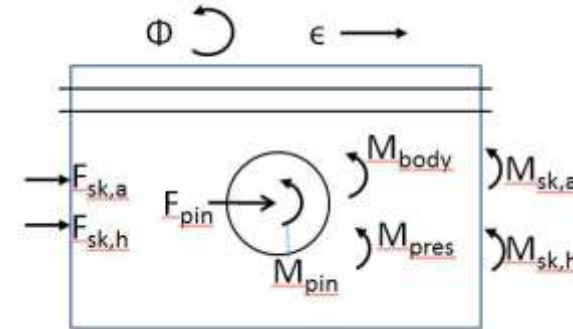
Lateral Force and Moment Balances (eccentricity ϵ and tilt angle Φ)

$$M_p d^2 \epsilon / dt^2 \sim 0^* = F_{pin} + F_{sk,h} + F_{sk,a}$$

$$I_p d^2 \Phi / dt^2 \sim 0^* = M_{body} + M_{pres} + M_{pin} + M_{sk,h} + M_{sk,a}$$

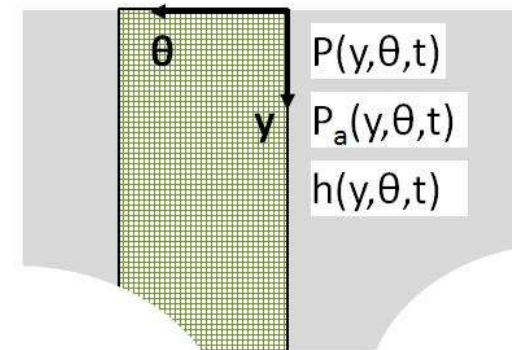
$$F_{sk,h}, F_{sk,a}, M_{sk,h}, M_{sk,a} = f(V_p, \epsilon, \Phi, d\epsilon/dt, d\Phi/dt)$$

(F, M values from by HD/asperity models)



Skirt Oil Film Hydrodynamics (Reynolds Eq. -oil film pressure $P(y, \theta, t)$)

$$\begin{aligned} \partial/\partial y (\Phi_p h_T^3 \partial P / \partial y) + (1/R^2) \partial/\partial \theta (\Phi_p h_T^3 \partial P / \partial \theta) \\ = 6V_p \mu (\partial h_T / \partial y + \sigma \partial \Phi_s / \partial y) + 12\mu \partial h_T / \partial t \end{aligned}$$



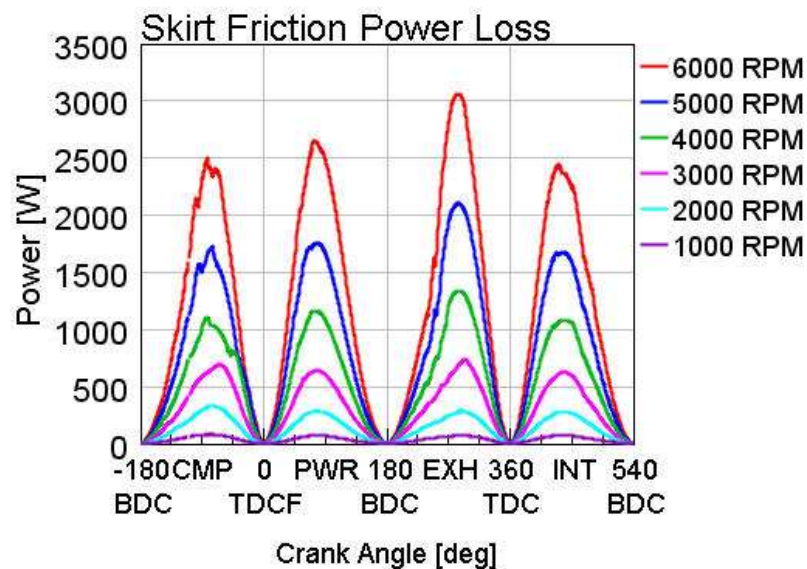
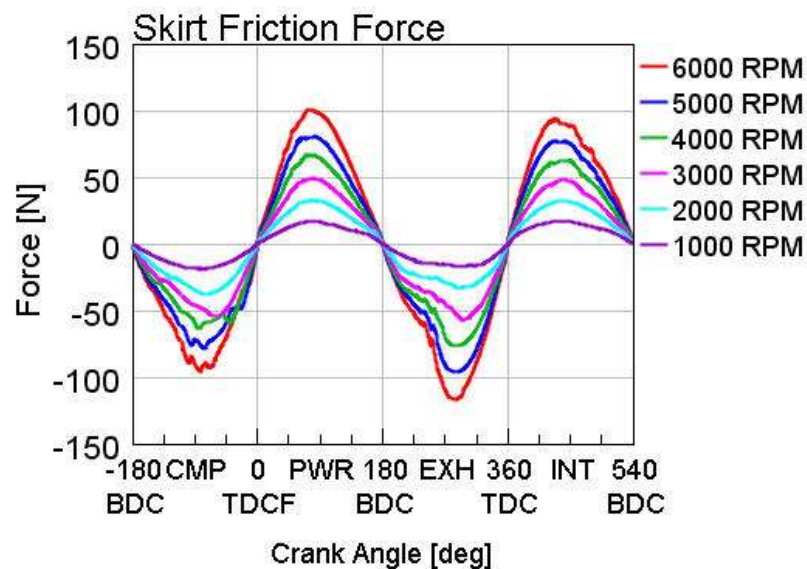
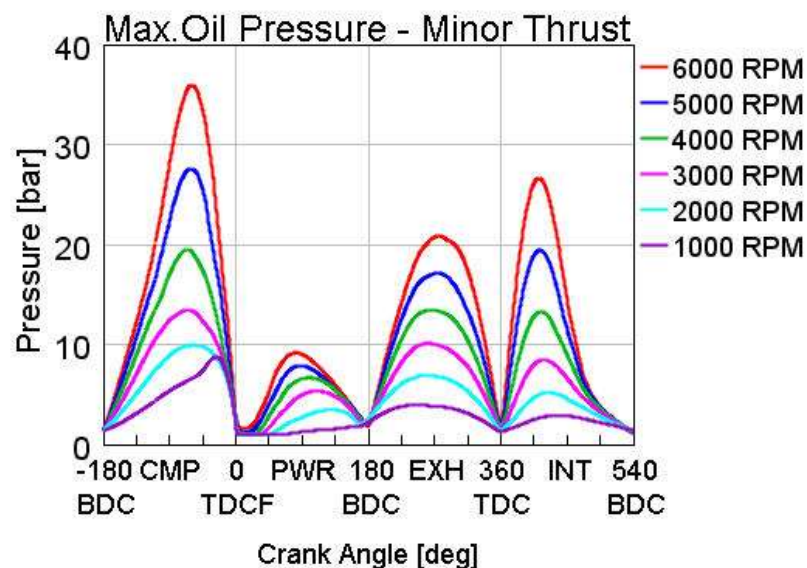
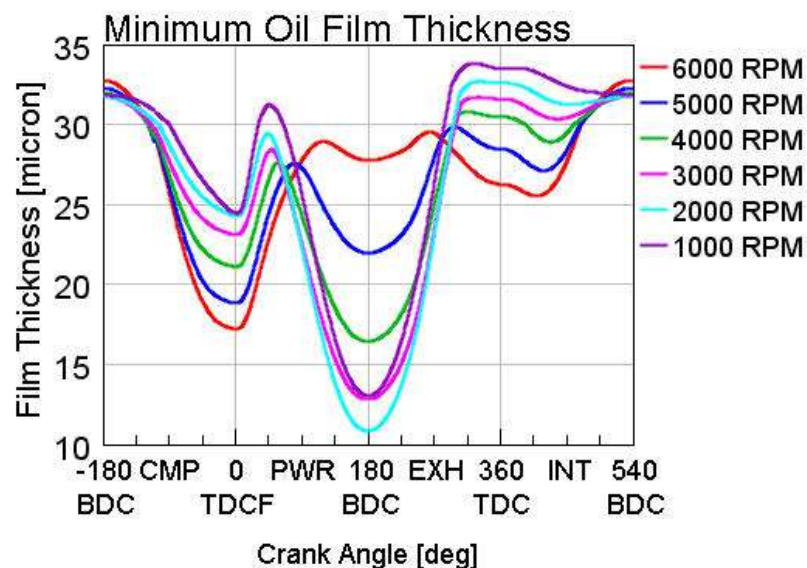
Skirt-Bore Asperity Contact (Greenwood-Tripp)

(Asperity contact pressure $P_{asp}(y, \theta, t)$)

$$P_{asp} = (16\sqrt{2/15}) \pi (\sigma \beta \eta)^2 E \sqrt{\sigma/\beta} F_2(h/\sigma)$$

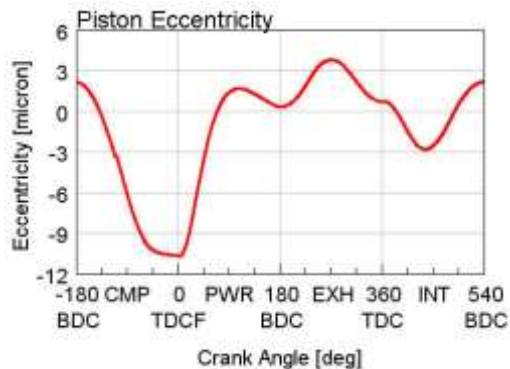
* Inertia may be ignored for a quasi-static force balance solved for (i), with little or no loss of accuracy, gain in CPU speed

PistonCylCnn: 活塞裙部摩擦分析

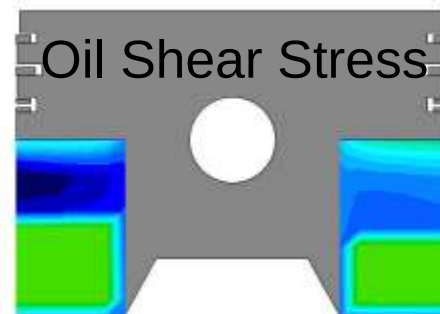
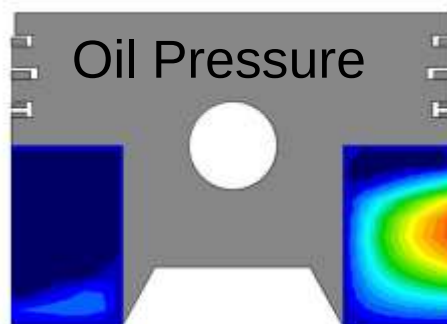
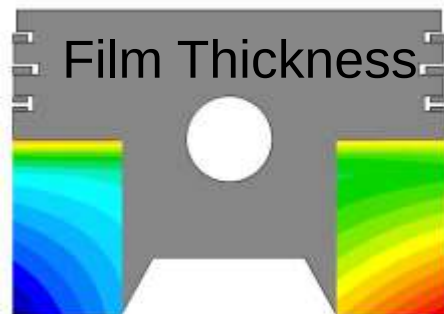
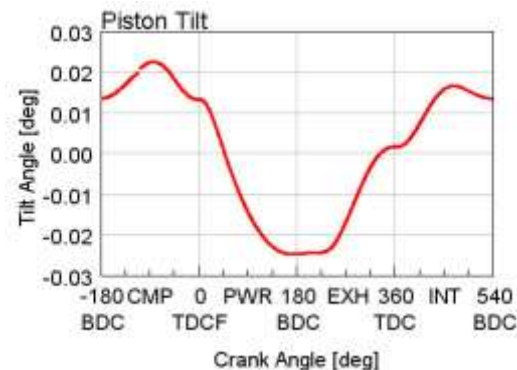


