螺栓仿真校核技术专题培训

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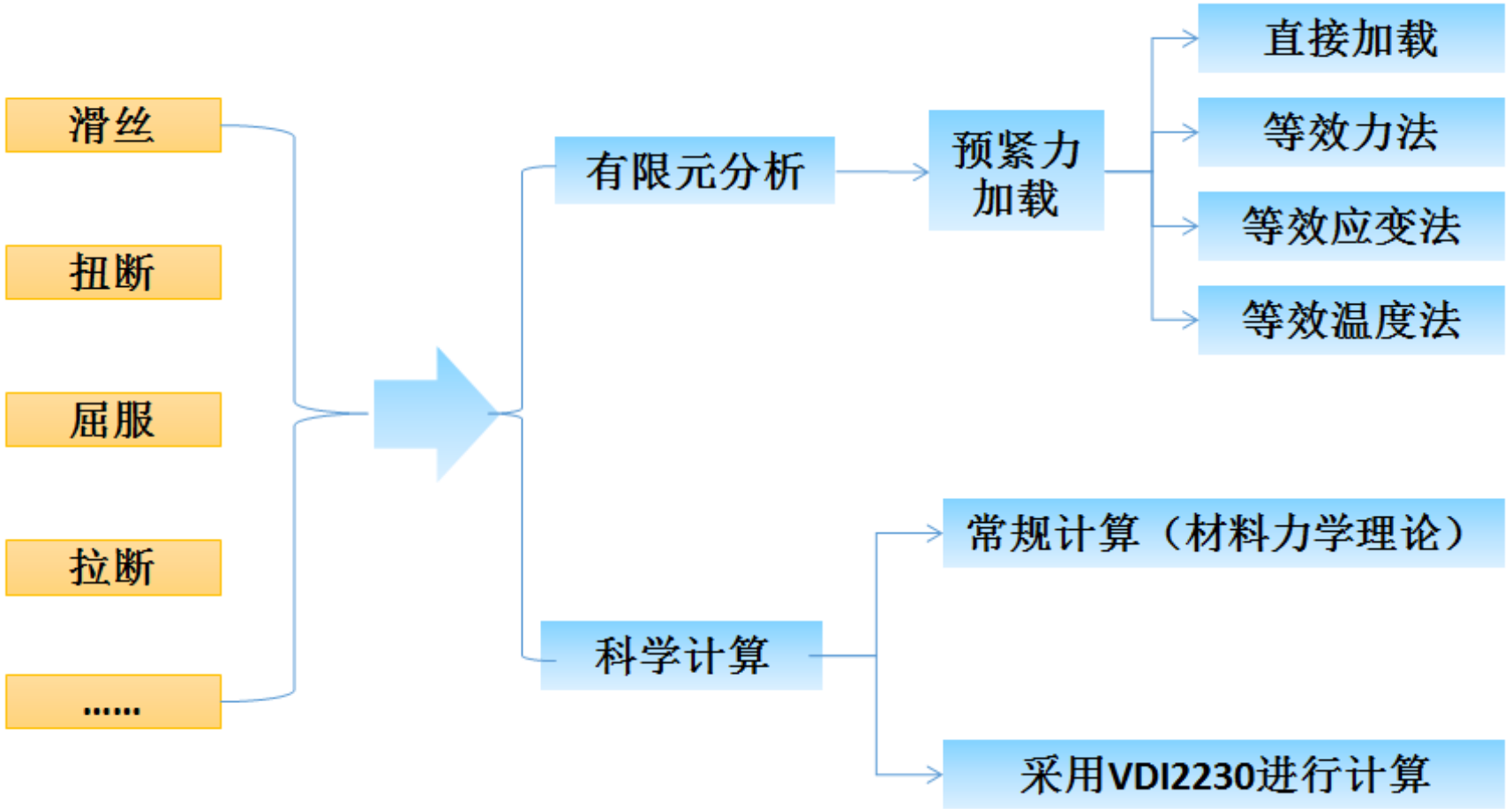
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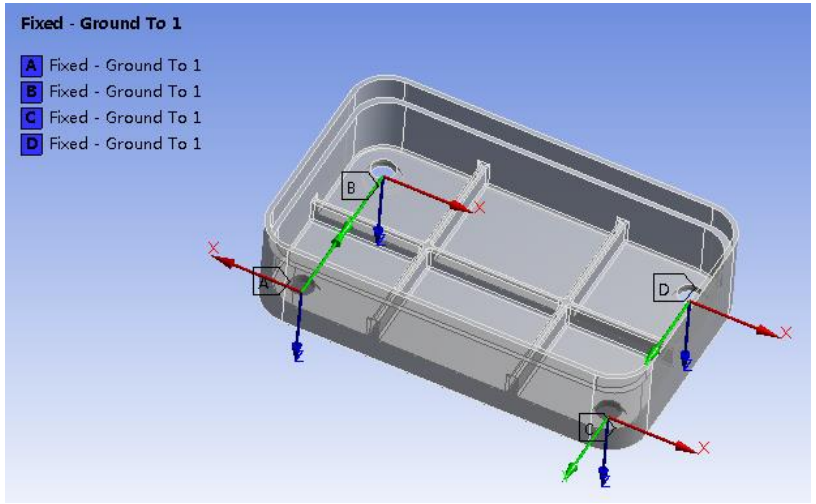
螺栓失效及校核

- 螺栓模拟问题比较复杂：
  - 需要根据工程实际问题；
  - 所关心的部位来区别对待，采用不同方法来模拟

- **模拟方法：**
  - 不建立任何几何体素，在边界的约束读取反力，通过理论公式进行校核；
  - 建立螺栓连接关系，采用BEAM CONNECTION方法来实现；
  - 建立线体，通过BEAM的方法来模拟螺栓，可以施加螺栓预紧；
  - 建立螺栓实体，但是不考虑螺纹，考虑真实接触，并施加螺栓预紧；
  - 建立螺栓实体，考虑等效螺纹效应；
  - 建立螺纹特征，进行精细分析

