柴油机摩擦副可靠性技术研究

Research on the reliability technology of the friction pair for diesel engine

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一、柴油机摩擦副可靠性研究背景

Research background for the reliability of friction pairs in diesel engine

摩擦副可靠性研究背景 Research background for the reliability of friction pairs

□ 高可靠性、长寿命柴油机是全球内燃机行业的竞争主题

High-reliability and long-life diesel engine is a competition topic in the global diesel engine industry

摩擦副可靠性研究背景 Research background for the reliability of friction pairs

□ 高可靠性、长寿命柴油机设计的关键：摩擦副可靠性和寿命的提升

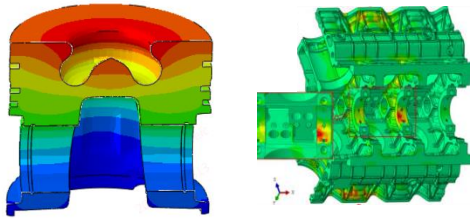
Key for designing high-reliability and long-life diesel engine: improving reliability and life of friction pair

✓ 愈发严苛的工况对摩擦副可靠性和寿命带来严重冲击，制约整机可靠性和寿命提升

More serious working conditions affect greatly the reliability and life of friction pair, which consequently restricts the improvement of the engine reliability and life

低排放、高热效率柴油机 → **严苛的服役工况边界** → **摩擦副可靠性和寿命的冲击**

- 创新性燃烧模式
- 先进EGR技术
- 先进增压技术
- 新型结构设计（轻量化）
- …



更高的温度、更高的爆发压力 …

- 润滑失效与润滑模式差异
- 局部接触强化
- 结构变形、动力学特性差异
- 润滑油/冷却液流场变化
- …

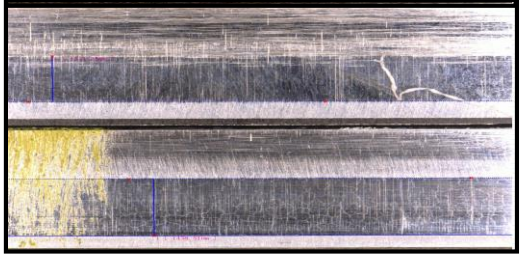
摩擦副可靠性研究背景 Research background for the reliability of friction pairs

□ 制约摩擦副可靠性和寿命的瓶颈：摩擦磨损、积碳、穴蚀

Bottleneck for improving the reliability and life of friction pairs: friction and wear, carbon deposit, cavitation

- ✓ **摩擦磨损：**活塞环组、凸轮轴及其从动件、气门座圈
  Friction and wear: piston ring pack, camshaft and its follower, valve seat
- ✓ **积　　碳：**活塞环槽、活塞内冷油腔
  Carbon deposit: piston ring groove, piston cooling gallery
- ✓ **穴　　蚀：**轴承轴瓦、气缸套水侧
  Cavitation: bush of bearing, water side of cylinder liner

摩擦磨损 | *Friction and wear*



积碳 | *Carbon deposit*

穴蚀 | *Cavitation*

二、摩擦副可靠性研究进展

Research progress on the reliability of friction pair

摩擦磨损

Friction and wear

- ✓ 摩擦润滑理论分析模型与方法
  Theoretical analysis model and method for the friction and lubrication
- ✓ 摩擦润滑性能的关键影响规律
  Key influence laws for the friction and lubrication performance
- ✓ 磨损机理与预测评估
  Wear mechanism, wear prediction and evaluation
- ✓ 减磨降摩技术
  Wear and friction reduction technology