活塞裙部摩擦 关联输出

活塞运动和裙部油膜动画



Piston Motion

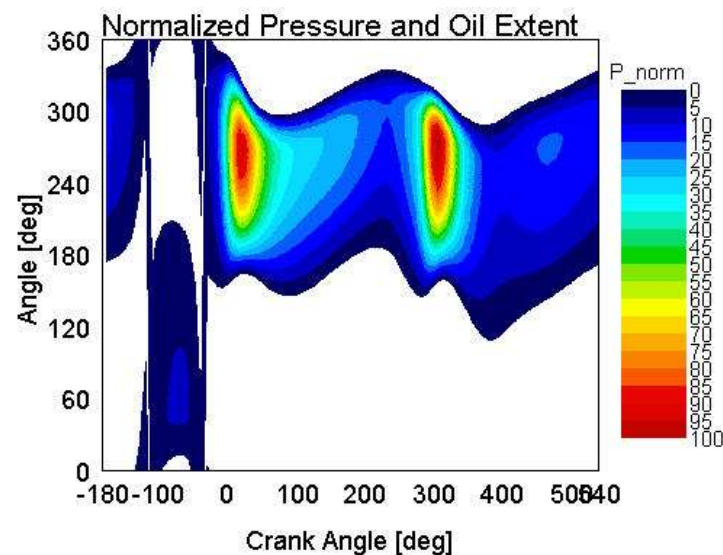
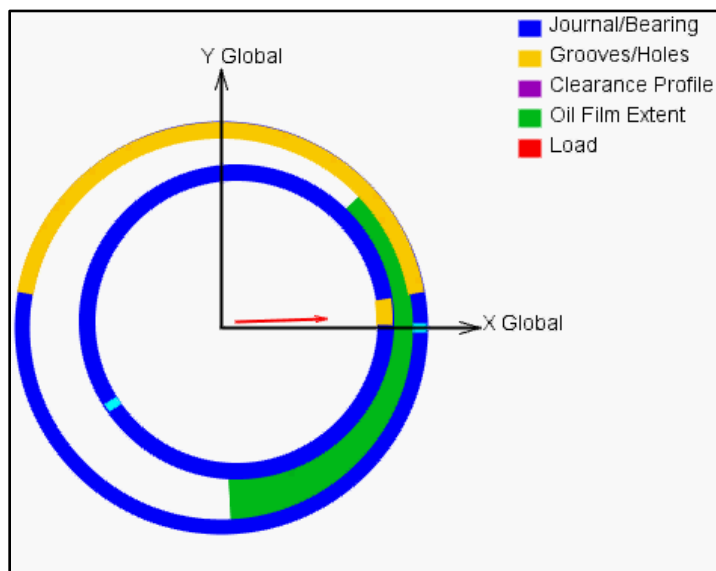
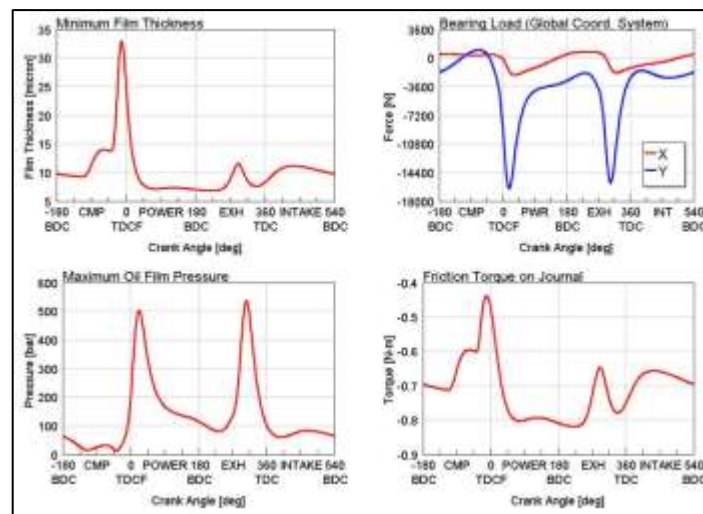
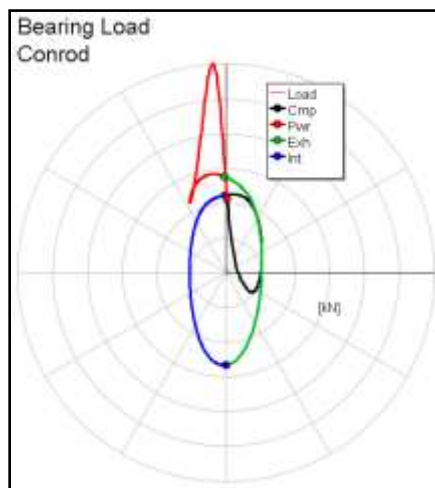
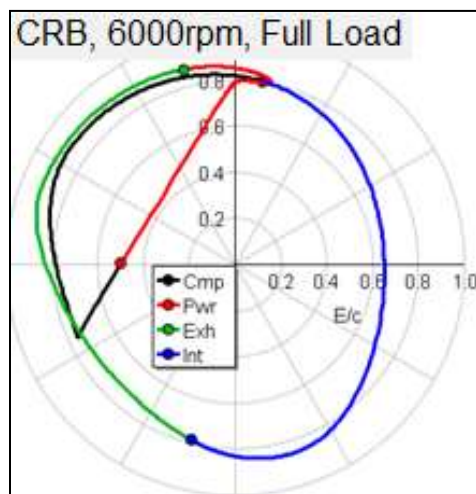


轴承油膜HD,摩擦: **Journal Bearing**

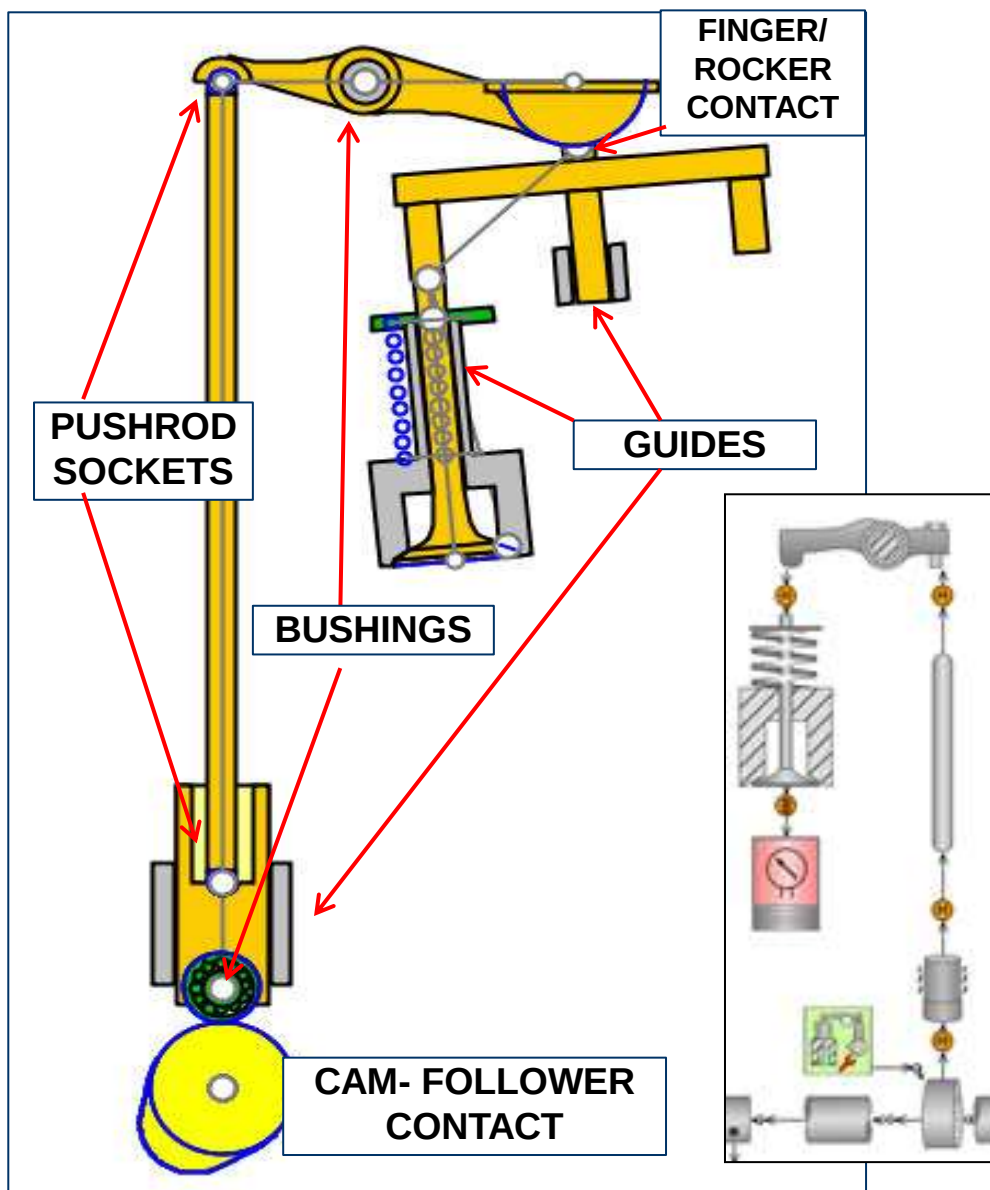
- Hydrodynamic (HD) 油膜求解
- 采用预处理: MAP图/拟合fits of relationship between force and motion used, for fast orbit/MOFT, soln.
- 预测运行过程中: 摩擦力矩, 功率损失, 油膜的延展性, 最大油膜压力等
- 油温上升预测
- Greenwood-Tripp粗糙面接触模型
- 油槽/油孔压力感受模型;
- 与GT-SUITE的润滑系统联合仿真

轴承油膜&摩擦模型

输出:轴心轨迹, 负荷, 动动, 油膜的延展性, MOFT,摩擦等

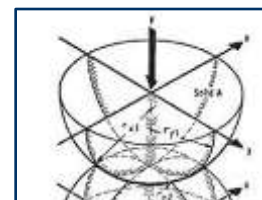


配气机构摩擦- **Contact2D**, 各种铰接



接触副, 摇臂等:

- EHD油膜压力 (Dawson-Hamrock EHD)
- 粗糙度的接触压力 (Greenwood-Tripp)
- 热模拟 (间隙、温度)

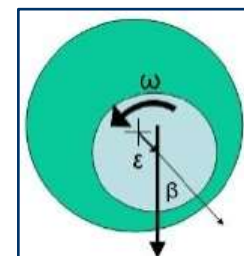


导管, 推杆:

- 油膜的剪切力
- 与负载相关的摩擦系数 (fric. coeffs. for load, moment)

