船用柴油机相继增压高温阀机械老化分析

Mechanical Aging Analysis For High Temperature Valves of Sequential Turbocharging of Marine Diesel Engines

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Reliability problems faced by high temperature

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Failure analysis of mechanical aging

- 总结

Summarize

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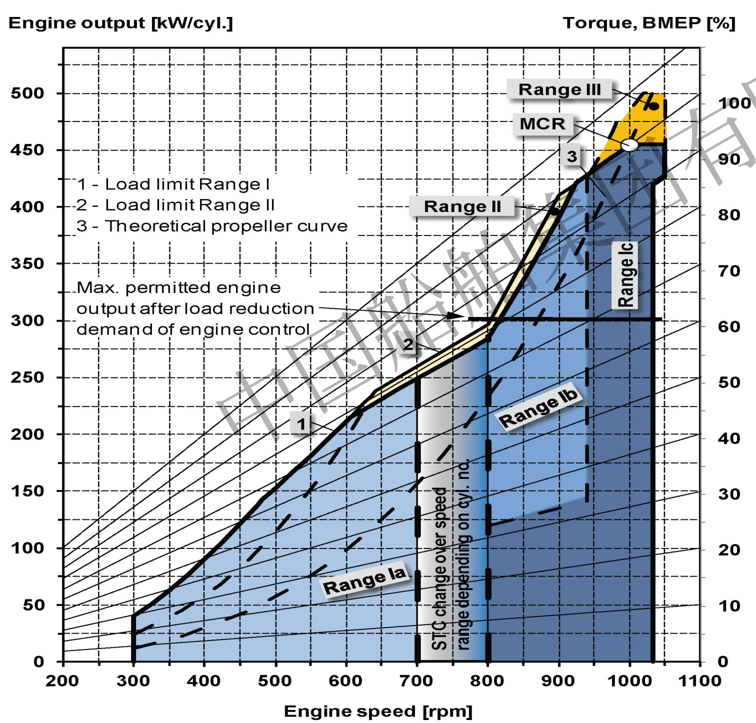
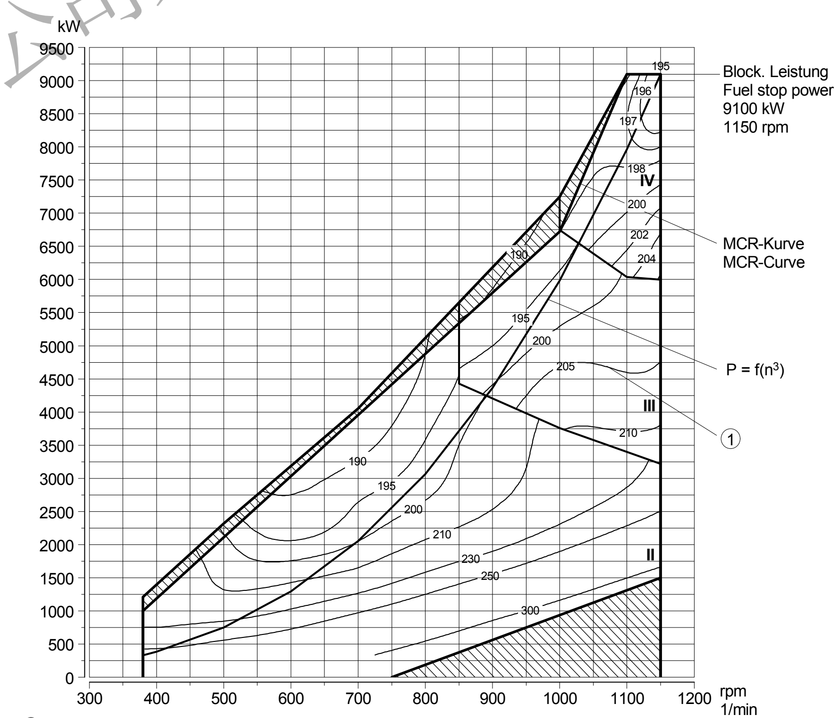
一、 研究背景Research Background

1、目前船用柴油机基本上“无机不增压”，增压柴油机难以同时满足在高、低工况下运行的要求，并且增压程度越来越高，该矛盾越突出。

At present, almost all marine diesel engines are turbocharged. Turbocharged diesel engines are difficult to satisfy the requirements between high and low loads operation conditions, and the contradiction is more prominent with the boost pressure increasing.





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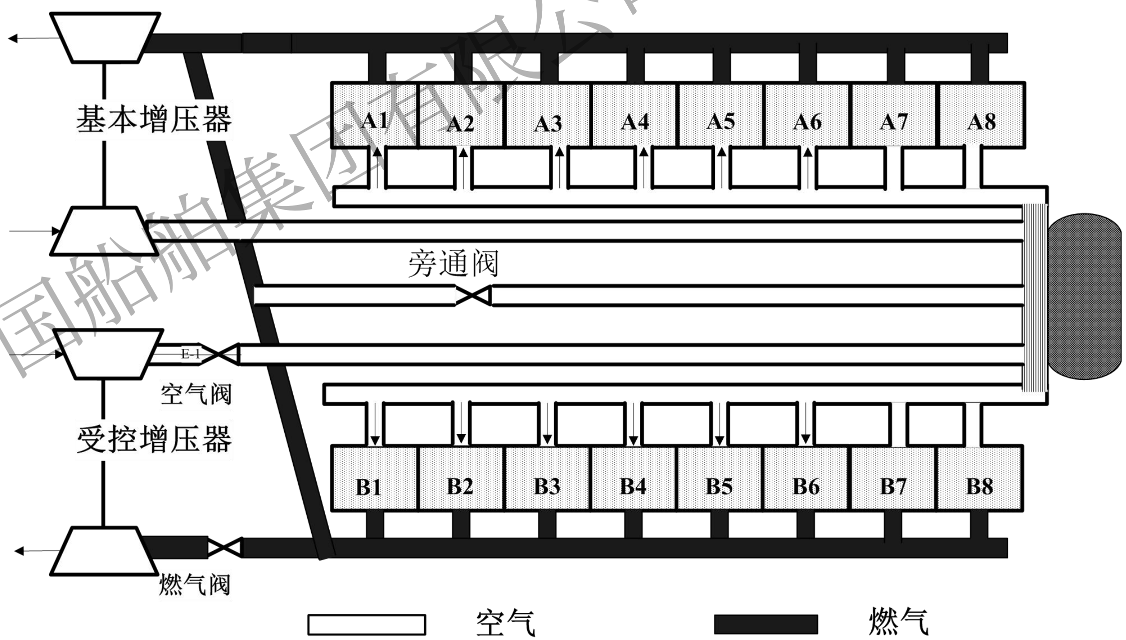
一、 研究背景Research Background

- 燃气阀、空气阀开/关闭控制受控增压器的切入与切出，实现相继增压；
The gas valve and air valve open or close control the controlled turbocharger on operation or inoperation.