螺栓处理方式（1）

- 建立接触面与大地或者其他接触面之间的连接关系
- 求解结束后，提取接触处的反力，进行理论计算



Definition	
Type	Joint Probe
Boundary Condition	Fixed - Ground To 1
Orientation Method	Joint Reference System
Suppressed	No
Options	
Result Type	Total Force
Result Selection	All
Display Time	End Time
Results	
Maximum Value Over Time	
X Axis	-500.69 N
Y Axis	13.898 N
Z Axis	-843.73 N
Total	981.21 N
Minimum Value Over Time	
X Axis	-500.69 N
Y Axis	13.898 N
Z Axis	-843.73 N
Total	981.21 N

这里选取螺栓最大拉伸载荷和螺栓最大剪切载荷计算其相关强度

螺栓拉伸：

$$\sigma = \frac{F_z}{\frac{\pi}{4}\cdot D^2} = \frac{110.94}{\frac{3.14}{4}\times 6^2} = 3.93Mpa$$

螺栓剪切：

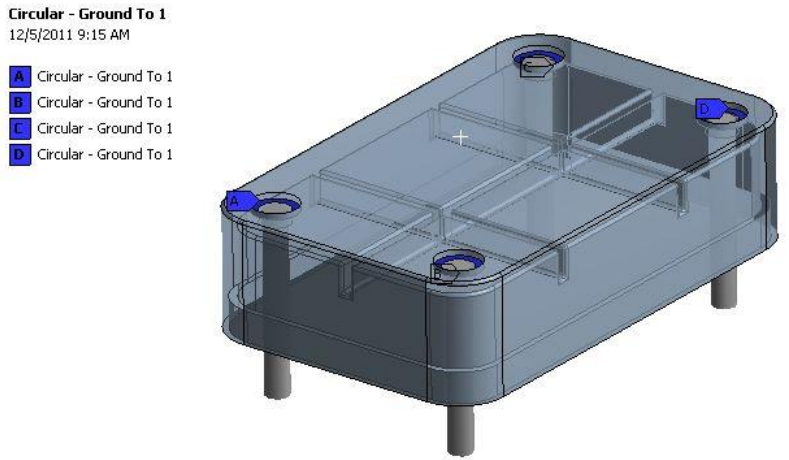
$$\tau = \frac{F_{jq}}{\frac{\pi}{4}\cdot D^2} = \frac{14.243}{\frac{3.14}{4}\times 6^2} = 0.5Mpa$$

根据第四强度理论：

$$\sigma_{eq.4} = \sqrt{\sigma^2 + 3\times\tau^2} = \sqrt{3.93^2 + 3\times 0.5^2} = 4.02Mpa$$

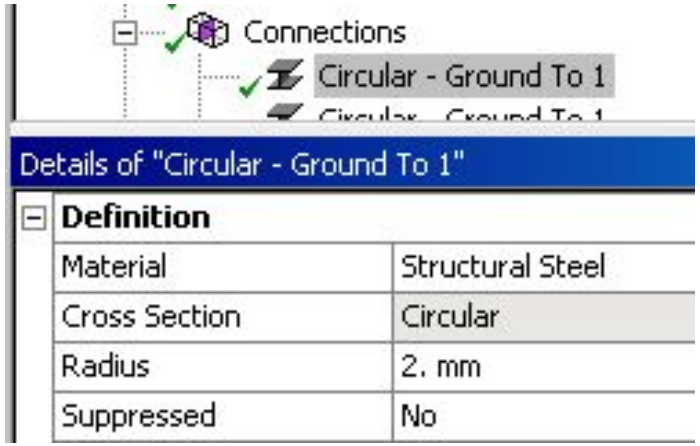
螺栓处理方式（2）

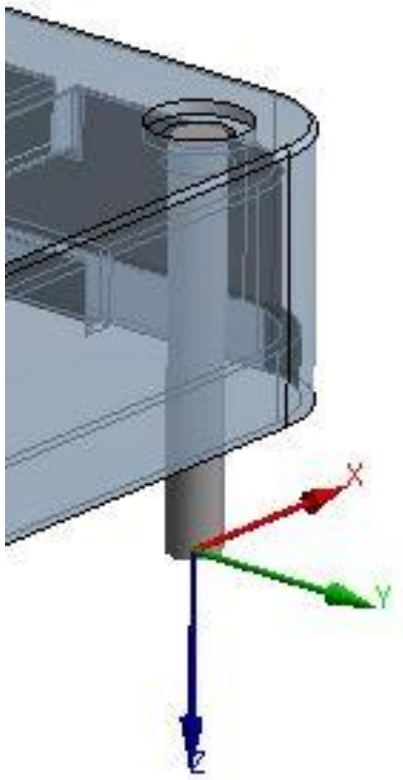
- Beam Connection可以用于体与体、体与大地之间的联系。
- Beam Connection也可以用于模拟紧固件（比如，螺栓）。
  - 梁根据参考面和移动面来定义。
  - Behavior属性可以是刚性也可以是柔性。
  - 定义pinball 区域可以减少建立的约束方程。



螺栓处理方式（2）

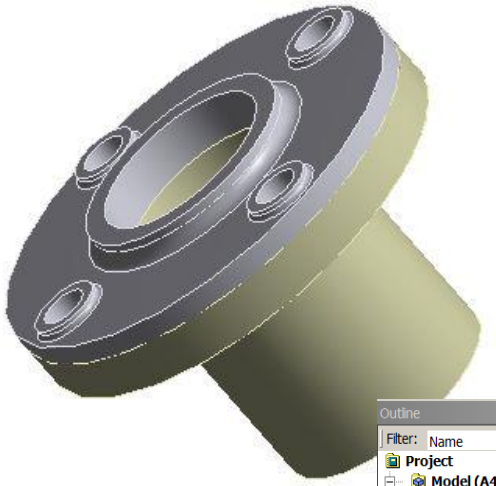
- Beam Connection的属性中，材料和半径部分都要指定（注意，目前为止的梁只能用圆截面定义）。
- 如果与大地进行连接，建立一个局部坐标系有利于指定地面的位置。