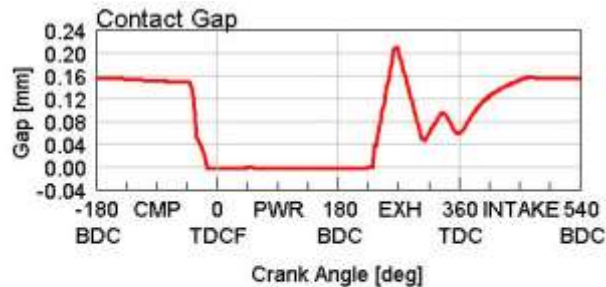
凸轮轴的轴承

- HD轴承



可选择性的选择配气机构摩擦模型及相应输出

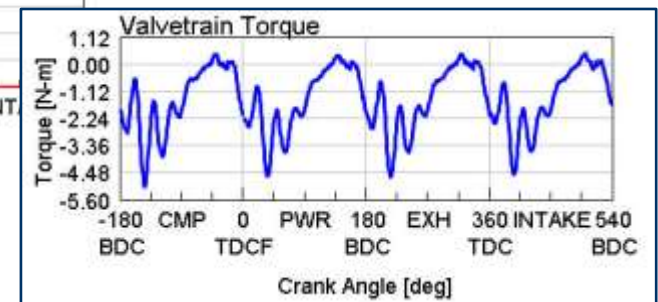
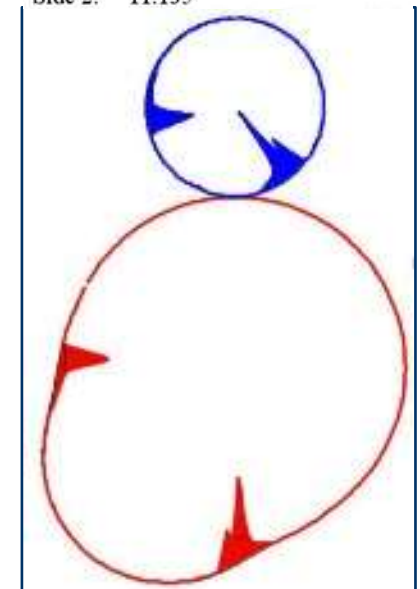
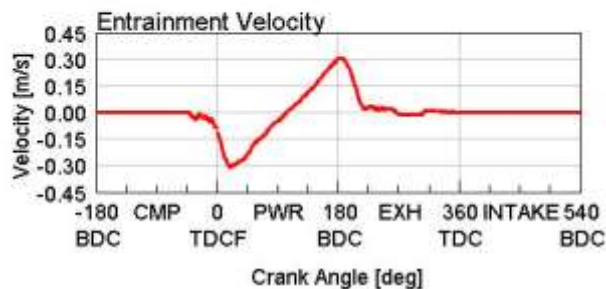
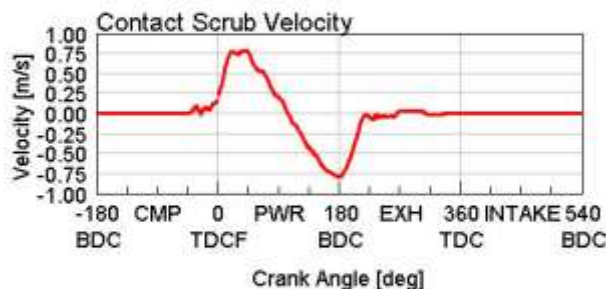
Contact physics, friction/wear, valvetrain torque



Maximum Wear Load Values (kW/m^2):

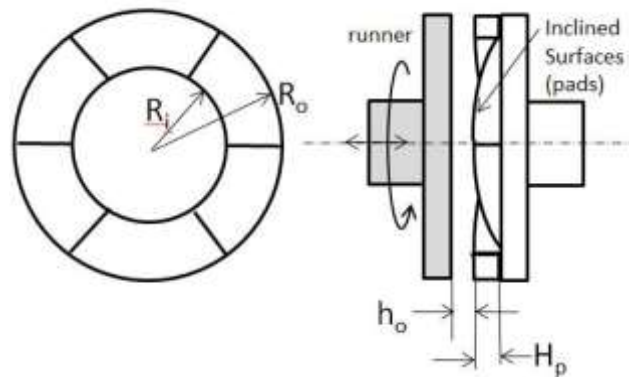
Side 1: 11.469

Side 2: 11.135

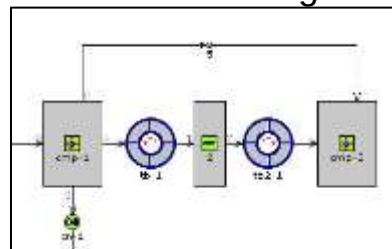


增压器摩擦 Journal Bearing, Thrust Bearing

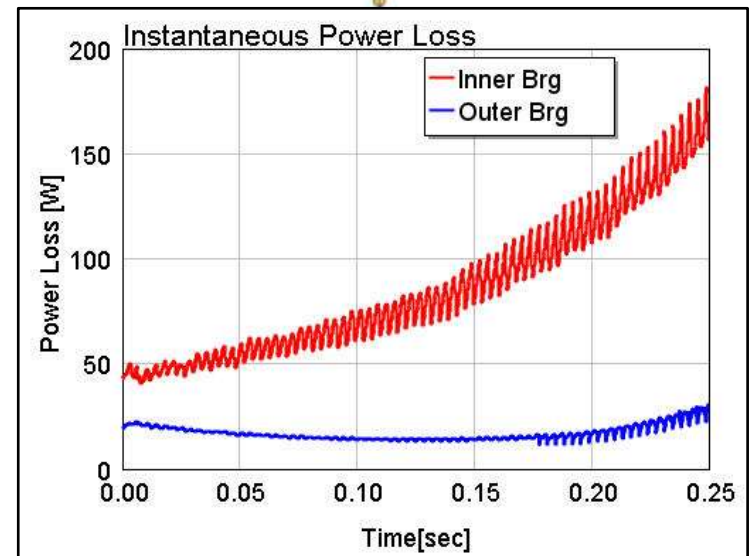
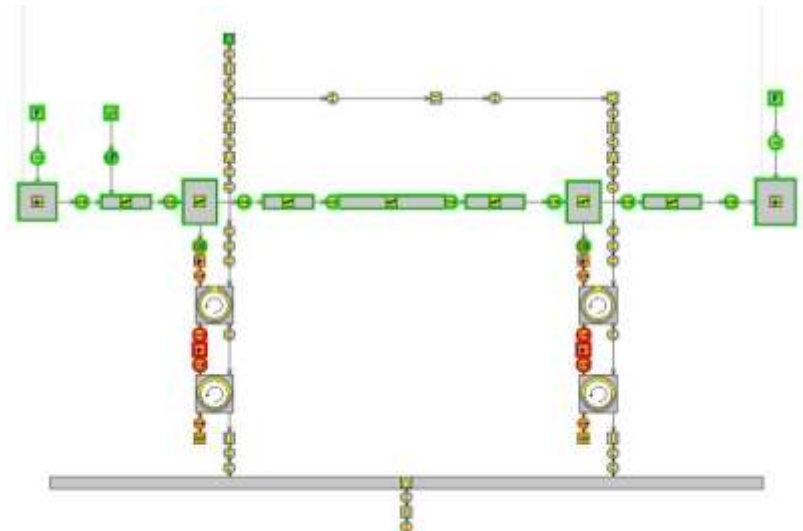
- 增压器的机械动力学
- 浮动式轴承 (double JB)
- 倾斜平面的止推轴承
 - HD求解
 - Greenwood-Tripp粗糙度接触
- 摩擦力矩、功率损失和流量预测



Thrust Bearings

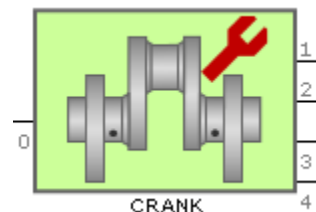


T/C Lubrication Circuit and Bearings



全局性发动机摩擦输出

- 很方便的实现：可视化、扫掠/MAP输出
- 所有的摩擦RLT可以作为优化对象来考虑



Example: Cranktrain friction global output in **CrankAnalysis** part– speed

Part:
Cranktrain

Template:
CrankAnalysis

Print ...