□ 摩擦磨损：摩擦润滑理论分析模型与方法

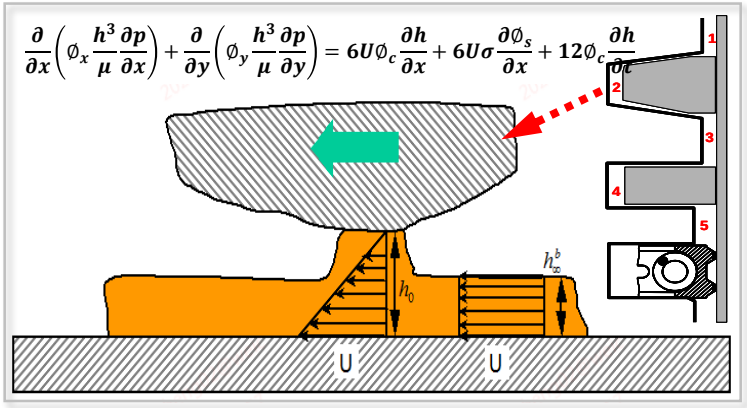
Friction and wear: theoretical analysis model and method for the friction and lubrication

- ✓ 活塞组件、凸轮轴及其从动件的流体动力润滑计算模型

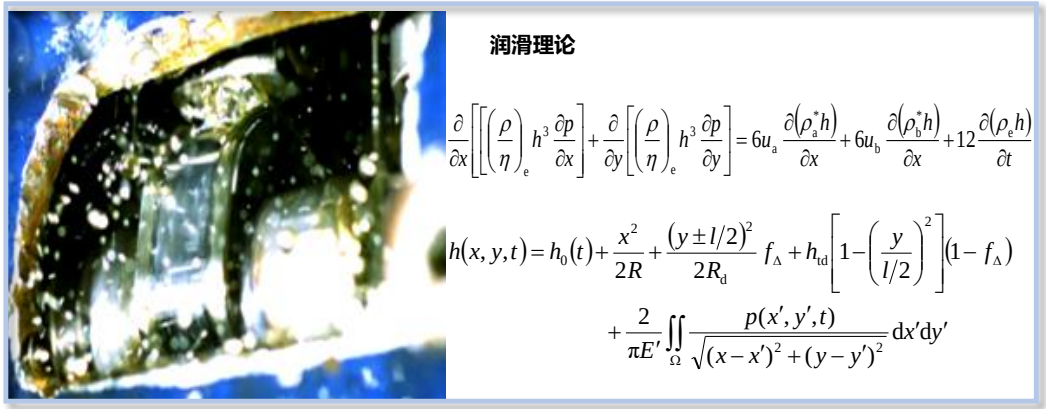
  Hydrodynamic lubrication model for the piston assembly, the camshaft and its follower

- ✓ 连杆大端轴承和主轴承的动力学-摩擦学耦合分析模型

  Dynamic-tribological coupling analysis model for the big end bearing of connecting rod and main bearing



活塞环润滑计算 lubrication calculation of ring



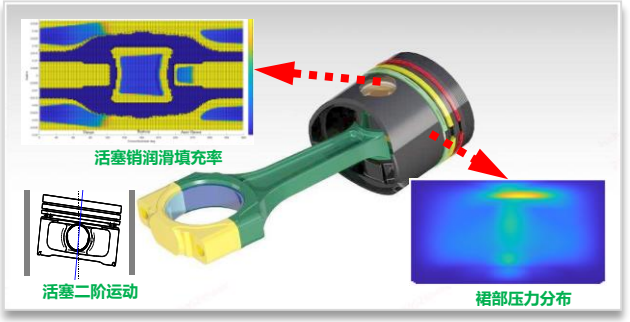
凸轮轴润滑计算 Lubrication calculation of camshaft

□ 摩擦磨损：摩擦润滑性能的关键影响规律

Friction and wear: key influence laws for the friction and lubrication performance

- ✓ 活塞组件、配气凸轮等的结构参数对摩擦润滑的影响
  Influence of the geometry of piston assembly and cam on the friction and lubrication
- ✓ 润滑油膜在摩擦副间隙中的流动特性和分布规律
  Flow and distribution characteristics of lubrication oil film in the friction pair
- ✓ 润滑介质特性与配副材料对摩擦特性的影响
  Influence of lubricant properties and pair's materials on the friction characteristics