- 相继增压高温阀是柴油机兼顾高、低运行工况的关键部件。
High temperature valves of sequential turbocharging system are key components of STC diesel engines, which guarantee the high and low loads performance of STC diesel engines .



一、 研究背景Research Background

1、在工作状态下，阀前为高温带压气体，阀后为高温常压气体，通过蝶阀的高温气体使得蝶阀温度升高，且温度分布不均匀，导致蝶阀产生热应力和热变形。

In the working state, the gas in front of the butterfly valve is high temperature and high pressure, and the gas behind the valve is high temperature and constant pressure. The temperature of butterfly valve is gradually increasing when the gas pass the butterfly valve, and the distribution of temperature is not uniform, which result in thermal stress and thermal deformation of the butterfly valve.

2、蝶阀受管内气体激振力作用导致的受迫振动，有可能导致高温状态下蝶阀的某些零部件上产生裂纹甚至是振动破坏。

The butterfly valve will be on forced vibration because of the shock excitation force of gas in the pipe, which may lead to cracks or even vibration failure on some components of butterfly valve under high temperature.

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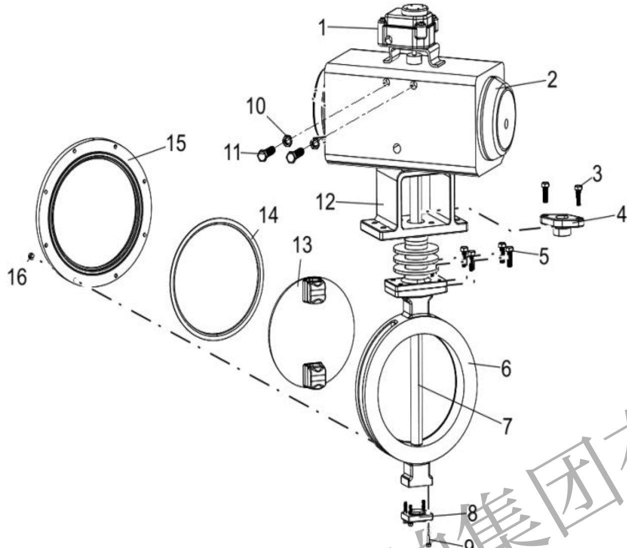
二、面临的可靠性问题Reliability problems

■ 机械老化 Mechanical aging



➢ 卡环：高温阀门阀杆轴向定位作用，失效后阀杆上下窜动，导致密封圈失效；

Half clasp: high temperature valve axial position orientation, valve axial fluctuate up and down after half clasp failure, finally, result the seal ring failure.

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二、面临的可靠性问题Reliability problems

故障现象 → 原因推测 → 计算预测 → 设计改进

Fault phenomenon → reason analysis → calculation predict → improvement design

❑ **研究内容**Research Contents

- 相继增压高温阀CFD热流体计算

  CFD thermal fluid calculation of STC high temperature valves.

- 相继增压高温阀热应力分析

  thermal stress analysis of STC high temperature valves.

- 相继增压高温阀受迫振动分析

  Force vibration analysis of STC high temperature valves.

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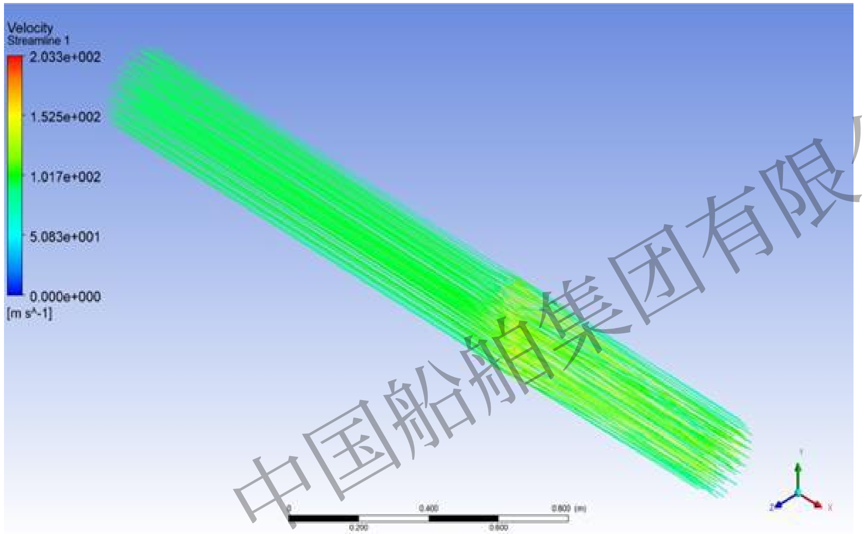
三、机械老化失效分析（热流场）
Mechanical aging failure analysis(thermal flow field)

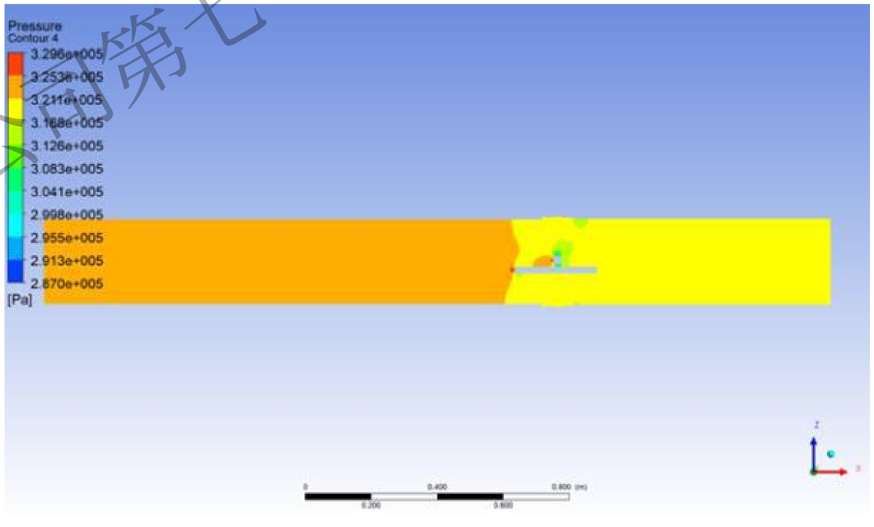
❑ 流场 flow field

湍流模型采用标准k-ε 模型，求解器选择为Couple 算法， 循环迭代至稳定；

Turbulence model adopt standard k-ε model Solver is chosen the couple algorithm, loop iterates to stability.