☒ Show Multiple Case
Case 1

☐ Show Template Group

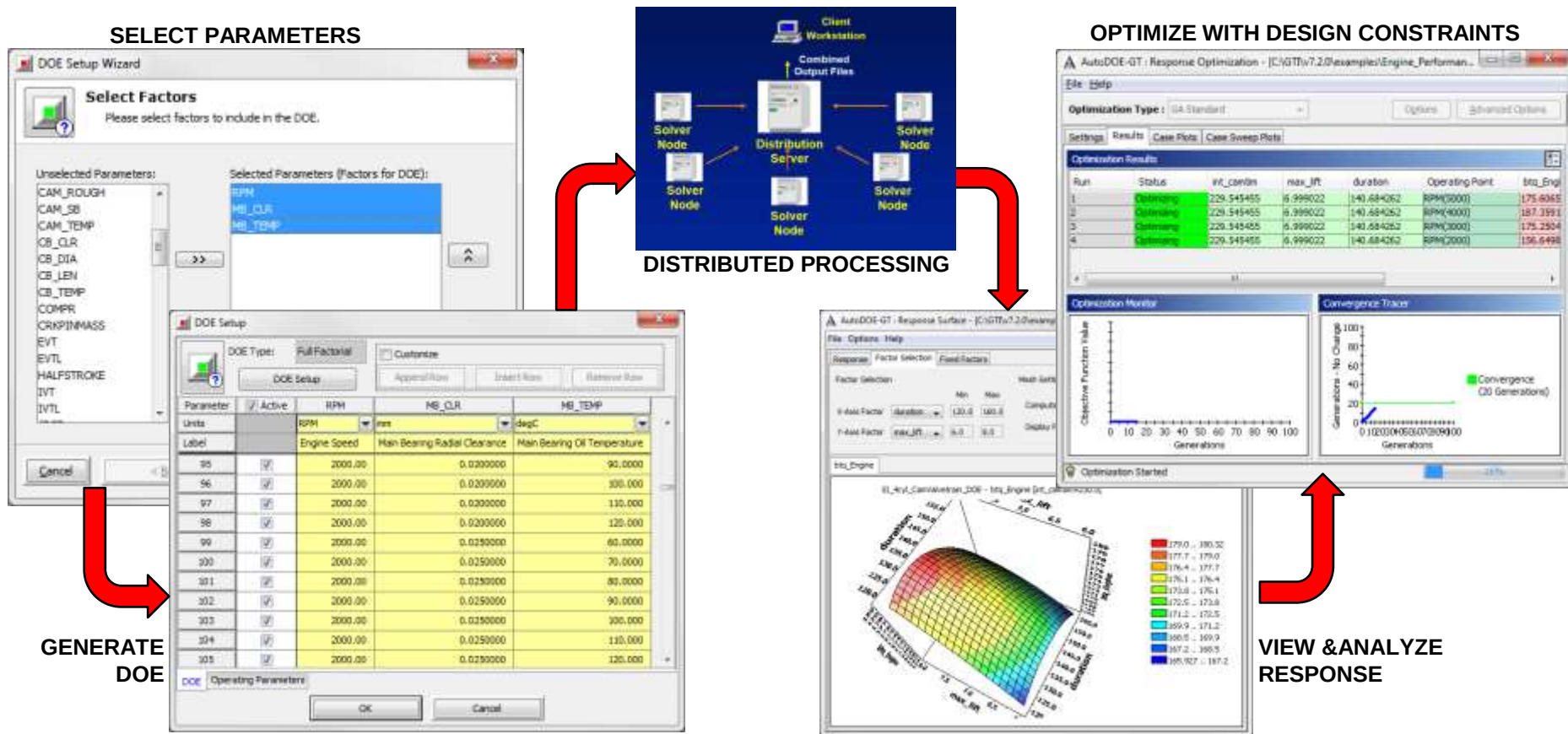
☐ Show Time RLT vars

	Attribute Value	Unit	Short Name	6000 RPM Case # 1	5000 RPM Case # 2	4000 RPM Case # 3	3000 RPM Case # 4	2000 RPM Case # 5	1000 RPM Case # 6
	Favorites								
	Main								
	Balance								
	Friction								
	Frictional Power Loss	kW	fricpwr	5.46799	3.34959	1.98363	1.07566	0.48189	0.135076
	Fric. Power - Main Bearings	kW	fricpwrmn	2.79335	1.56889	0.855521	0.429549	0.179564	0.0464012
	Fric. Power - Lrge.End Bearings	kW	fricpwrle	1.09958	0.662613	0.382233	0.19946	0.0864562	0.0231415
	Fric. Power - Sml.End Bearings	kW	fricpwrse	0.0309701	0.0220705	0.0153922	0.0100955	0.00573824	0.00222297
	Fric. Power - Piston Rings	kW	fricpwrctyr	0.318027	0.24496	0.178533	0.119303	0.0674888	0.0256736
	Fric. Power - Piston Skirts	kW	fricpwrctys	1.22607	0.851051	0.551954	0.317249	0.142643	0.0376371
	Fric. Power - Other Cylinder	kW	fricpwrcty	0.0	0.0	0.0	0.0	0.0	0.0
	Working Stresses (Rigid/Torsion)								
	Safety Factors								
	Stress_Recombination								

Done

GT-SUITE DoE/Optimization 工具

- 必不可少的设计拓展, 'tradeoffs' 和限制的优化, 获得最小的摩擦损失
- 对于获得未知参数 (如: 粗糙度) 去与尽可能的与试验数据相匹配也是很有用的



主要内容

1 GT-SUITE在发动机摩擦中的预测分析与模拟

- 动机、原因和需求
- GT-SUITE能提供的关键技术
- 发动机摩擦模拟的关键模板
- 校核

2 摩擦和润滑; v7.5新功能和开发进展

3 应用分析

4 Q&A, 讨论

用来进行对比的测试数据 (V6 SI Engine)

典型的测量数据

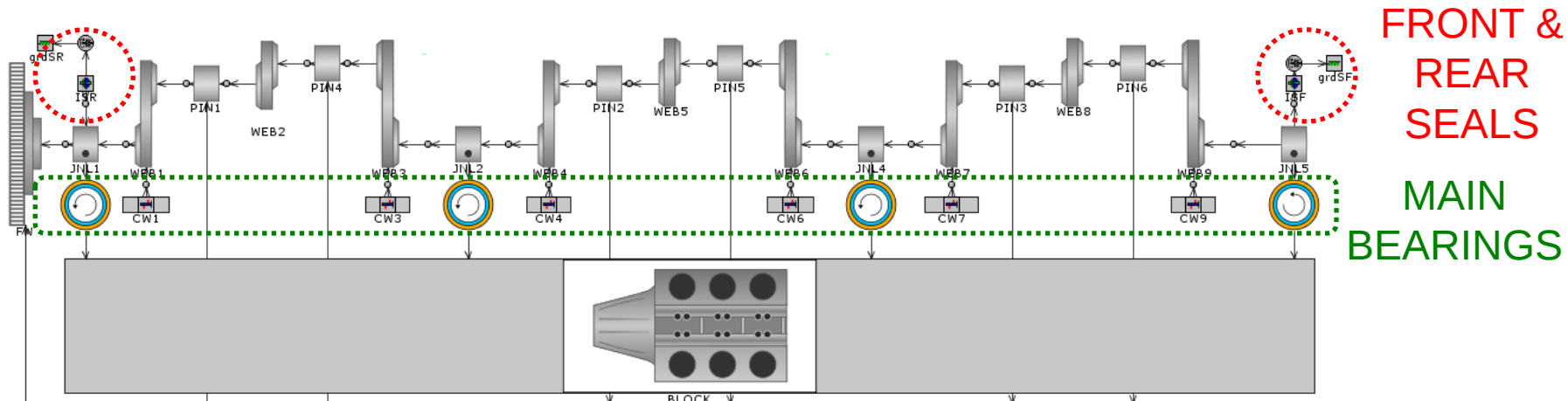
- 发动机拆解试验数据
- 单缸发动机 浮云衬套驱动力矩
- 配气机构驱动力矩

测试参数

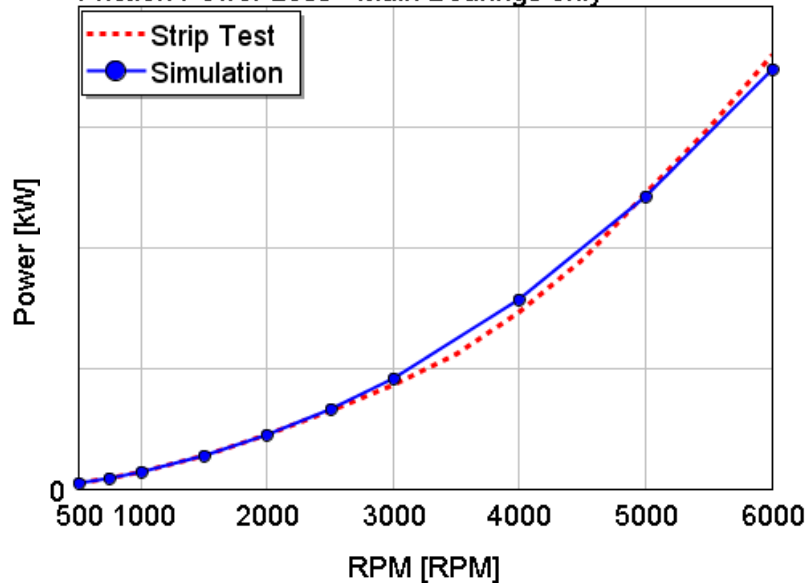
- 润滑
- 油温 (供油温度)
- 发动机转速
- 表面抛光
- 表面材料 (coatings)

对发动机Strip-down的测试数据对比

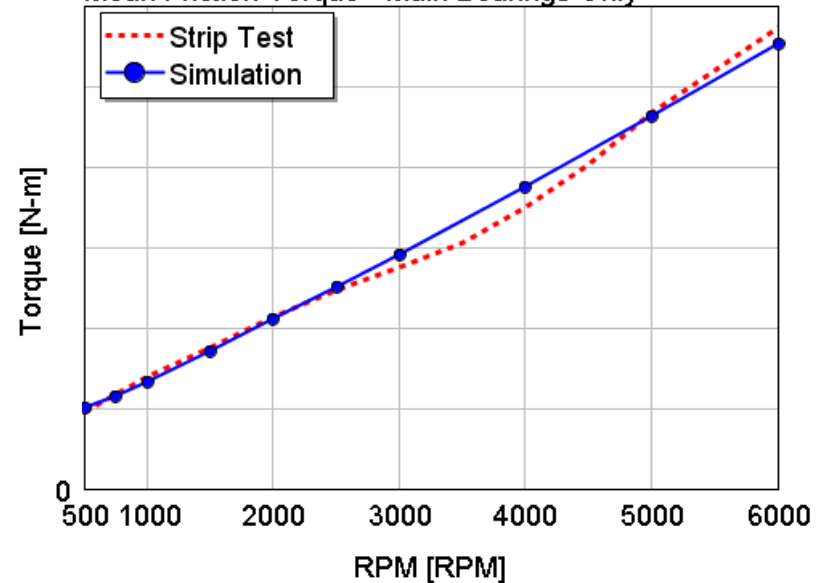
主轴承+ 油封的 FMEP (只有曲轴)