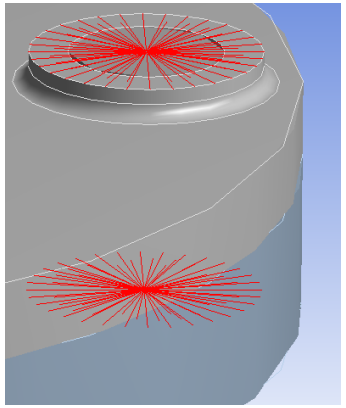


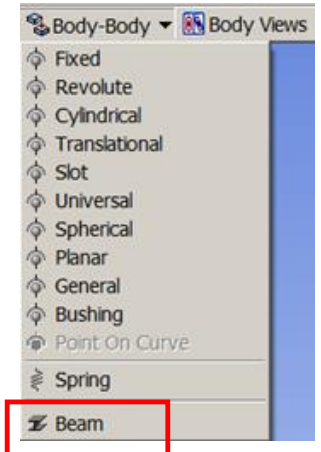


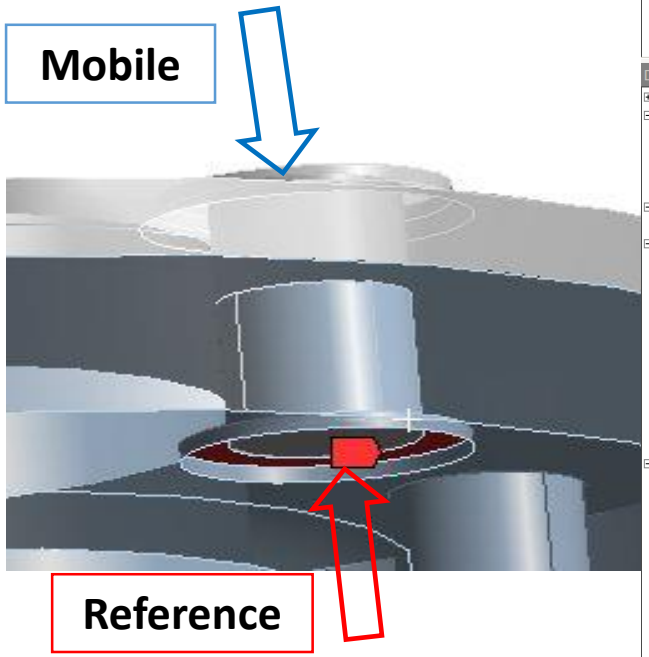
螺栓处理方式（2）

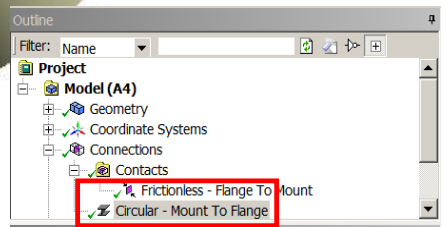
- 法兰盘之间的连接是通过螺栓紧固
- 采用Mechanical中的beam特征来代替真实的螺栓连接
- Beam connection位于connection接触设置处
- 需要指定beam的属性和直径
- 有移动端和参考端的选择
- 必要时，需要设定pinball区域