90° 流场线图



90° 压力线图

➢90° 条件下，阀板上下游流线分布均匀，阀门前后压差较小。

Under the condition of 90°，the streamline upstream and downstream the disk distributes evenly and pressure difference is less .

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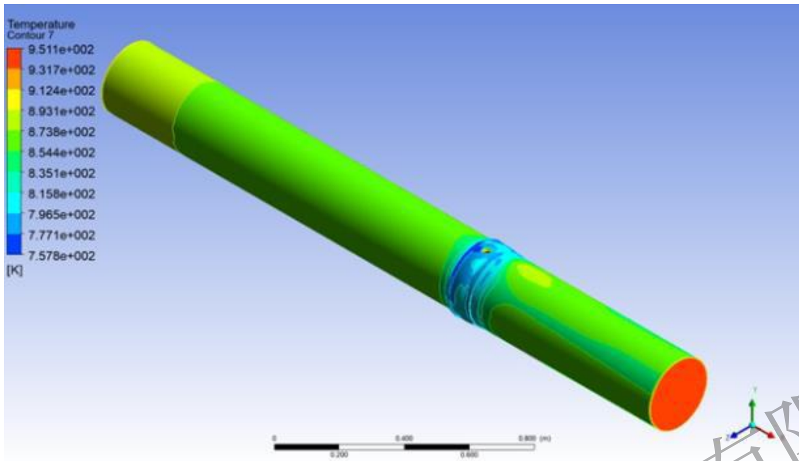
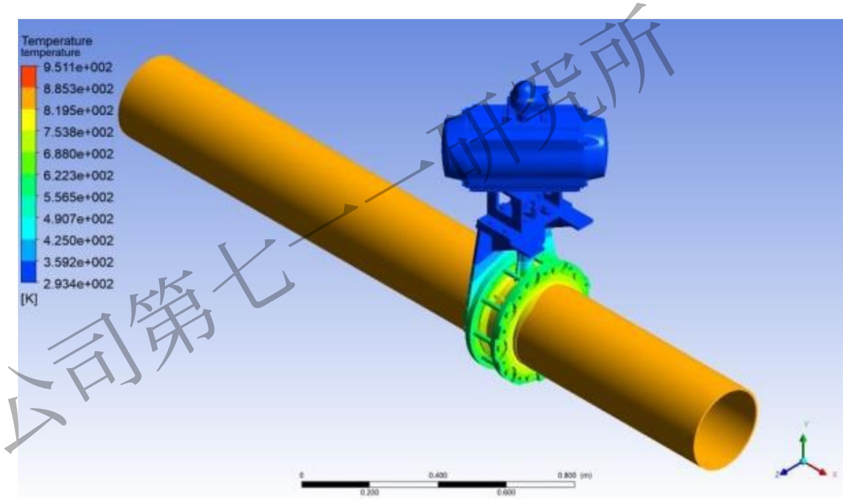
三、机械老化失效分析（热流场）

Mechanical aging failure analysis(thermal flow field)

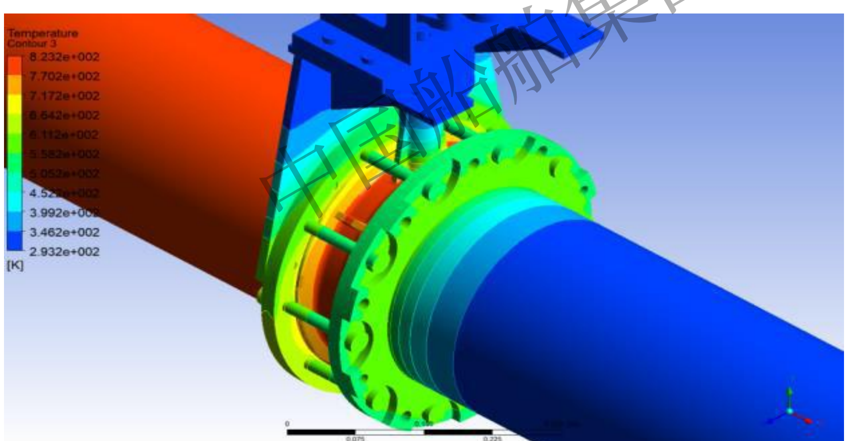
❑ 温度场 Temperature field



90°流体域温度图 temperature field in flow domain



90°固体域温度图temperature field in solid domain



0°固体域温度图temperature field in solid domain

➢距离流体越近，固体温度越高；

The closer to the fluid , the higher temperature the solid is

➢阀门关闭时，仅计算固体的温度分布。

When the valve is closed, only the temperature distribution of the solid is calculated

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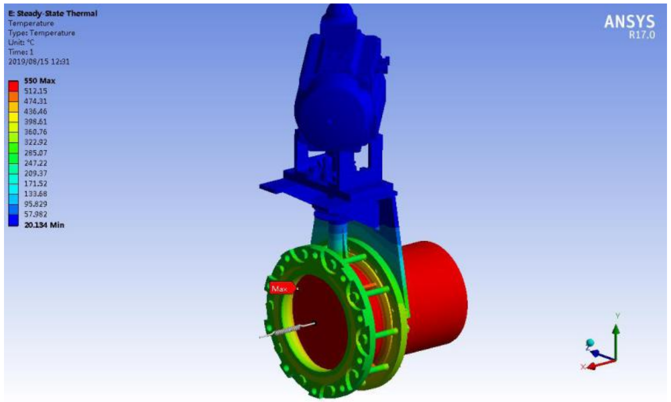
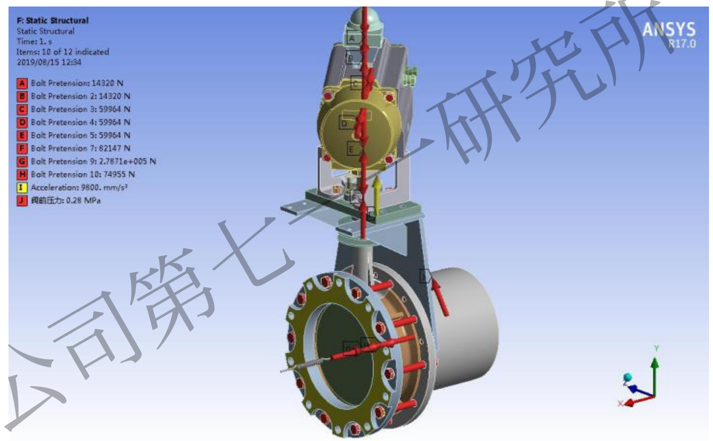
三、机械老化失效分析（热应力分析）

Failure Analysis of Mechanical Aging(Thermal Stress Analysis)