Friction Power Loss - Main Bearings only

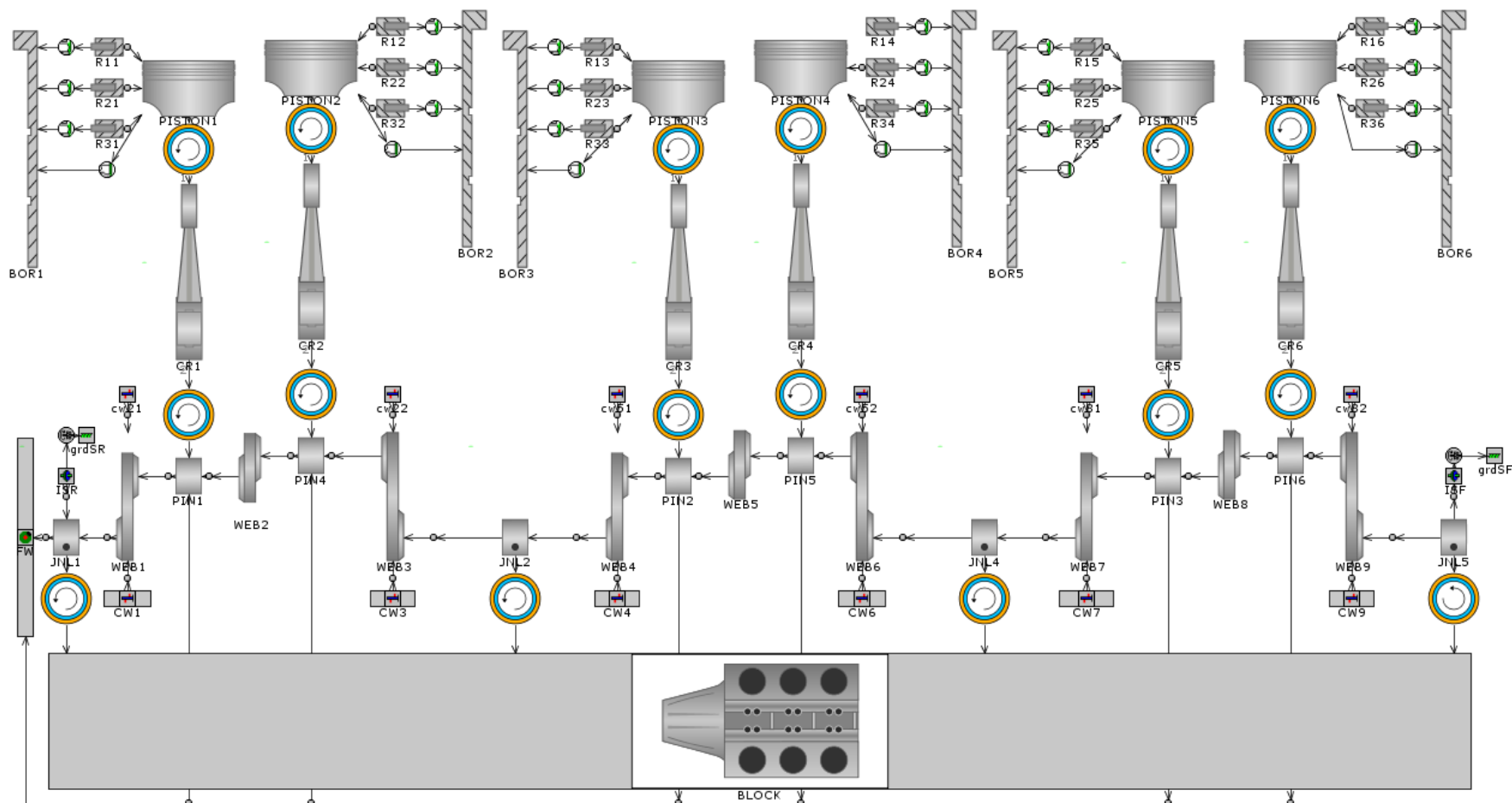


Mean Friction Torque - Main Bearings Only



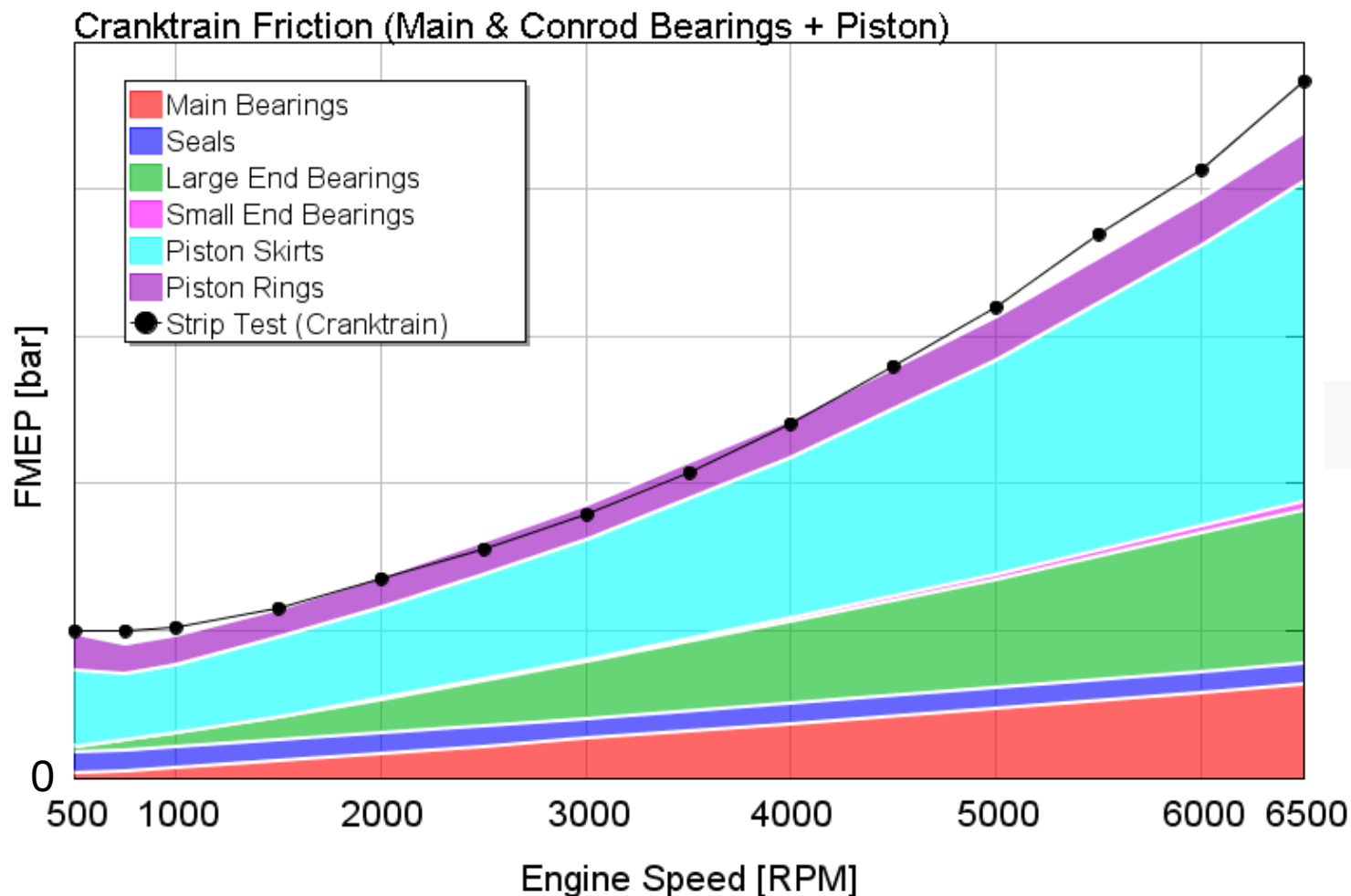
与发动机的Strip-down测试数据对比

完整的曲柄连杆机构模型，带有轴承、活塞和活塞环油膜/摩擦子模型 (没有缸太远, “开”的发动机)



与发动机的Strip-down测试数据对比

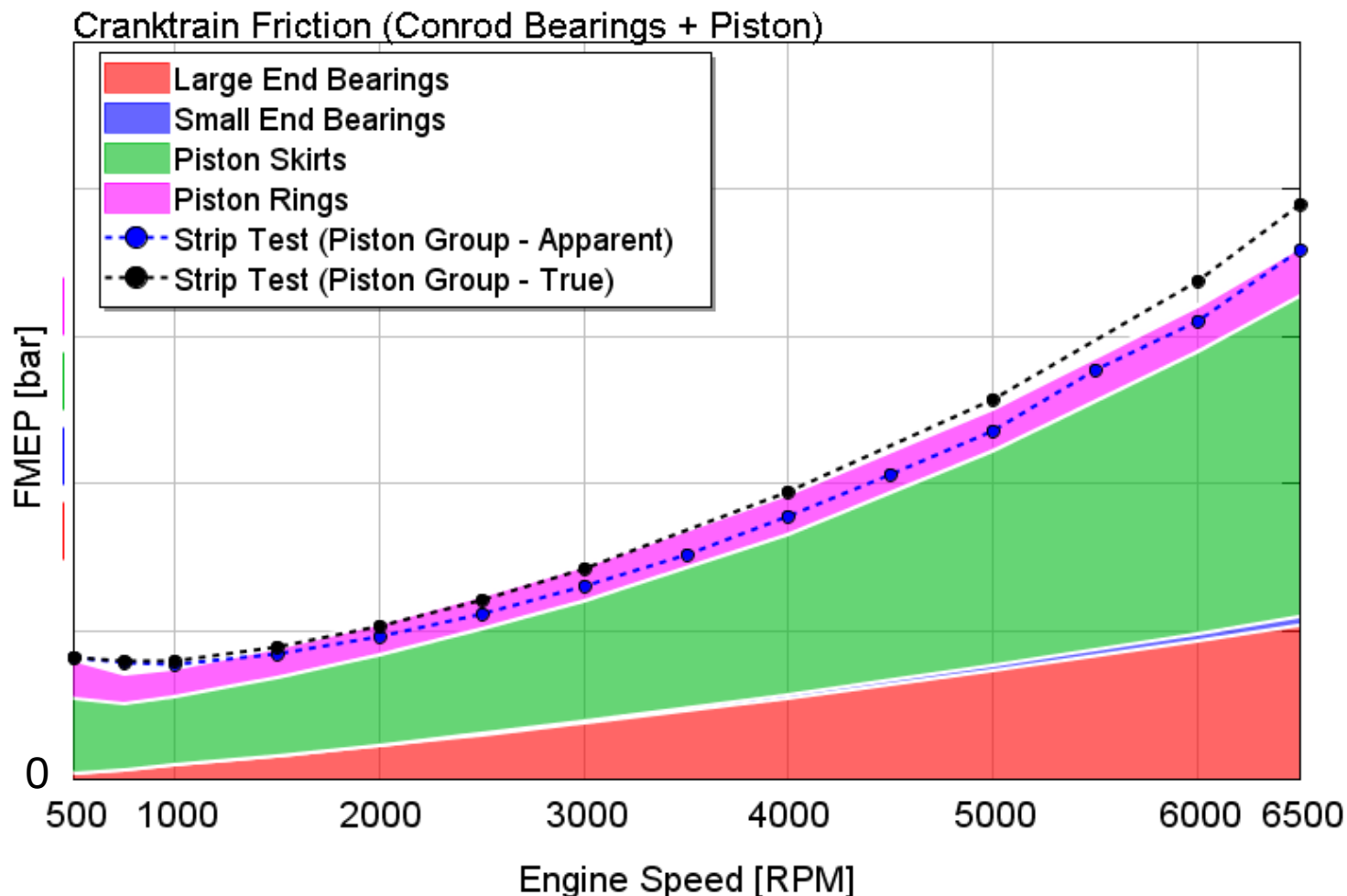
完整体的曲柄连杆机构的FMEP



与发动机的Strip-down测试数据对比

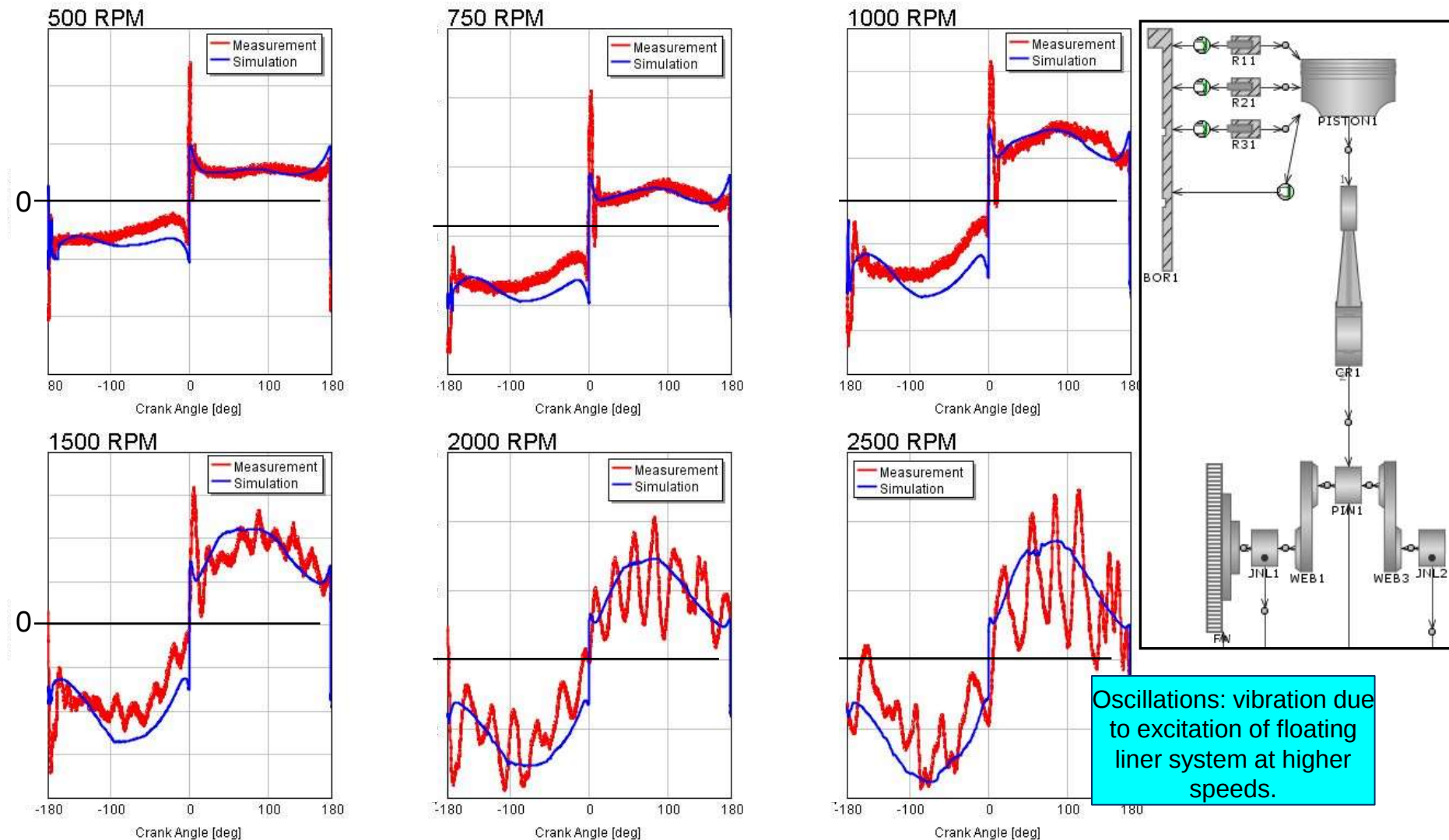
活塞组 (活塞环、活塞裙部、连杆轴承) FMEP

$$\text{FMEP}_{\text{test}} = \text{FMEP}_{\text{cranktrain}} - \text{FMEP}_{\text{main bearings}}$$