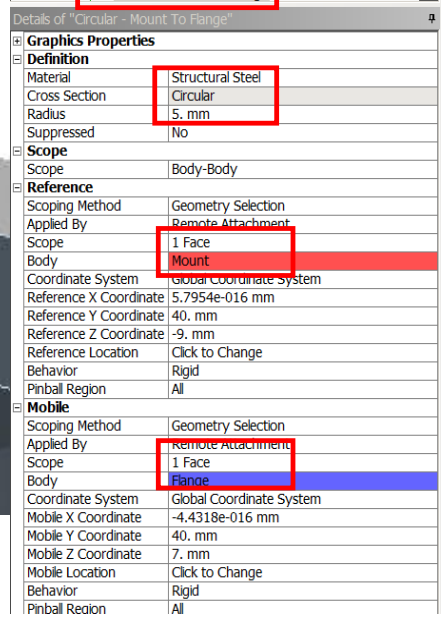






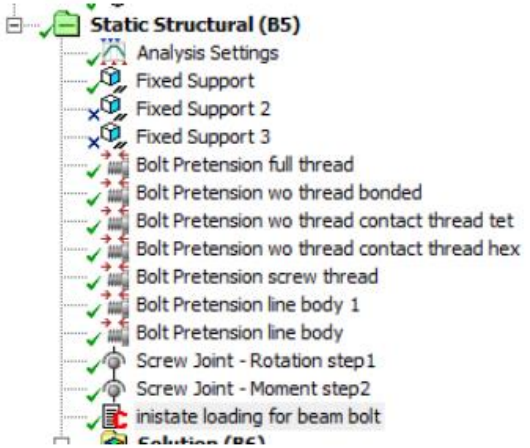






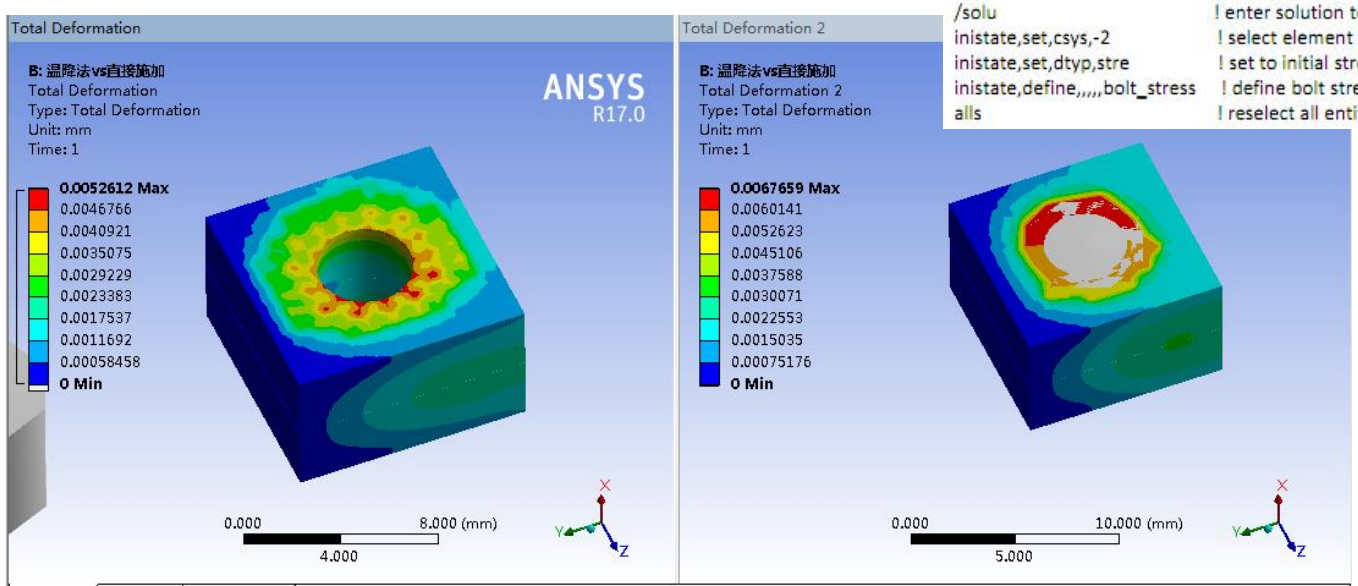
螺栓处理方式（2）

- Beam Conection施加预紧力
  - 通过插入command命令



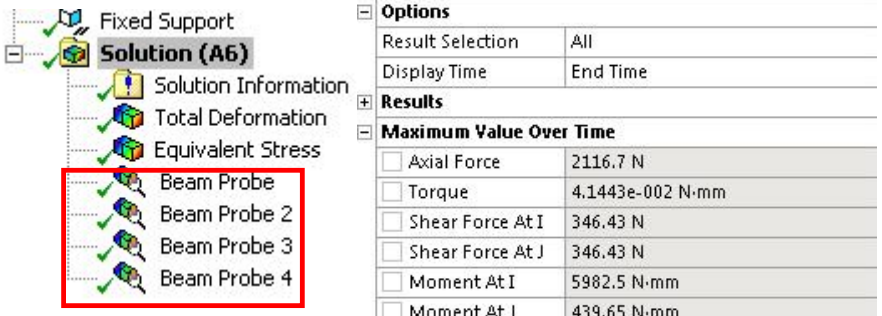

```
bolt_rad  = 2.5   ! bolt shank radius mm
bolt_load = 500   ! bolt pretension load N

bolt_area  = (22/7)*(bolt_rad*bolt_rad)
bolt_stress = 1.5*bolt_load/bolt_area

esel,s,ename,,188              ! select all beam elements in model
esel,r,real,,beam_bolt_id      ! select bolts defined as beams only
nsle                           ! select nodes on beam bolt element
/solu                          ! enter solution to define bolt load
inistate,set,csys,-2           ! select element coordinate system
inistate,set,dtyp,stre         ! set to initial stress definition
inistate,define,,,,,bolt_stress  ! define bolt stress
alls                           ! reselect all entities
```