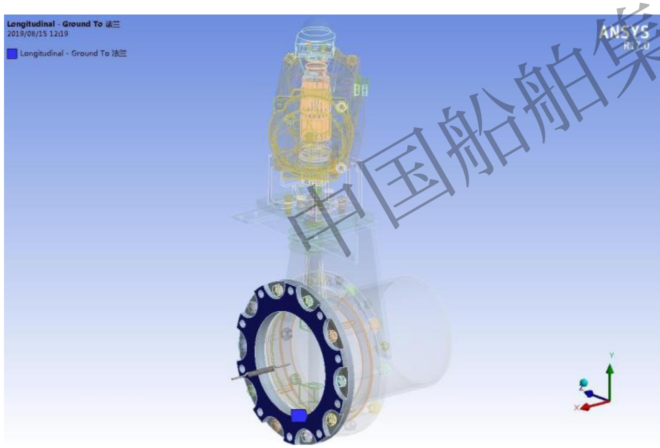
❑ 0°（关闭）边界条件



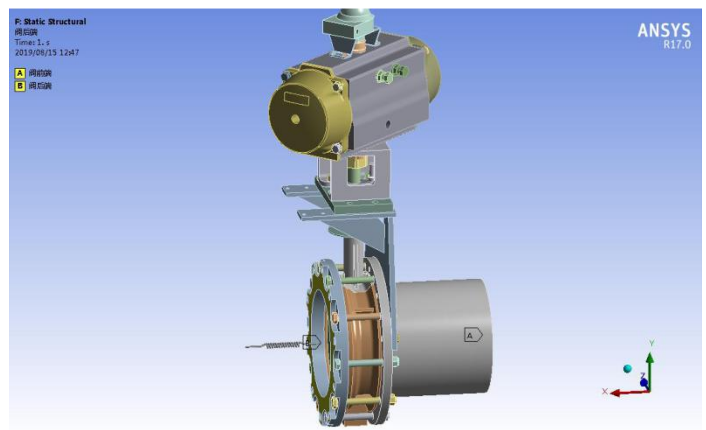
➢温度场映射结果作为热载荷边界条件；
Mapping of temperature field as thermal load BC



➢压力载荷、重力、螺栓预紧力
➢Pressure load, Gravity, bolt oreload



➢波纹管轴向补偿—弹簧约束；
Bellows axial compensation Spring constraint



➢阀前管道端面和阀后法兰密封面设置位移约束；
Pipe before valve and flange after valve as displacement constraint

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三、机械老化失效分析（热应力分析）

Failure Analysis of Mechanical Aging(Thermal Stress Analysis)

- 基于第四强度理论（又称为畸变能理论或Von Mises 理论）进行等效总应力计算；

  Calculate equivalent total stress based on forth strength theory (Distortion Energy Theory or Von Mises theory)

- 整体模型分析中阀杆最大VonMises等效应力280.94MPa，位于阀杆与卡环处；

  Maximum VON Mises of the valve shaft is 280.94 MPa, located at joint of the shaft and half-calsp.

- 有限元应力评定，阀杆强度满足许用要求；

  Thermal stress assessment, valve stem to meet the strength requirements

- 对整个阀杆而言，阀杆下端最容易出现应力集中。

  the lower end of shaft is most prone to stress concentration for the entire shaft.

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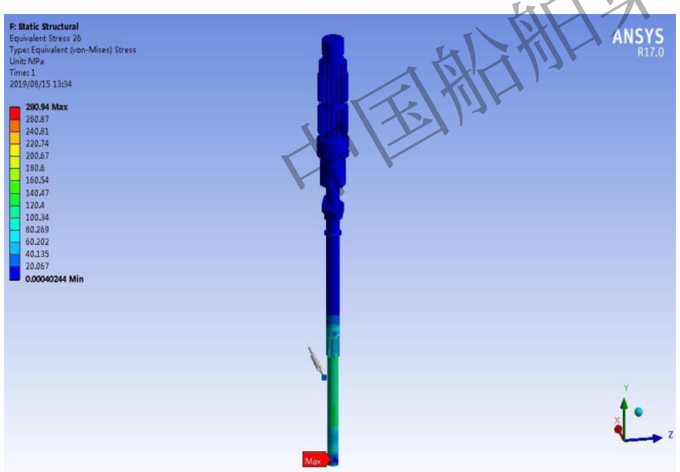
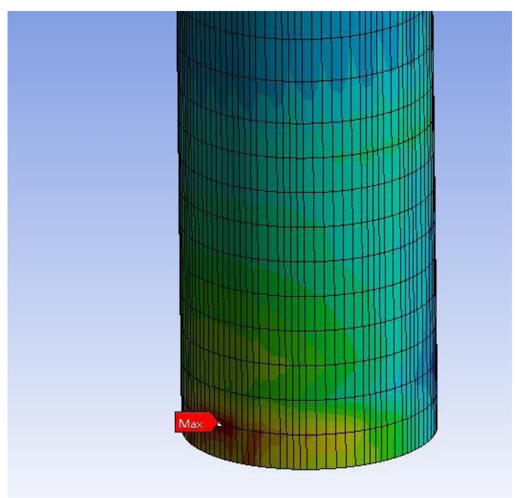
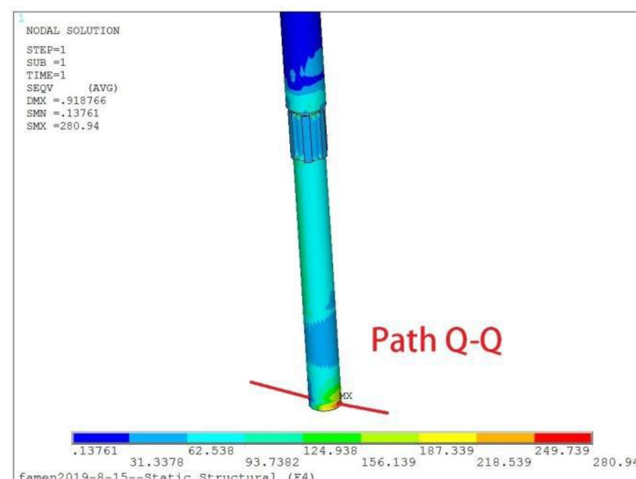