轴瓦的油膜压力 oil pressure of bearing bush



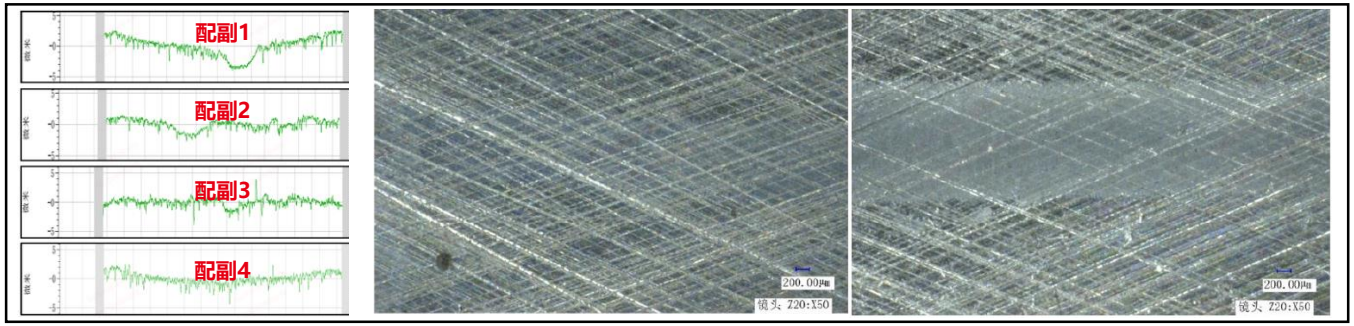
活塞组件润滑 Lubrication of piston assembly

□ 摩擦磨损：磨损机理与预测评估

Friction and wear: wear mechanism, wear prediction and evaluation

- ✓ 活塞环-缸套配副的磨损试验评价方法
  Experimental evaluation method for the wear of piston ring and cylinder liner
- ✓ 活塞环-缸套配副材料的优化匹配规律与配副选型匹配数据库
  Optimal matching rules and selection database for the piston ring and cylinder liner materials
- ✓ 气门座圈的磨损规律和磨损量预测模型
  Wear rules of valve seat and prediction of wear

SRV试验 SRV test



不同配副材料的磨损情况 Wear for different materials of pair

□ 摩擦磨损：减磨降摩技术

Friction and wear: wear and friction reduction technology

✓ 气缸套表面织构

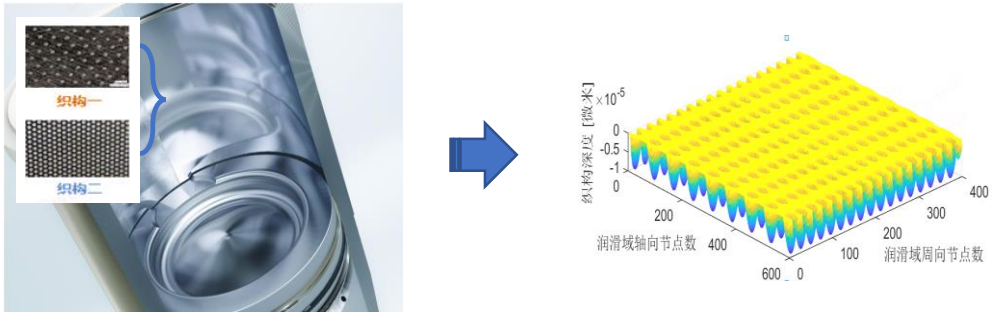
Surface texture of cylinder liner

- 织构表面摩擦润滑性能计算评估方法

  Calculation method for the friction and lubrication performance of textured surface

- 表面织构减磨降摩效果的影响因素及规律

  Influence factors and laws for the wear and friction reduction effect of surface texture



表面织构气缸套 Surface textured cylinder liner

□ 摩擦磨损：减磨降摩技术

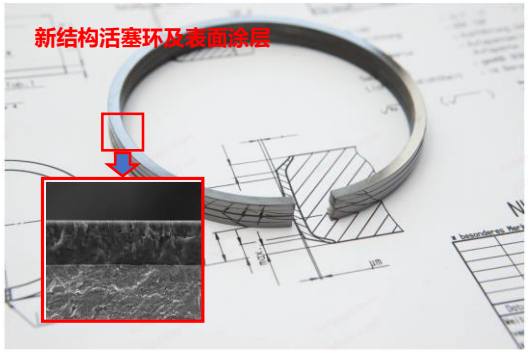
Friction and wear: wear and friction reduction technology