  - 通过温降法插入初应力

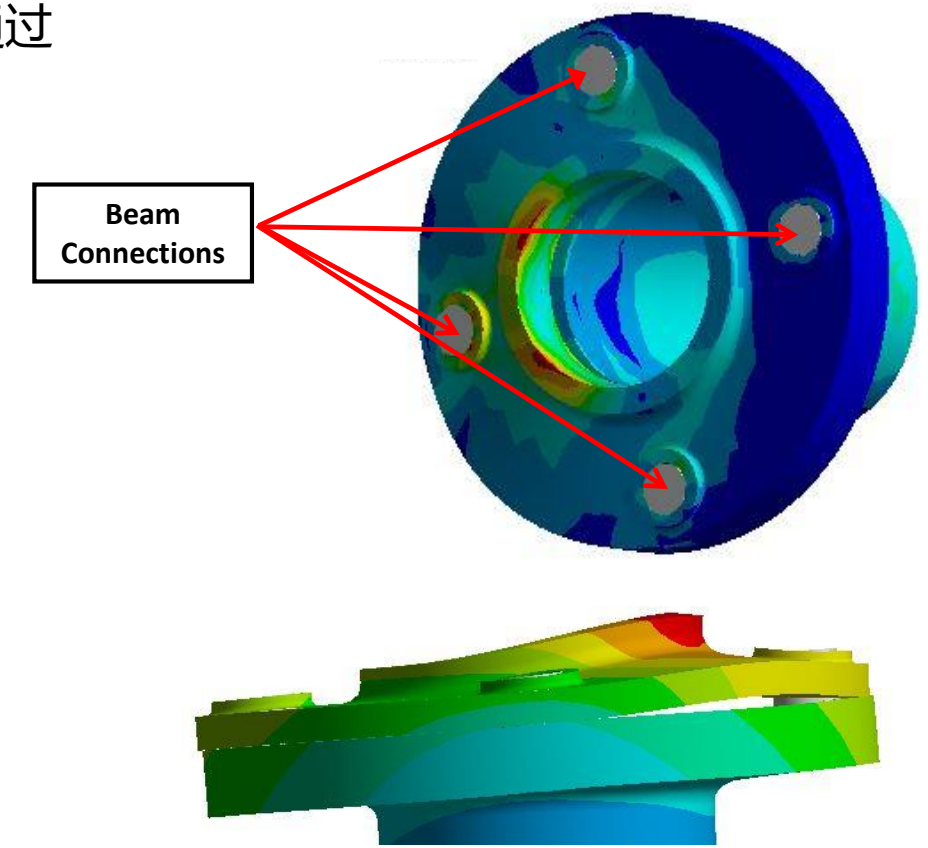


螺栓处理方式（2）

- 云图显示不会显示beam的结果，需要通过beam probe获得结果

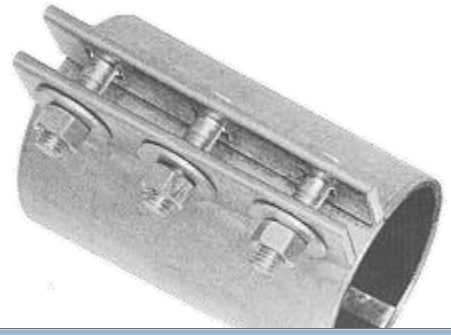


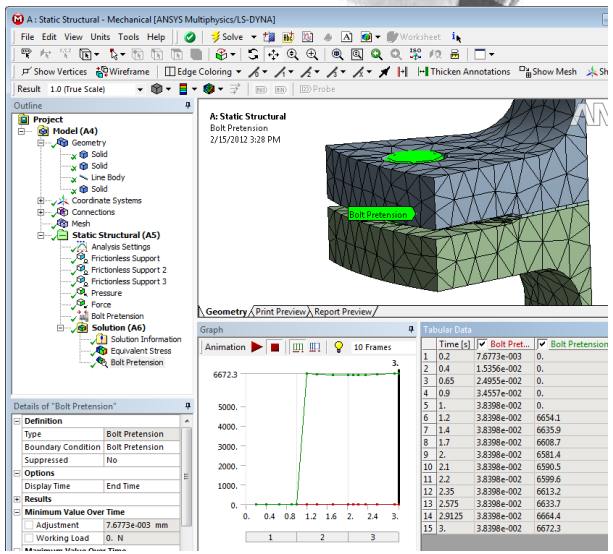
Definition	
Type	Beam Probe
Boundary Condition	Circular - Flange To Mount 2
Suppressed	No
Options	
Result Selection	All
Display Time	End Time
Results	
Maximum Value Over Time	
Axial Force	2116.7 N
Torque	4.1443e-002 N·mm
Shear Force At I	346.43 N
Shear Force At J	346.43 N
Moment At I	5982.5 N·mm
Moment At J	439.65 N·mm
Minimum Value Over Time	
Axial Force	2116.7 N
Torque	4.1443e-002 N·mm
Shear Force At I	346.43 N
Shear Force At J	346.43 N
Moment At I	5982.5 N·mm
Moment At J	439.65 N·mm
Information	

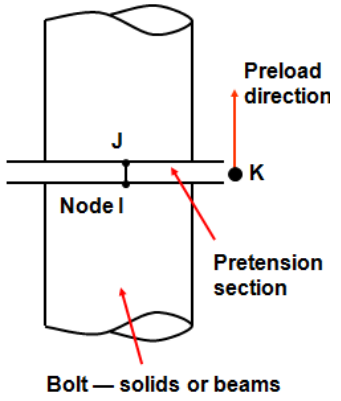


螺栓处理方式（3）

- Mechanical Application提供了一种方便的方法去考虑模拟螺栓连接
  - 自动生成预紧截面(3d实体和线体)
  - 通过约束方程来连接节点
  - 使用约束方程来定义一个数字偏离来表示用户定义的预加载
- 螺栓预紧力的特征:
  - 一组螺栓预紧单元式通过“section”定义
  - 3-D线单元好比一个吊钩的形式去连接螺栓的上下两部分
  - 节点 I, J末端的节点,通常是重合的
  - 节点K是预紧力节点
    - 位置是任意的；
    - 只含有一个自由度：UX.
    - 通常用于定义预紧力，比如FX力或者UX位移。
    - 实际作用方向是预紧力加载方向。