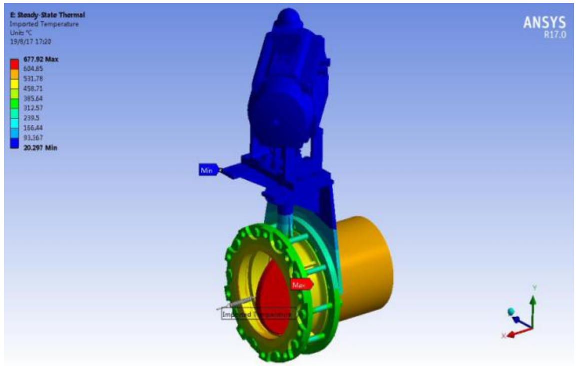




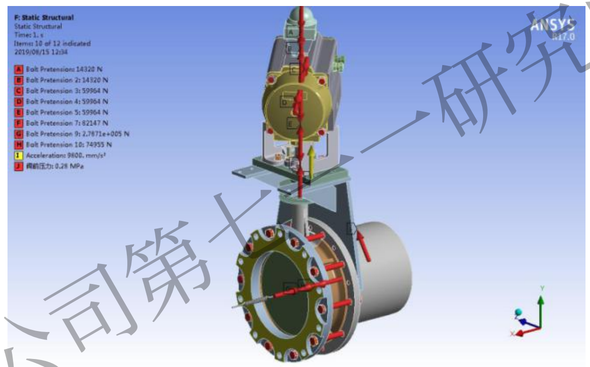
三、机械老化失效分析（热应力分析）

Failure Analysis of Mechanical Aging(Thermal Stress Analysis)

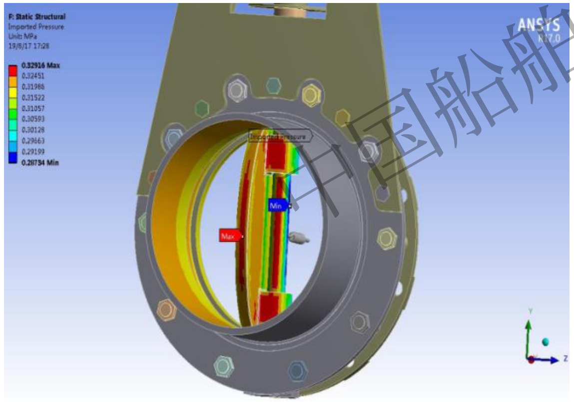
❑ 90°（开启）边界条件 90 °(Open)boundary condition



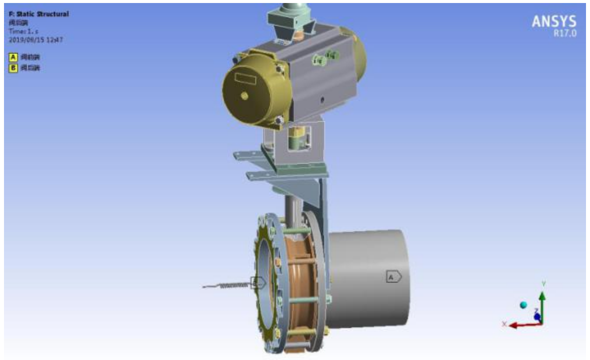
➢温度场映射结果作为热载荷边界条件；
➢Mapping of temperature field as thermal load BC



➢压力载荷、重力、螺栓预紧力
➢Pressure load, Gravity, bolt oreload



➢压力场映射结果作为压力边界条件；
➢Mapping of pressure field as pressure BC)



➢阀前管道端面和阀后法兰密封面设置位移约束；
➢Pipe before valve and flange after valve as displacement constraint

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三、机械老化失效分析（热应力分析）

Failure Analysis of Mechanical Aging(Thermal Stress Analysis)

- 阀杆最大Von Mises 等效总应力347.73MPa，位于阀杆与阀体连接处附近；

Maximum VON Mises equivalent total stress of the valve shaft is 347.73MPa, located at joint of shaft and body.

- 由于阀体和阀杆存在温度差导致阀杆与阀体间隙减小，阀体可向波纹管移动，阀杆下端合位移最大；

- Due to temperature difference between shaft and body, the gap between them is reduced.

- 对整个阀杆而言，阀杆下端易出现磨损。

The lower end of shaft is most prone to wear for the entire shaft.

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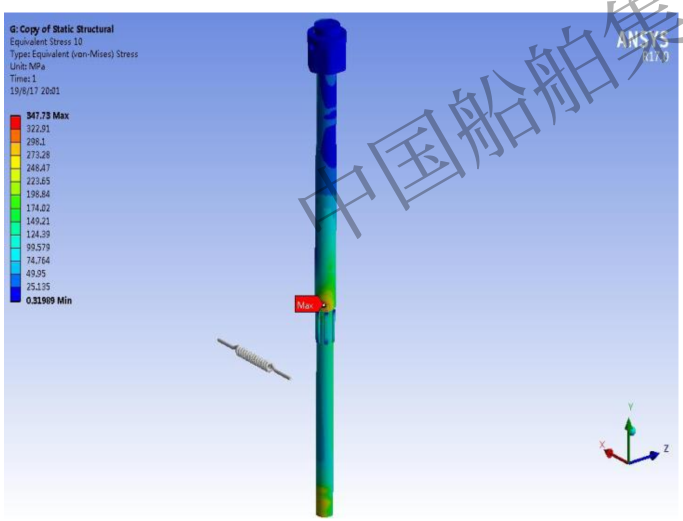

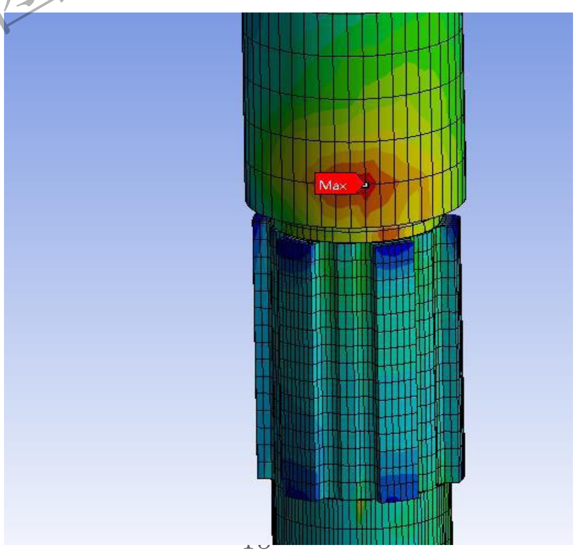

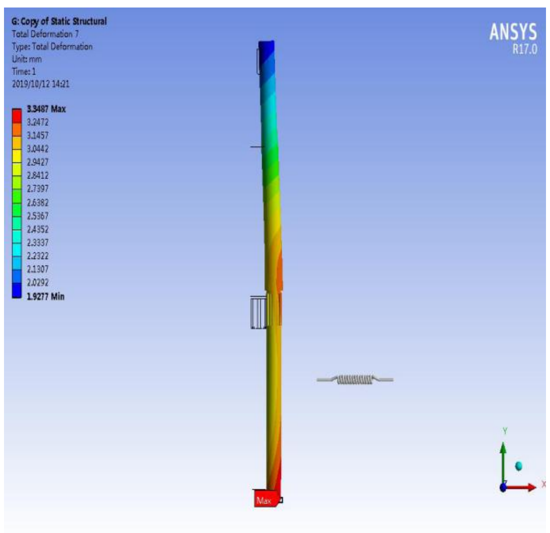

三、机械老化失效分析（受迫振动分析）

Failure Analysis of Mechanical Aging(Forced vibration analysis)

■受迫振动分析 Forced vibration analysis

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➢机械结构受迫振动分析可采用谐响应或随机振动分析；

The Forced vibration of mechanical structure can be analyzed by harmonic response or random vibration;

➢谐响应分析需要得出管道系统气柱固有频率及试验测得压力不均匀度，测试难度较大；

harmonic response analysis needs to obtain natural frequency gas in the pipe and pressure unevenness measured by test ,which is difficult.