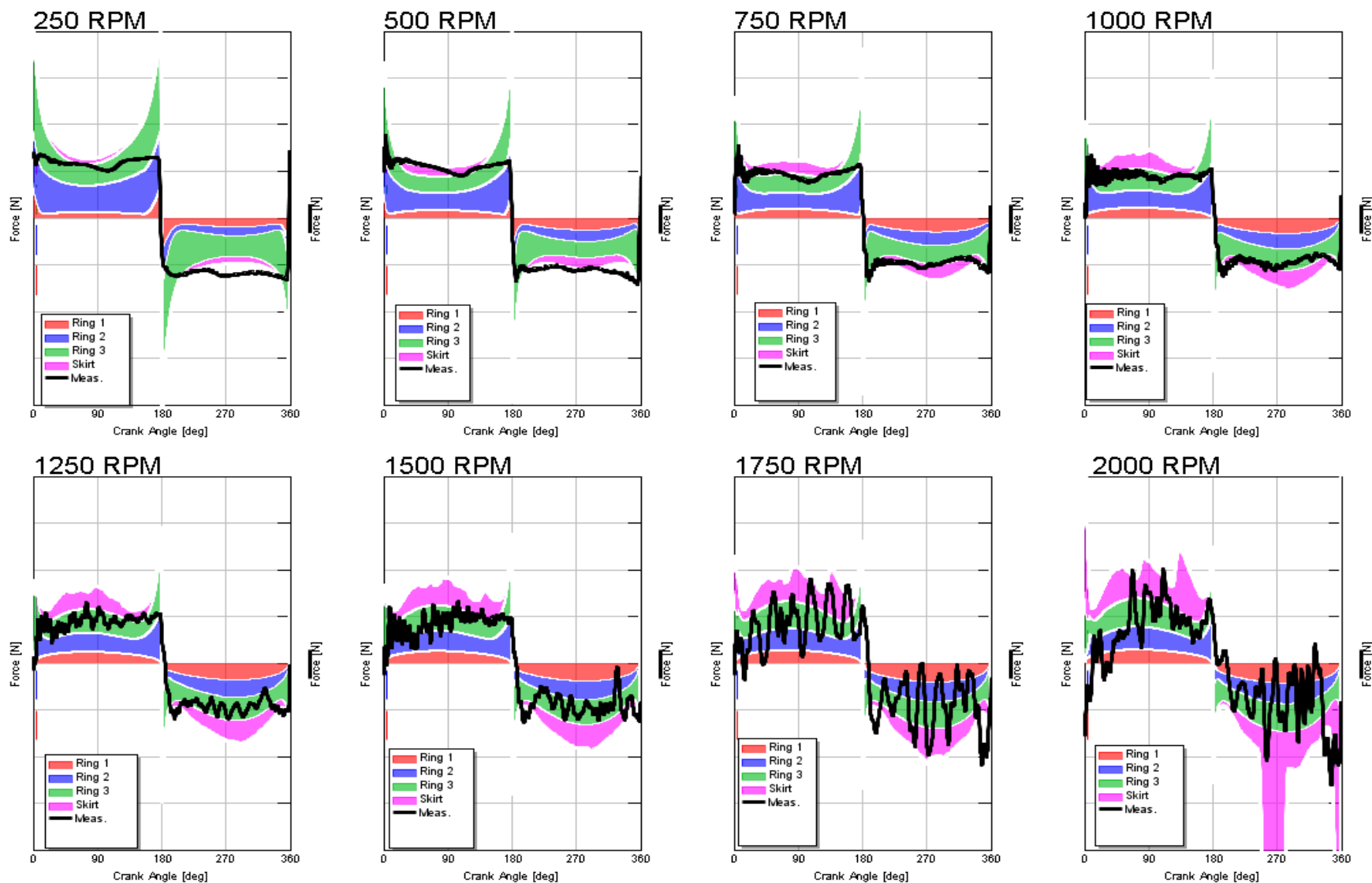
与浮动测试数据对比 A

活塞 + 活塞环的摩擦力



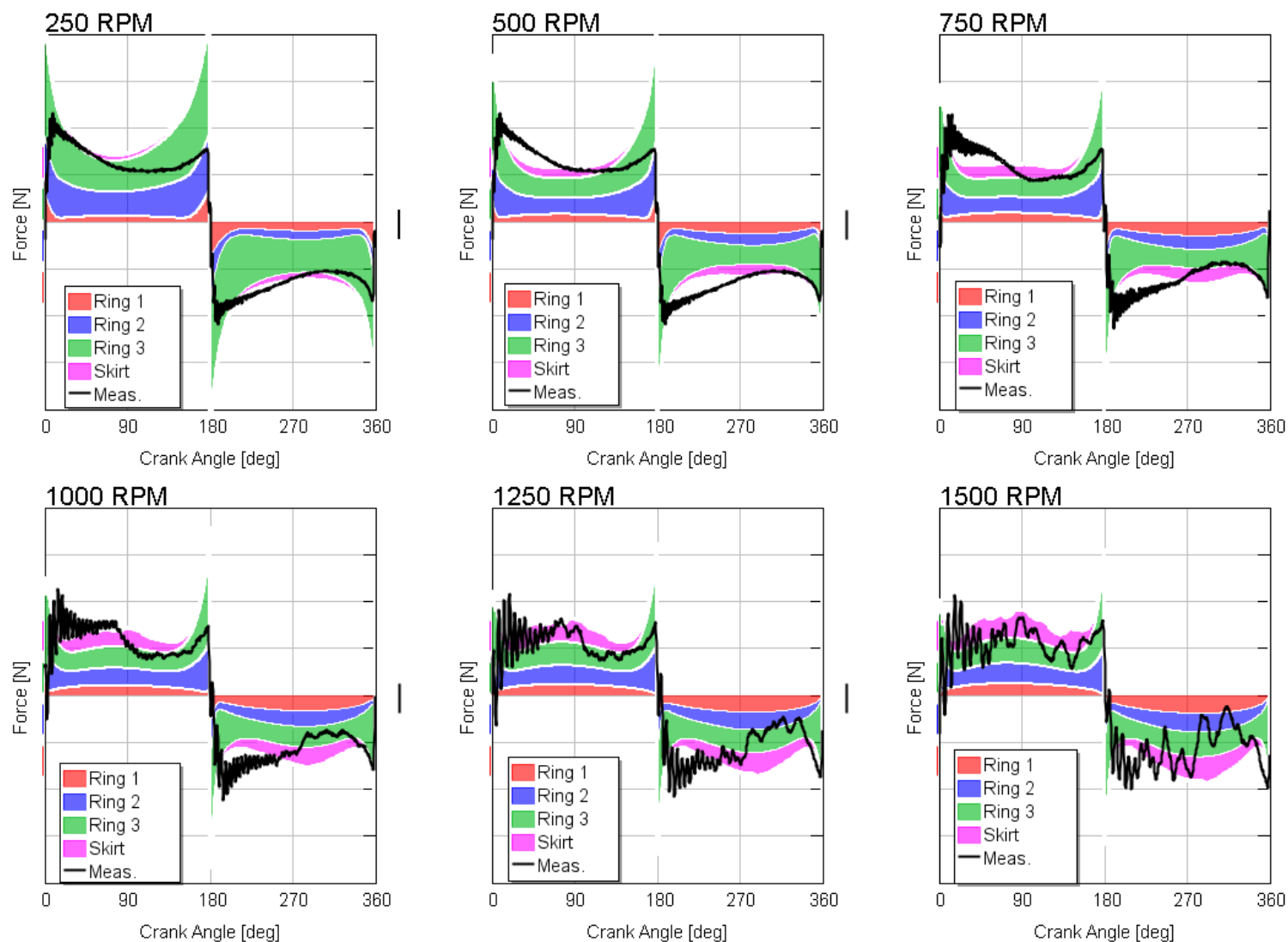
与浮动测试数据对比 B

Piston + Ring Friction – 100degC



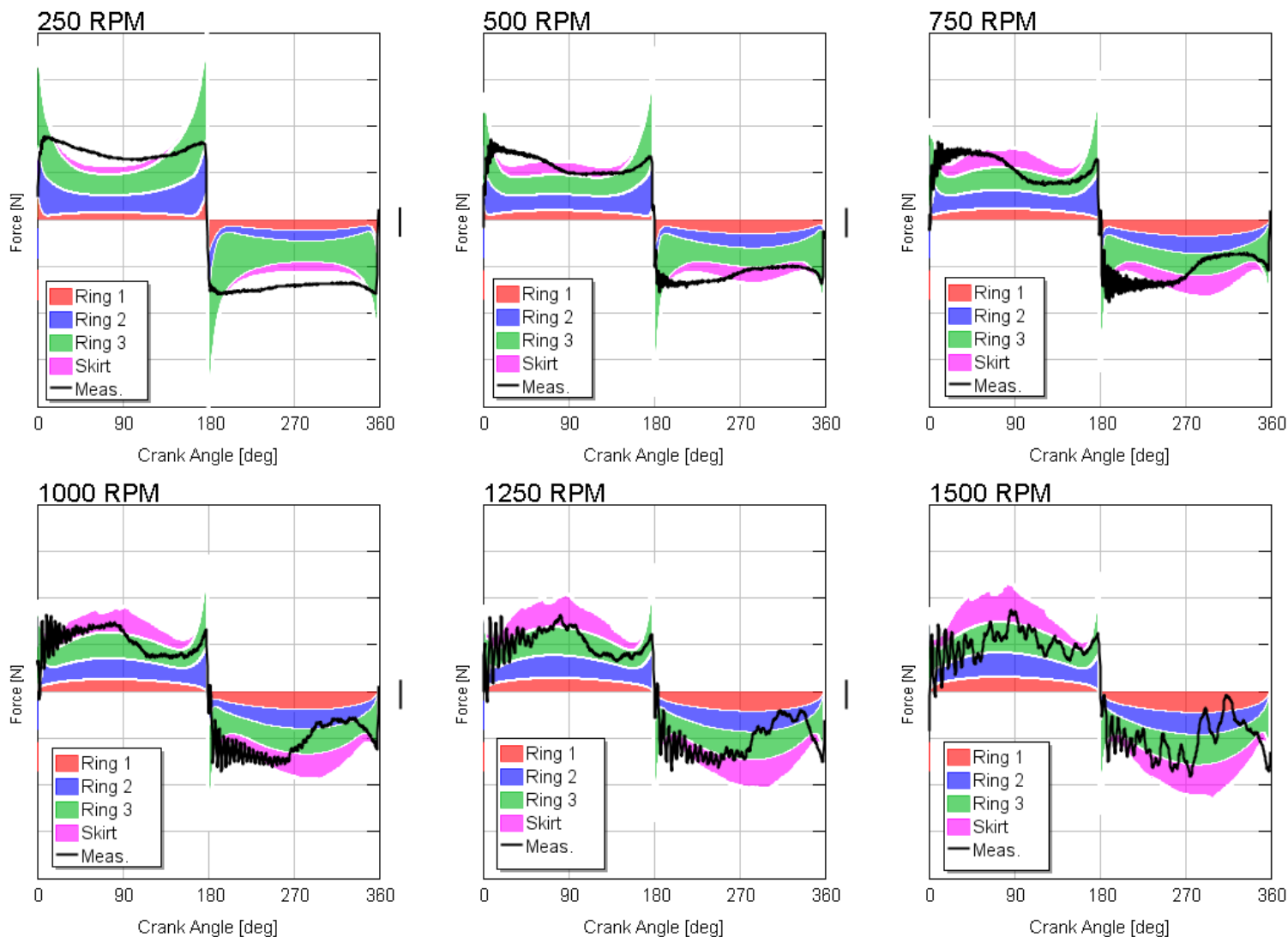
与浮动测试数据对比

Piston + Ring Friction – 100degC



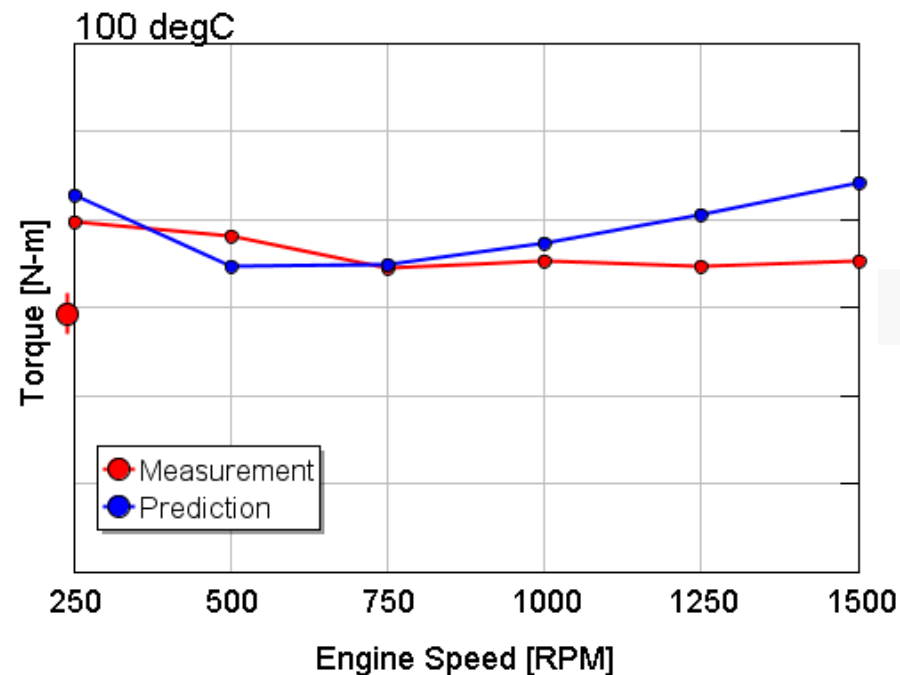
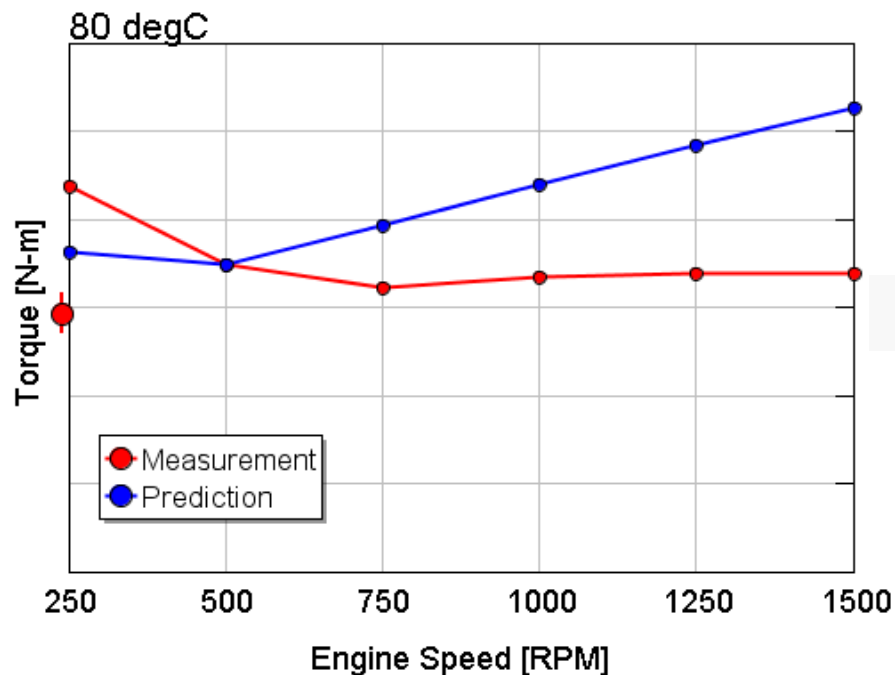
与浮动测试数据对比 C