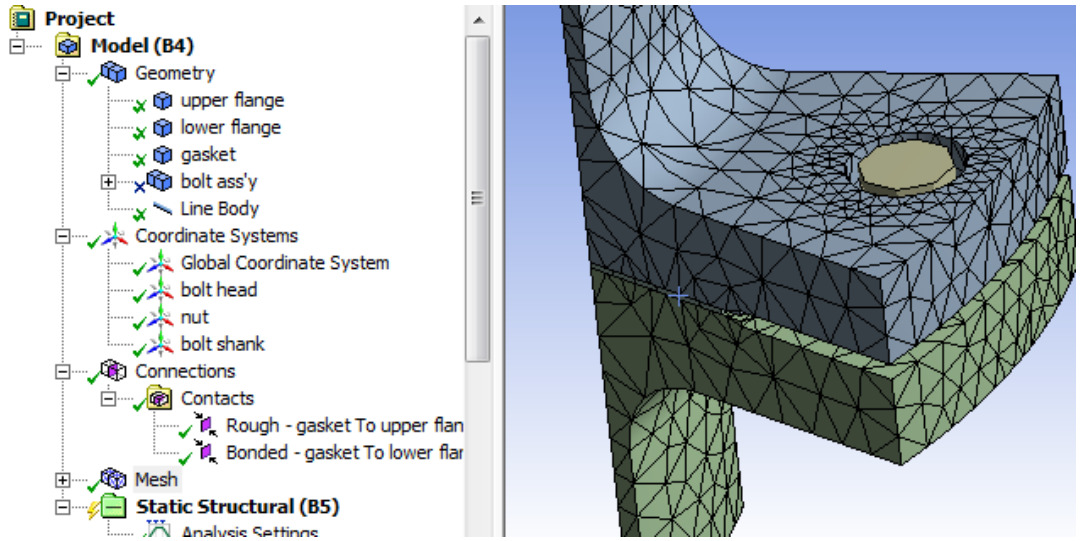






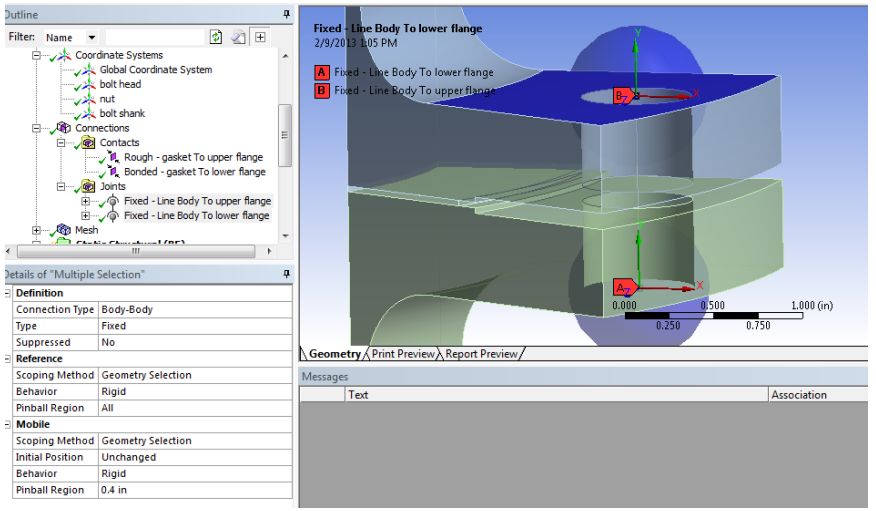
螺栓处理方式（3）

- 螺栓预紧力可以施加到一个圆柱面上、一个线体的直边上、一个体、或者一个多体上。
  - 螺栓载荷应用于圆柱表面的作用线默认会沿着圆柱体的轴线；
  - 螺栓载荷应用于线体时，作用线会平行于线的方向；
  - 如果施加螺栓预紧力到一个实体上，你需要定义一个局部坐标系（施加的预紧力将会在局部坐标系的原点，作用方向沿着Z轴方向；）