➢随机振动中的载荷采用频谱中载荷，准确度较高，且测试条件较为容易。

Adopting load in frequency spectrum as load in random vibration, is more accurate and feasible.

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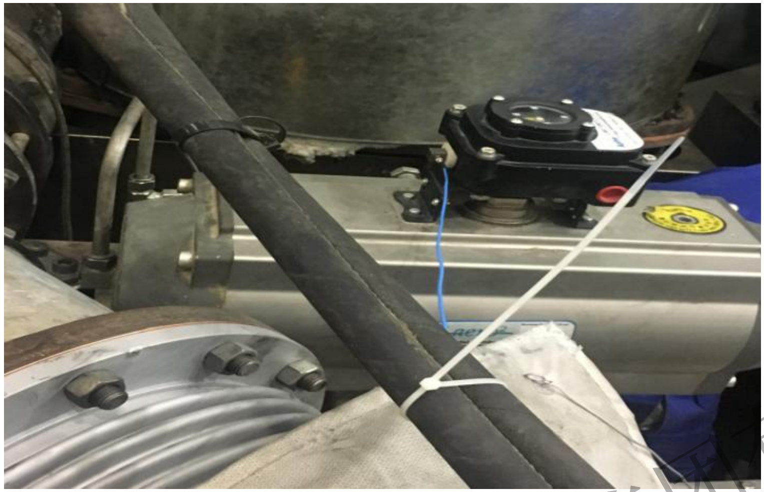
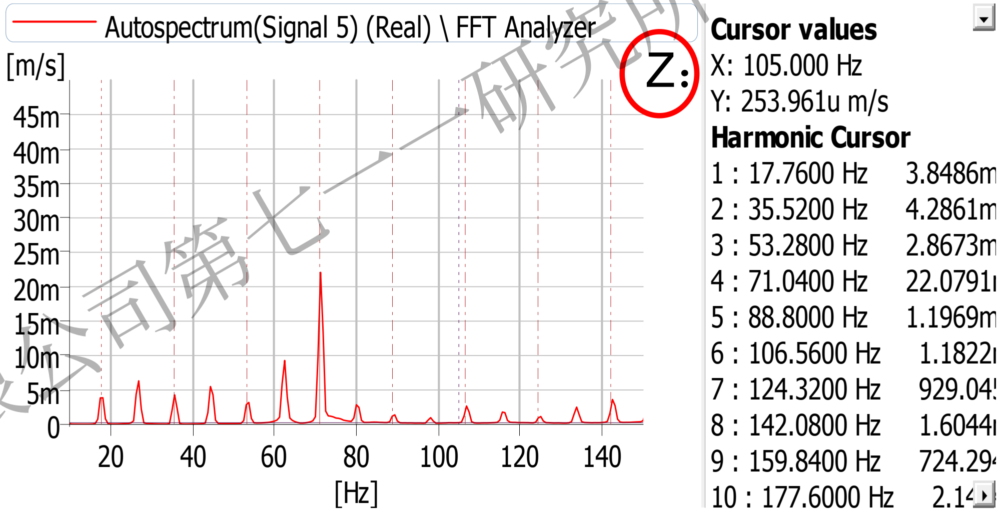
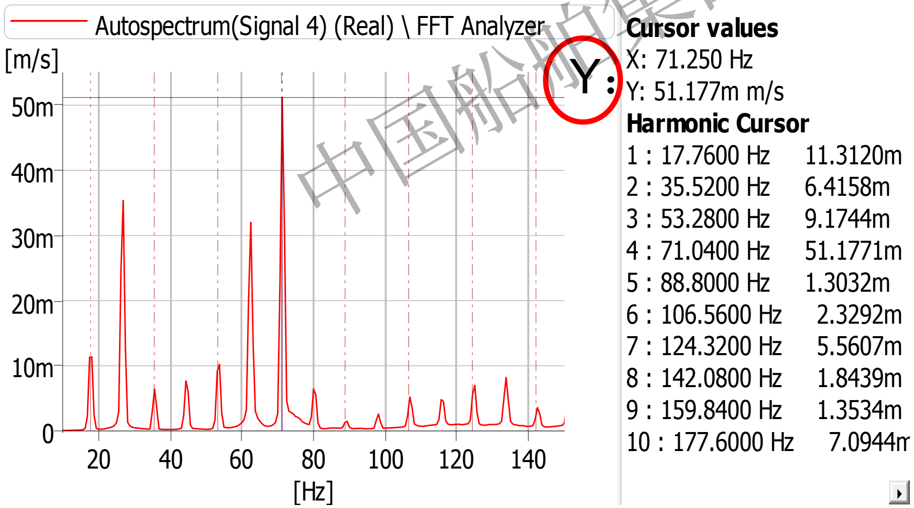
三、机械老化失效分析（受迫振动分析）

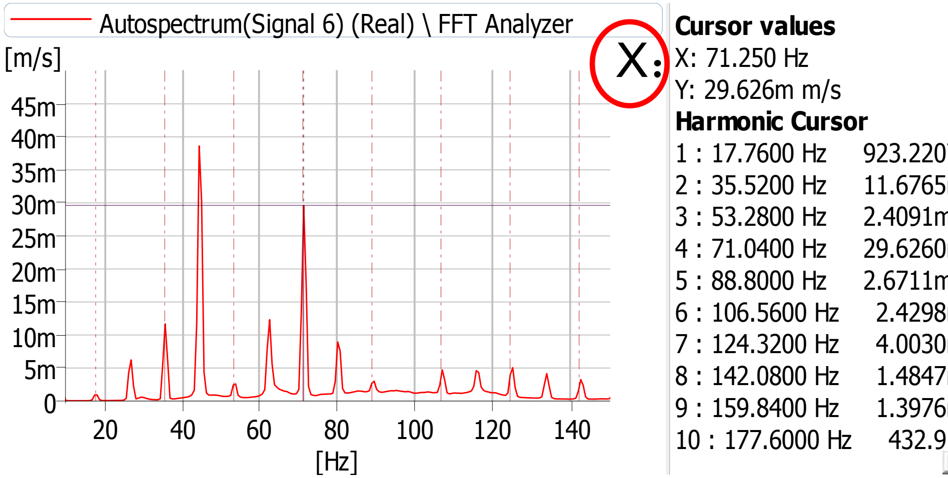
Failure Analysis of Mechanical Aging(Forced vibration analysis)