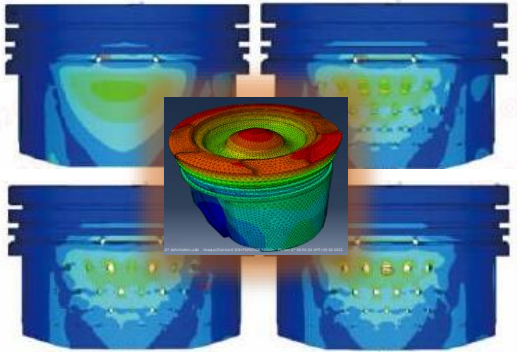
✓ 活塞组件结构-配副材料-润滑介质的协同优化

Coordination optimization for the geometry, materials, and lubricant of piston assembly

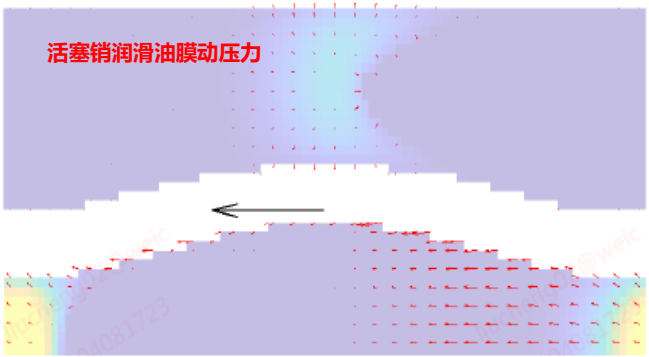
- 关键结构参数的优化设计方法+润滑介质和配副材料的优化匹配

  Optimal design method for the key geometry parameters + optimal matching of lubricant and pair materials





新结构与涂层的活塞环和活塞 Piston ring and piston with new geometry and coating



销孔型线优化 Optimization for pin bore

□ 摩擦磨损：减磨降摩技术

Friction and wear: wear and friction reduction technology

✓ 低磨损气门座圈

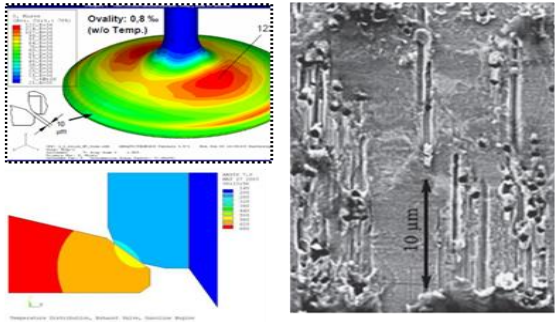
Low slip wear-reduction technology of valve seat

- 气门座圈低滑移减磨技术

  Low slip wear-reduction technology of valve seat

- 协调配气机构各配副磨损量的气门间隙控制方法

  Control method for the valve gap by matching the wear of pairs in the valve mechanism



气门座圈磨损 Wear of valve seat

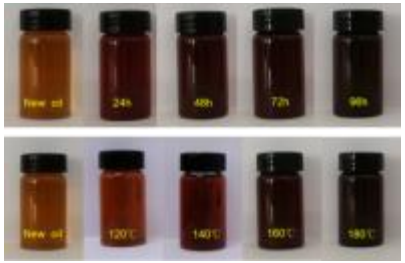
□ 摩擦磨损：减磨降摩技术

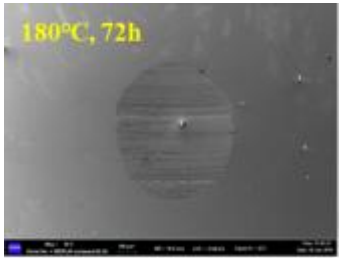
Friction and wear: wear and friction reduction technology