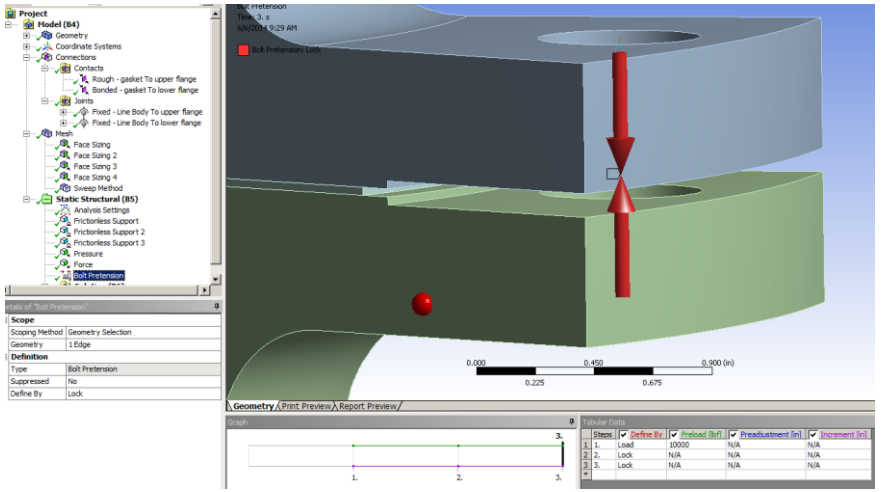


螺栓处理方式（3）

- 通过上下顶点和法兰的表面创建bonded接触
- 接触算法采用MPC多点约束方程
- 通过pinball半径来设置螺帽和螺母的作用区域

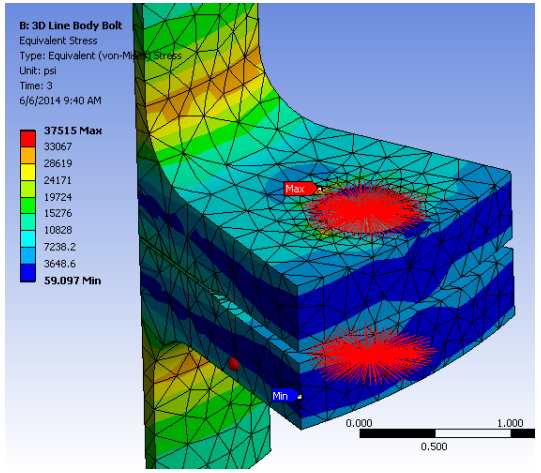


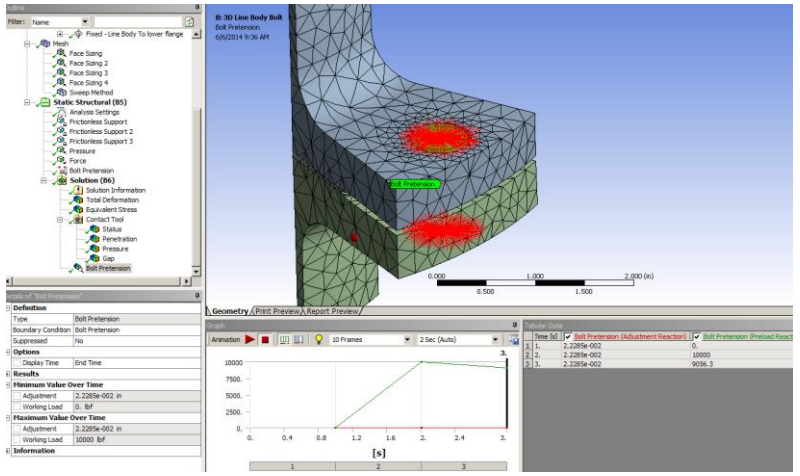
- 直接在beam上施加预紧力载荷



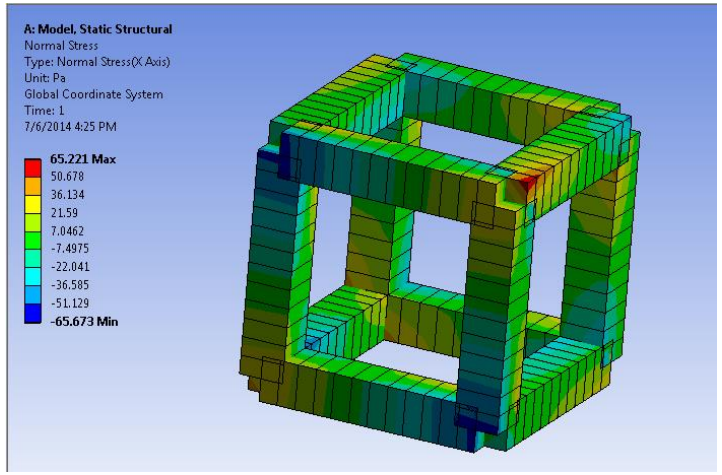
螺栓处理方式（3）

- 查看应力云图，以及通过beam pretension查看螺栓反力

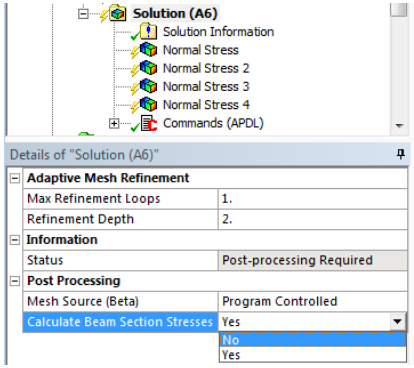




- 梁单元结果的扩展显示

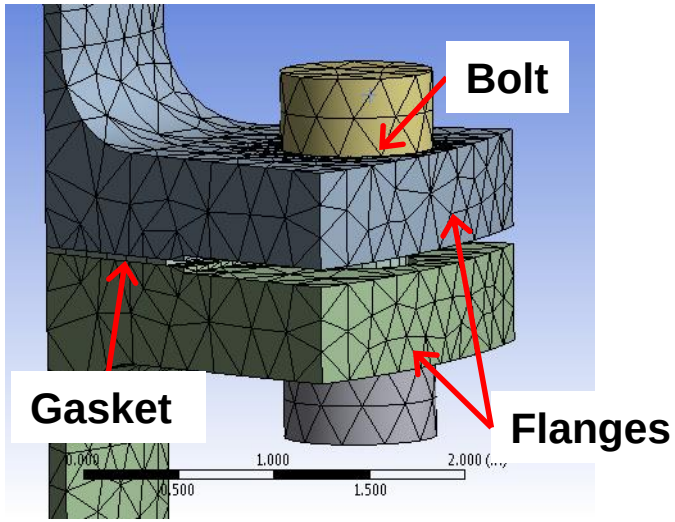


Maximum Normal Stress

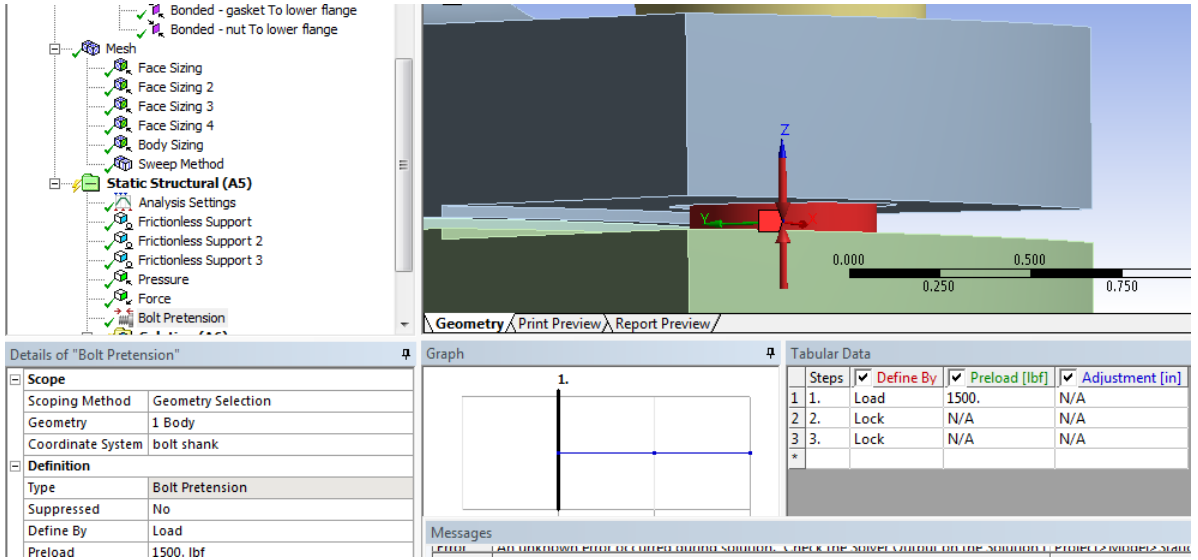


螺栓处理方式（4）

- 模型主要由上下两个法兰结构组成
- 法兰的交界面上存在一个薄的垫片结构