Piston + Ring Friction – 80degC



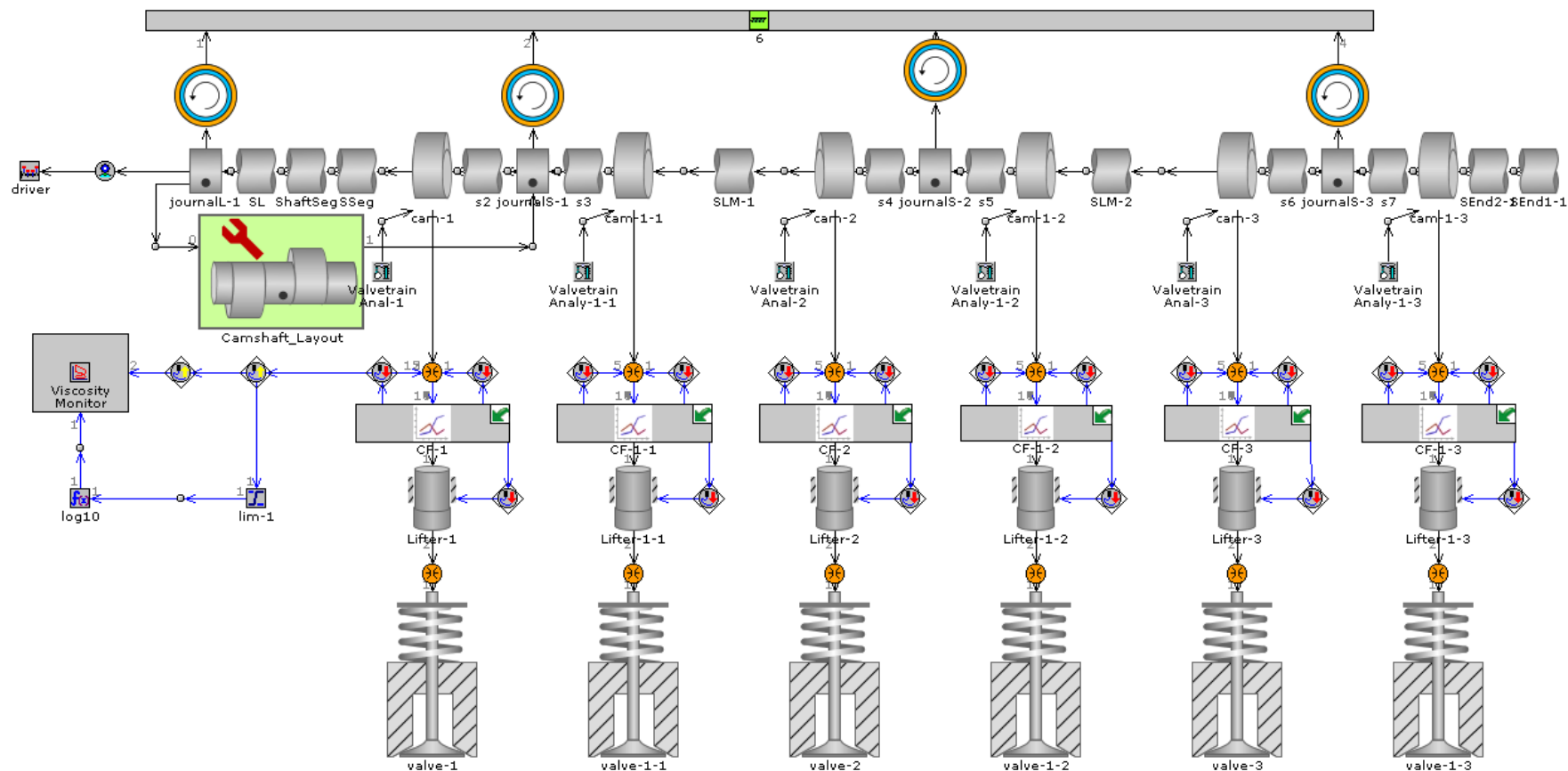
与浮动测试数据对比 C

Mean Torque of Piston+Ring Friction



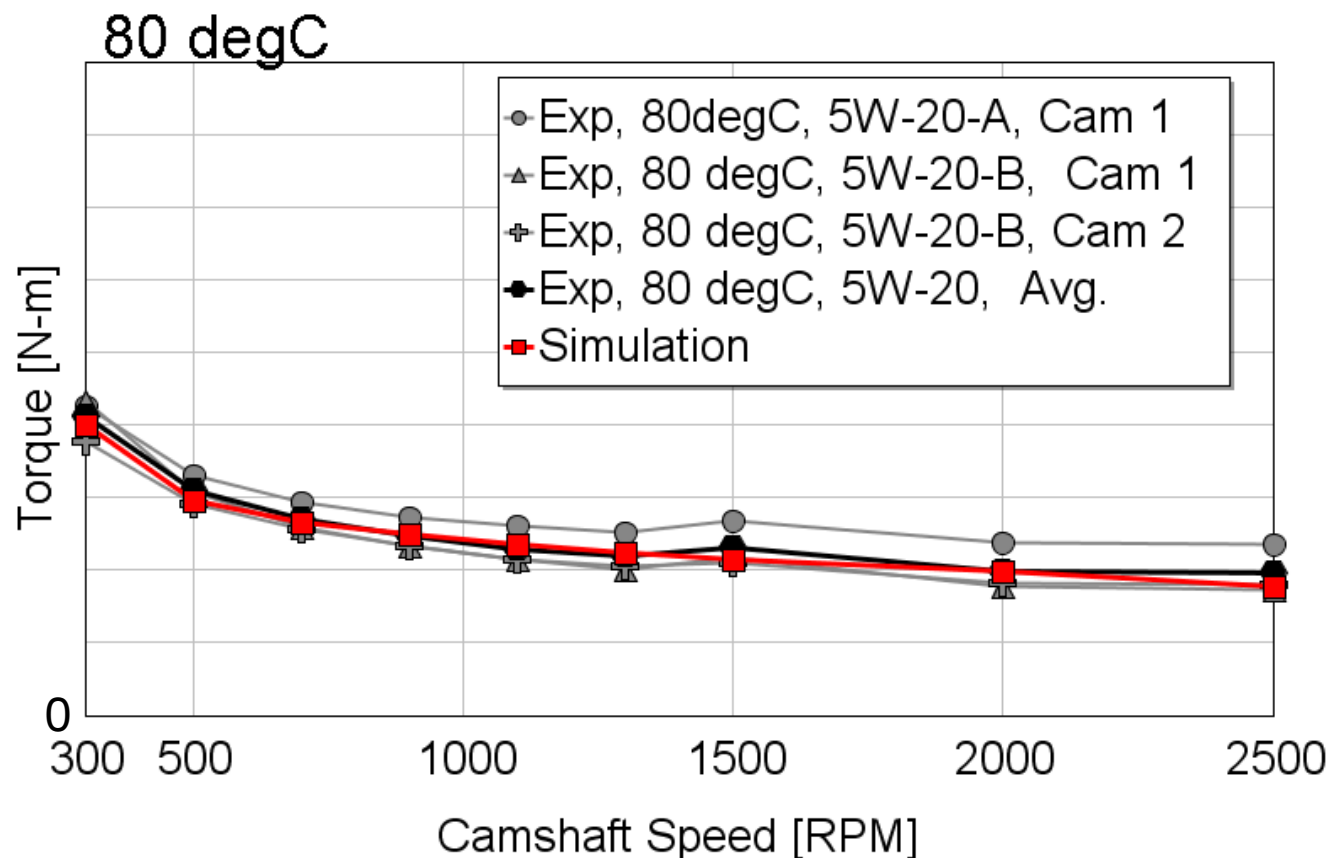
配气机构摩擦测试数据

Model of motored camshaft and valvetrain (direct-acting, flat-tappet)



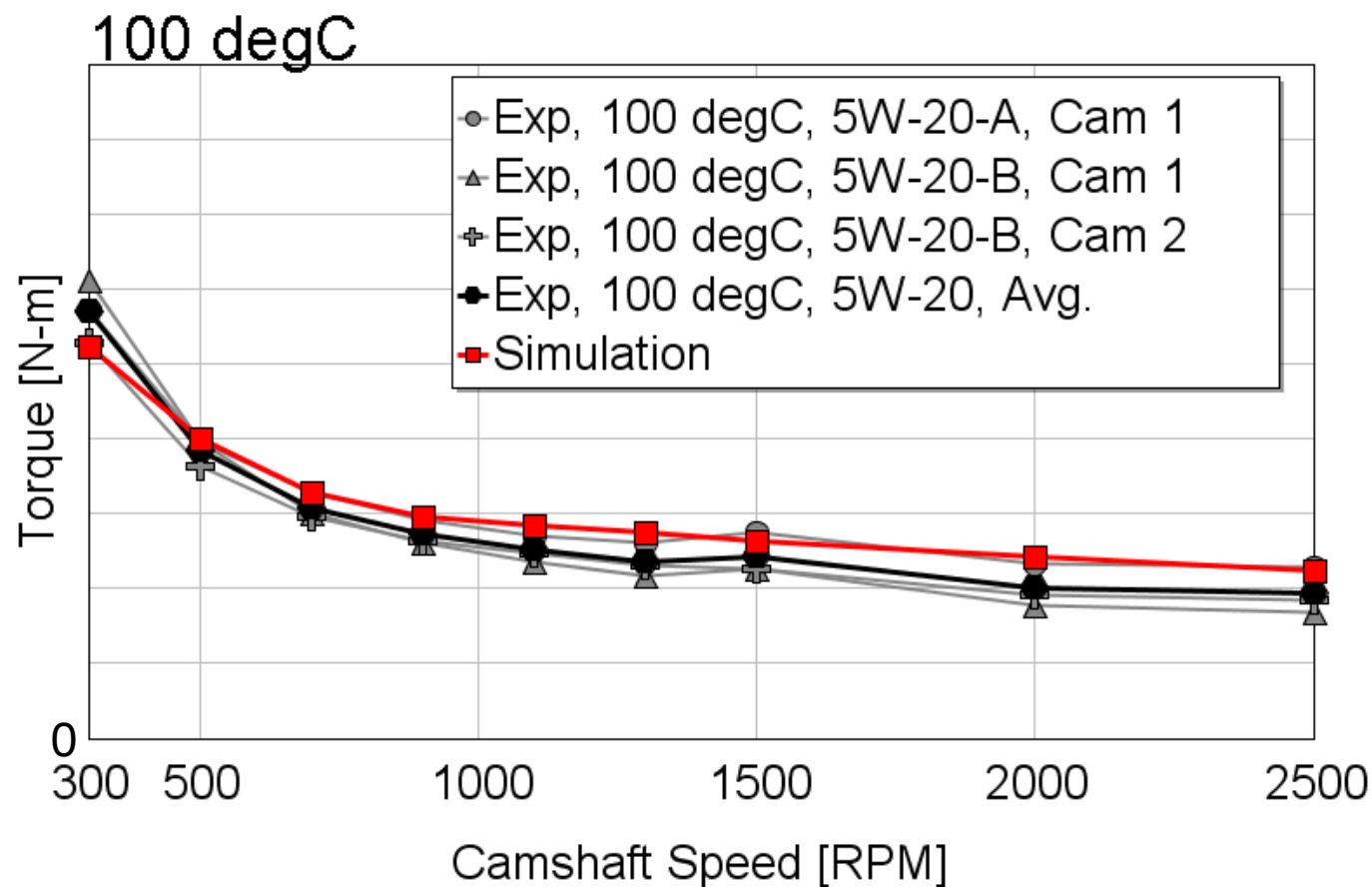
配气机构摩擦数据(Direct-acting, Flat-tappet VT)

Comparison to motored valvetrain (camshaft) torque