✓ 先进润滑介质与表面处理

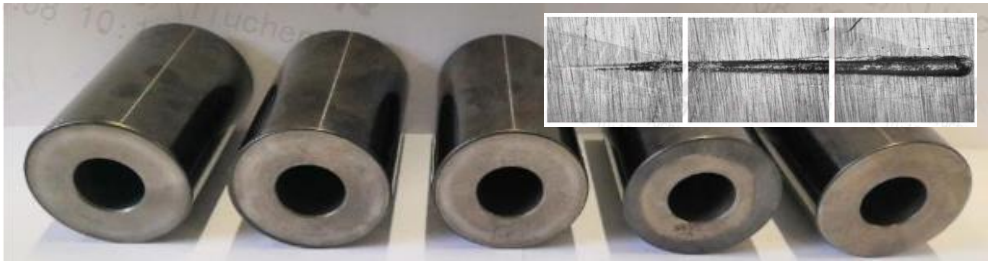
Advance lubricant and surface treatment

- 低粘度润滑油和先进减磨添加剂的减磨降摩效果评估
  Wear and friction evaluation for low viscosity lubricant and advance wear-reduction additives
- 低摩擦磨损表面涂层开发与性能评估
  Development of low friction and wear coating and its performance evaluation





润滑油的摩擦磨损 Friction and wear of lubricant



活塞销涂层及其结合力测试 Piston pin coating and its binding force test

活塞积碳

Carbon deposit of piston

- ✓ 活塞积碳的形成机理
  Formation mechanism of piston carbon deposit
- ✓ 活塞积碳的关键影响因素
  Key influence factors for piston carbon deposit
- ✓ 活塞积碳的控制方法
  Control method for piston carbon deposit

活塞积碳：形成机理与关键影响因素

Piston carbon deposit: formation mechanism and key influence factors

- ✓ 积碳形成的化学反应机理和典型的分布特征
  Chemical reaction mechanism and distribution of carbon deposit
- ✓ 环组动力特性对油气密封以及环槽积碳的影响
  Influence of ring pack dynamic properties on the oil/gas sealing and carbon deposit of ring groove
- ✓ 润滑油金属元素的析出机理、析出边界及其对活塞积碳的影响规律
  Precipitation mechanism and boundary for the metal element in lubricant, and its influence on the piston carbon deposit

积碳形成 Formation of carbon deposit

积碳分布 Distribution of carbon deposit

润滑油与积碳 Lubricant and carbon deposit

活塞积碳：控制方法

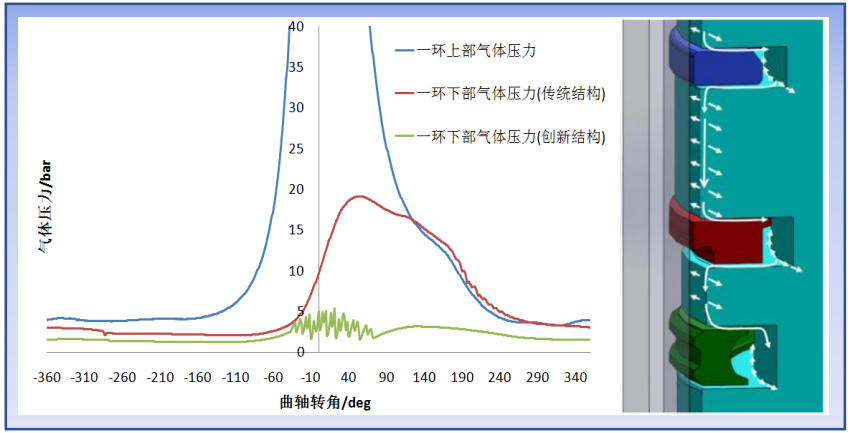
Research on the controlling method of piston carbon deposit