➢速度频谱测试结果 test result of speed spectrum









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三、机械老化失效分析（受迫振动分析）

Failure Analysis of Mechanical Aging(Forced vibration analysis)

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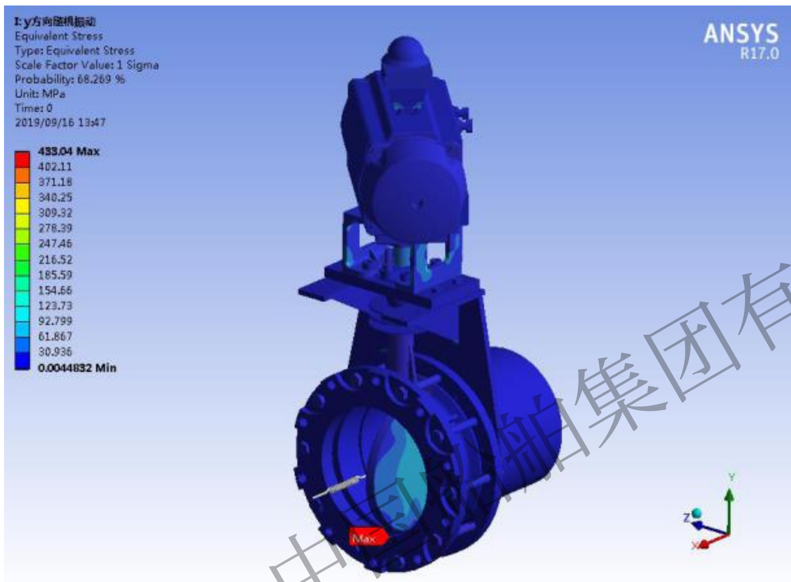
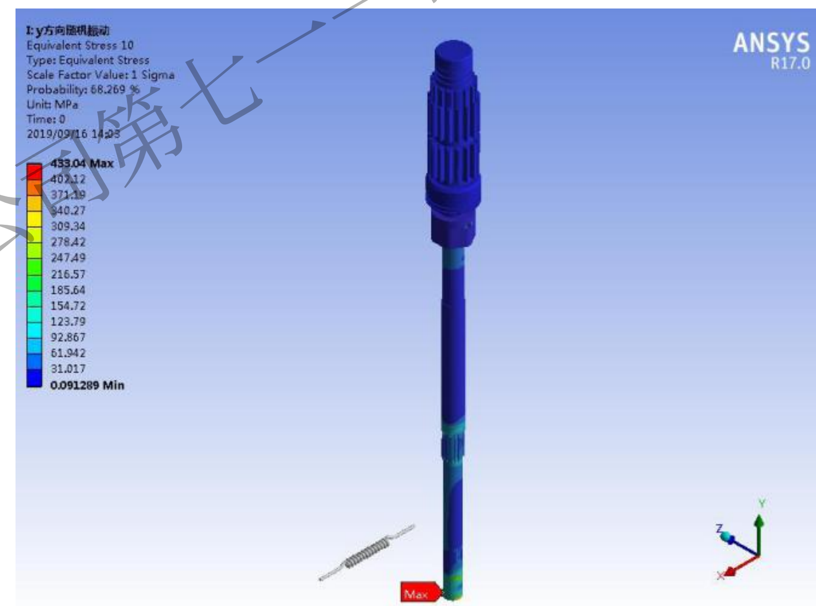
- 模态叠加法进行随机振动分析（X,Y,Z） Random vibration analysis by mode superposition method
- Z 方向（水平方向）随机振动结果 Z direction(horizontal direction) random vibration result:





- 最大动应力位于阀杆底部与阀体连接处；
  - Maximum dynamic stress at joint of body and lower end of valve shaft
- 阀杆最大动应力为433.04MPa，位于阀杆底部；
  - The maximum dynamic stress of Z direction is 433.04 MPa, which is located at the bottom of the valve shaft.

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三、机械老化失效分析（受迫振动分析）

Failure Analysis of Mechanical Aging(Forced vibration analysis)

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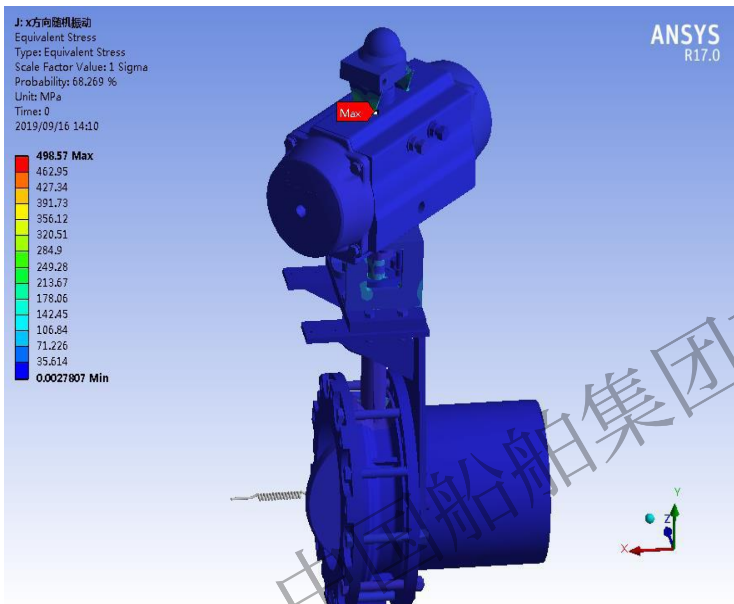
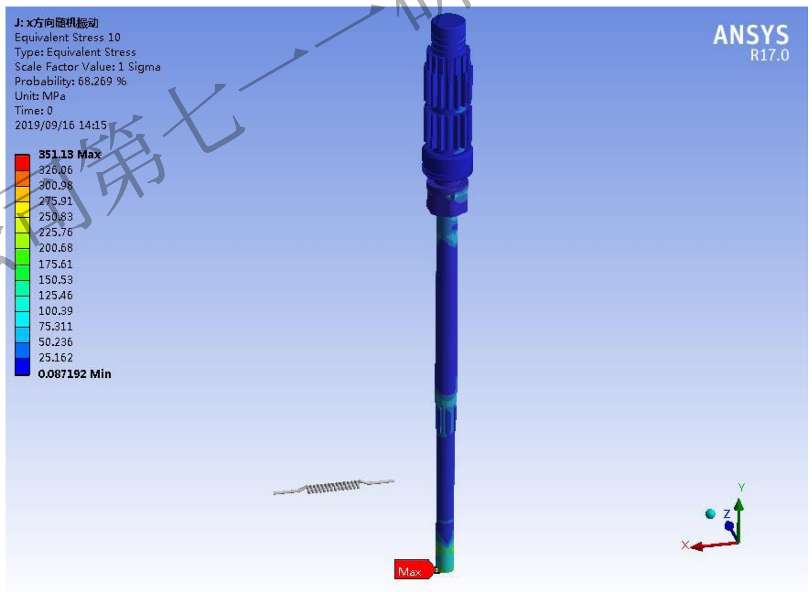
➢模态叠加法进行随机振动分析（X,Y,Z）； Random vibration analysis by mode superposition method