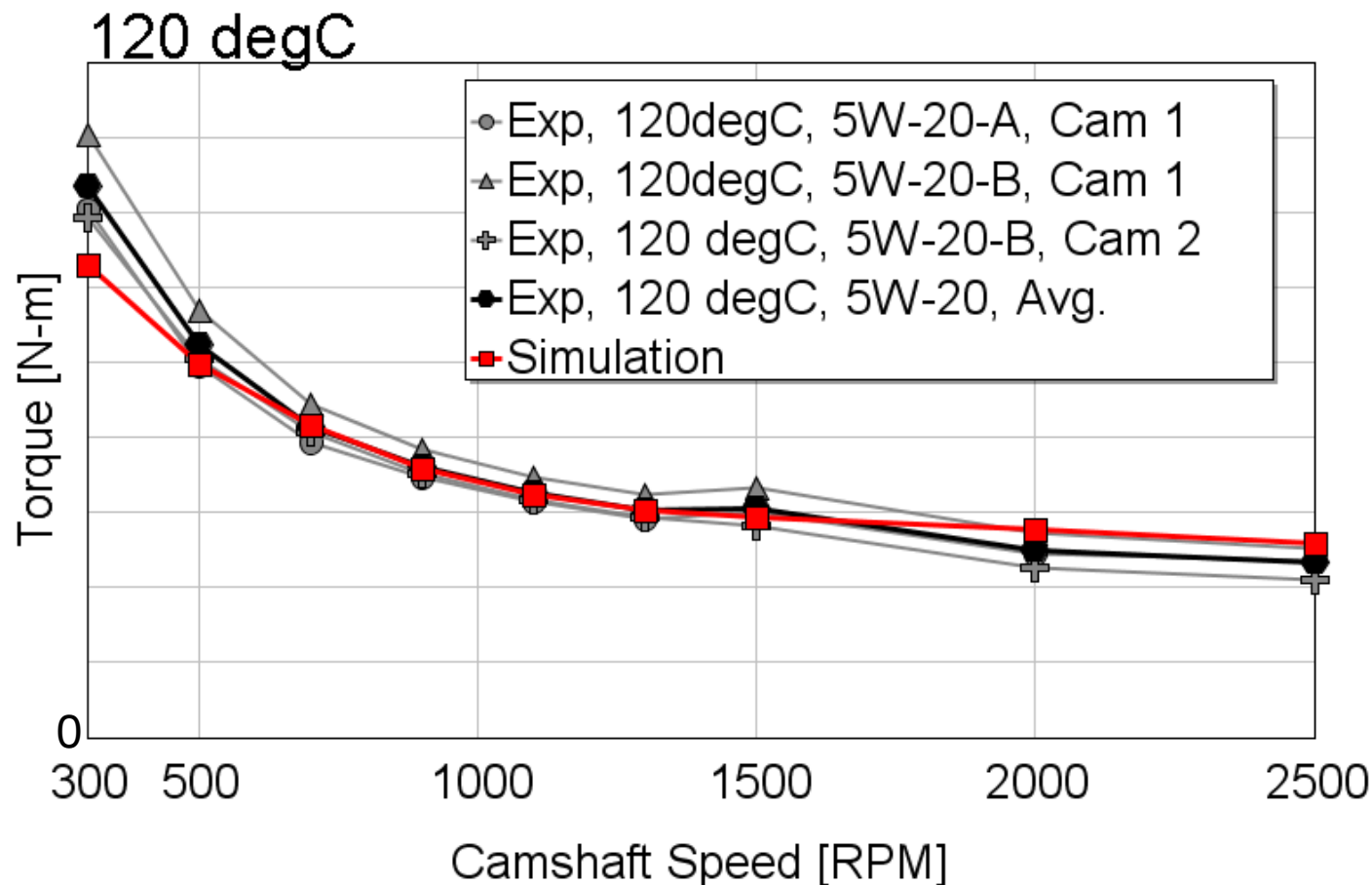
配气机构摩擦数据(Direct-acting, Flat-tappet VT)

Comparison to motored valvetrain (camshaft) torque



配气机构摩擦数据(Direct-acting, Flat-tappet VT)

Comparison to motored valvetrain (camshaft) torque



总结

- GT-SUITE平台已经提供了预测发动机摩擦损失所需要完全的模板，包括机械，流体/液压和摩擦等多种部件
- 发动机摩擦（EF）部件有足够的灵活性可以单独模拟，而且它们的计算效率适应于概念设计和优化设计时的相对优化处理
- GT 可以适当的展开进行发动机的摩擦研究的专门输出
- 灵活程度更高的关于HD/EHD油膜仿真技术v75有新的扩展，可用来进行更详细的仿真