- ✓ 活塞环岸减压技术

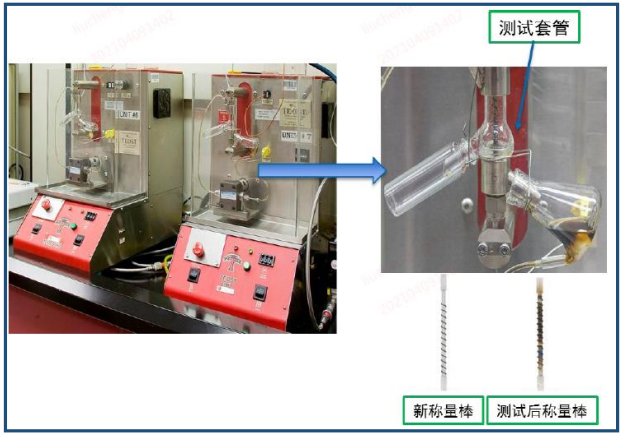
  Pressure reduction technology for piston ring land

- ✓ 基于润滑油改性方法的活塞积碳控制技术

  Controlling technology for the piston carbon deposit based on modification of lubricant



环岸减压技术 Pressure reduction technology of ring land



润滑油沉积试验 Deposition test of lubricant

轴瓦、气缸套穴蚀

Cavitation of bearing bush and cylinder liner

- ✓ 穴蚀理论建模

  Theoretical model of cavitation

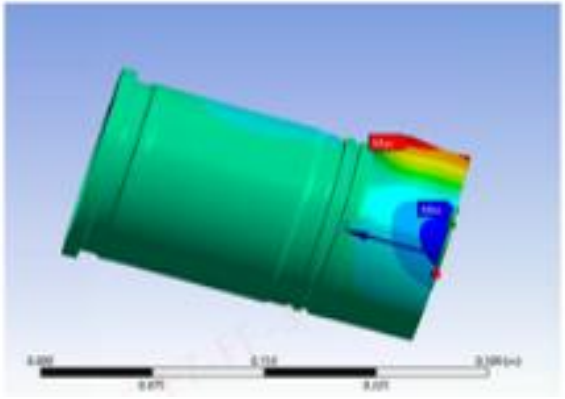
- ✓ 穴蚀机理及影响规律

  Cavitation mechanism and influence laws

□ 轴瓦、气缸套穴蚀：穴蚀理论建模

Cavitation of bearing bush and cylinder liner: theoretical model of cavitation

- ✓ 考虑润滑油膜空穴特征的轴瓦弹性流体动压润滑（EHD）模型
  EHD model of bearing bush with consideration of oil film cavitation features
- ✓ 考虑活塞侧向力激励的气缸套壁面振动CAE模型（辨识穴蚀风险）
  CAE model for liner wall vibration with consideration of piston side force (distinguishing cavitation)

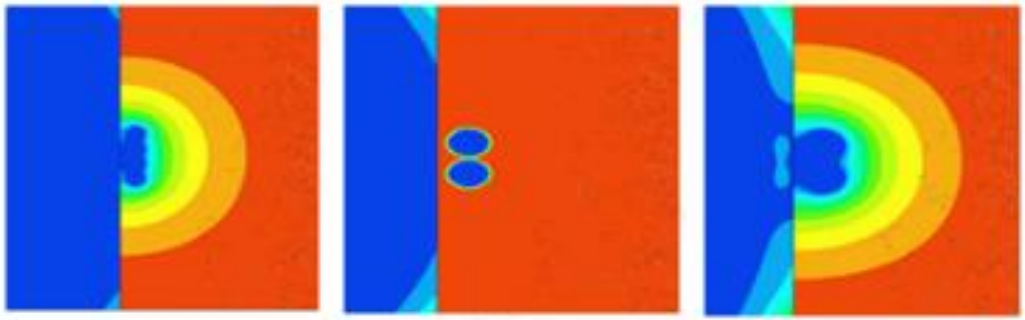


缸套壁面振动的CAE模型 CAE model for liner wall vibration

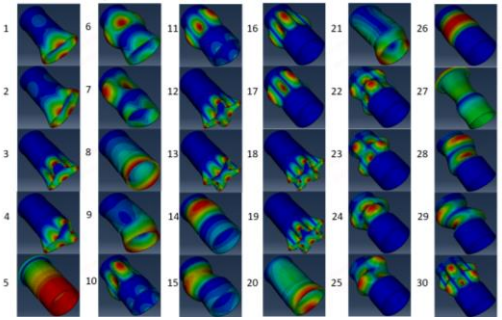
□ 轴瓦、气缸套穴蚀：穴蚀机理及影响规律

Cavitation of bearing bush and cylinder liner: cavitation mechanism and influence law