➢X 方向（轴向）随机振动结果:X direction(axial direction) random vibration result:





➢最大动应力位于回讯器支架折弯板圆角处；

➢Maximum dynamic stress at bend of bracket of positioning feedback.

➢X方向随机振动下阀杆最大动应力为351.13MPa，位于阀杆下端。

➢The maximum dynamic stress of valve shaft under random vibration in X direction is 351.13MPa.

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三、机械老化失效分析（受迫振动分析）

Failure Analysis of Mechanical Aging(Forced vibration analysis)

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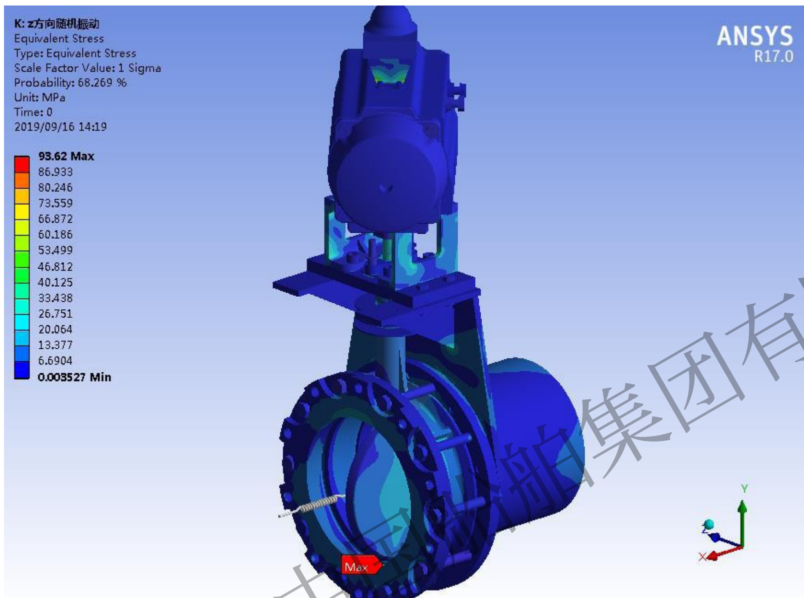
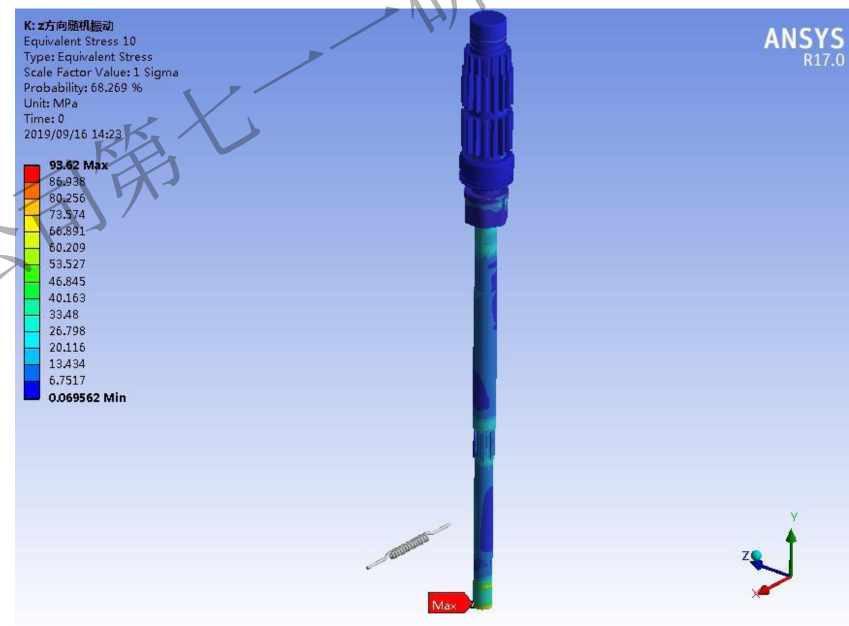
- ➢模态叠加法随机振动分析（X,Y,Z） Random vibration analysis by mode superposition method
- ➢Y 方向（垂直方向）随机振动结果: Y direction(vertical direction) random vibration result:





- ➢Y方向随机振动下阀杆最大动应力为93.62MPa，位于阀杆下端。

The maximum dynamic stress of valve shaft under random vibration in Y direction is 93.62MPa.

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四、总结 Conclusion

- 阀门关闭时整体模型中阀杆最大等效应力280.94MPa，位于阀杆与卡环处；阀门开启时阀杆下端合位移最大，且位置正处于阀杆与卡环处；

  When the valve is closed, maximum equivalent total stress of the valve shaft is 280.94 MPa, located at joint of the shaft and half-calsp.When the valve is open, the maximum displacement occurs at lower end of valve shaft, which is the joint of the shaft and half-calsp.

- 随机振动分析，在水平方向（Z）、竖直方向（Y）随机振动时，阀门最大应力均在阀杆与阀体连接处，且处于阀杆下端；轴向（X）随机振动下，回讯器支架折弯板圆角处动应力最大，但仅针对阀杆分析，其阀杆最大应力也出现在下端；

  From random vibration analysis, in horizontal(Z) and vertical(Y) direction, maximum stress appears at the lower bottom of valve shaft, near the connection of shaft and body. In axial(X) direction, maximum stress appears at the bend of bracket of positioning feedback. For valve shaft, the maximum stress appears at lower end.

- 综上所述，由于高温和振动的影响，阀门阀杆下端与卡环连接处易出现磨损现象，与实际状态吻合；同时为提升阀杆可靠性设计改进提供支撑。

  In summary, due to high temperature and vibration, the joint of the shaft and half-calsp is easy to wear, which is consistent to actual state. This provide support to improving the reliability of valve shaft.

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