- ✓ 空泡数量、分布等特征对壁面应力及疲劳损伤的影响
  Influence of vacuoles number and distribution characteristics on the wall stress and fatigue damage
- ✓ 润滑油空化特征的演变规律及其与轴瓦穴蚀的相关性
  Laws of cavitation features of lubricant and its relationship with the bearing bush cavitation
- ✓ 缸套壁面振动响应和变形与缸套穴蚀特征之间的相关规律
  Relationship among the vibration response, deformation, and cavitation features of cylinder liner



空泡数量对壁面应力的影响 Influence of vacuoles number on the wall stress



缸套振动模态 Vibration mode of liner

三、研究展望

Research prospect

□ 持续提升摩擦副的可靠性和寿命，助力高可靠性长寿命柴油机设计水平发展

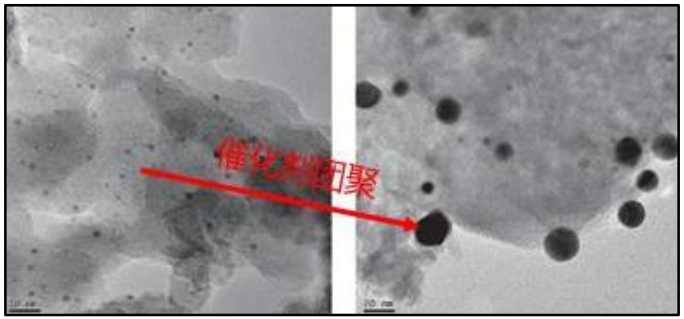
Improving reliability and life of friction pair continuously, and enhancing the design level of high-reliability and long-life diesel engine

- ✓ 完善摩擦磨损技术理论分析方法，实现低摩擦磨损技术突破
  Improving theoretical method for friction and wear, achieving breakthrough of low friction and wear technology
- ✓ 察明积碳形成机理，发展积碳识别与预测技术
  Finding the formation mechanism of carbon deposit, developing identification and prediction technology
- ✓ 发展穴蚀仿真与预测技术，揭示穴蚀对可靠性和寿命的影响规律
  Developing cavitation simulation and prediction technology, revealing the influence laws of cavitation on the reliability and life

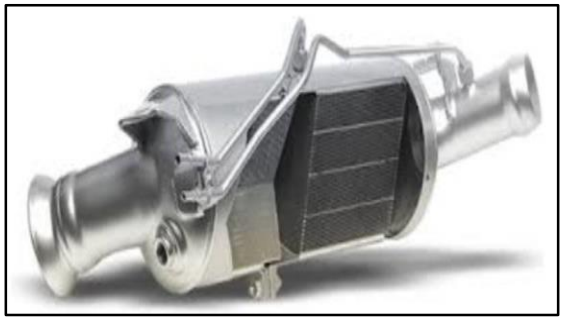
□ 排放升级给柴油机后处理系统的可靠性和寿命带来新的挑战

Emission upgrade brings a new challenge on the reliability and life for the post-processing system of diesel engine

- ✓ 更高的可靠性与寿命要求
  Higher reliability and longer life demands
- ✓ 新技术对可靠性和寿命的新需要
  New requirements in reliability and life for new technology



催化剂老化 Catalyst aging



DPF

EGR

新技术的应用给可靠性和寿命带来新的要求

Emission upgrade brings a new challenge on the reliability and life for the post-processing system of diesel engine

- ✓ 高热效率技术
  High thermal efficiency technology
- ✓ 智能附件、电动化、混合动力等技术
  Smart parts and accessory, electrification, hybrid power technologies
- ✓ 新燃料发动机技术
  New fuel diesel engine technology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