- 模型之间的接触形式是bonded的接触形式

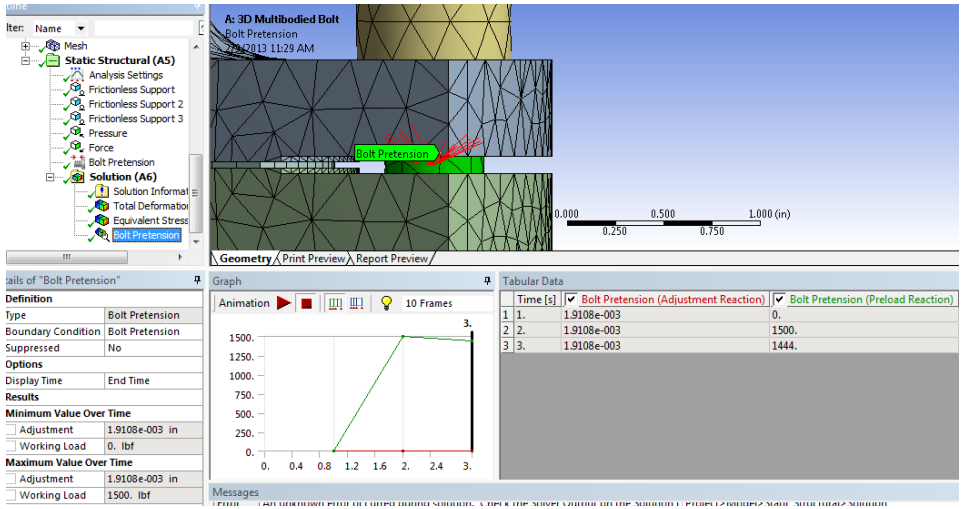


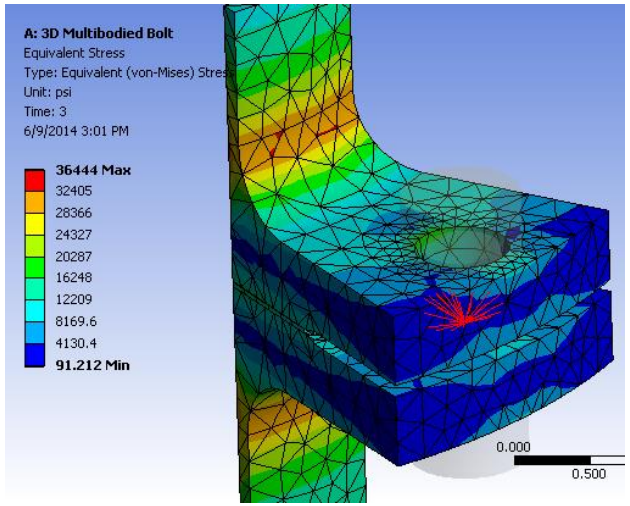
- 对实体建模的螺栓进行预紧力的施加，需要在中间部位定义局部坐标系，然后在该坐标系下施加预紧力



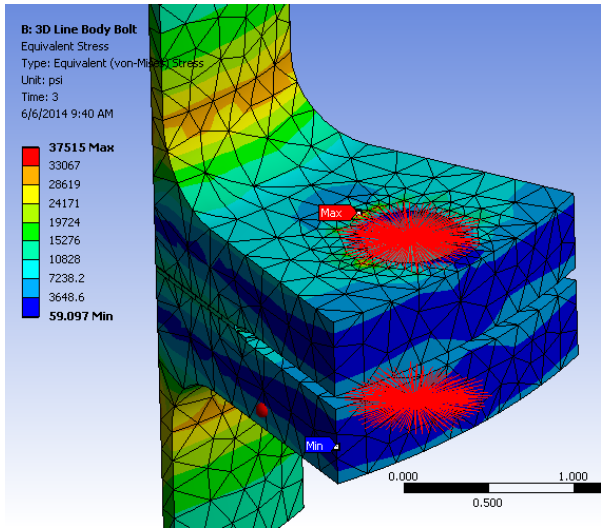
螺栓处理方式（4）

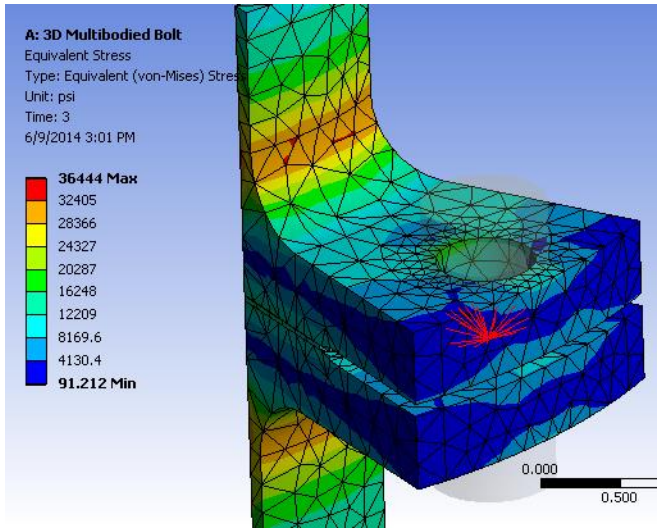
- 通过CE方程施加预紧力，查看多载荷步下的结果。





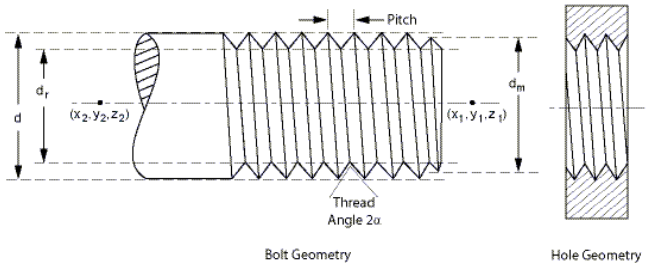
- 实体模型VS梁模型



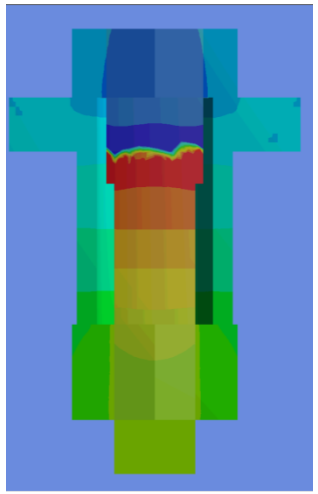


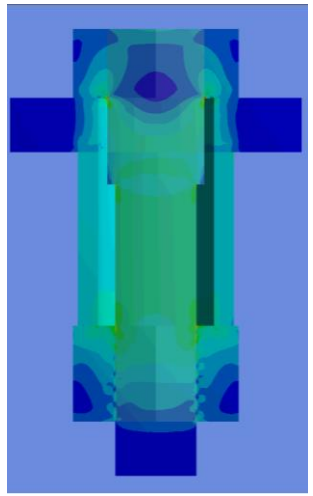
螺栓处理方式（5）

- 对螺纹进行分析，但是不对螺纹进行建模
- 通过定义的螺纹参数对其进行计算
- 可以支持2D或者3D的形式
- 支持非线性接触以及No Separation接触
- 小应变小转动理论
- 可以快速提高分析效率



- 对啮合处的反对称接触面进行参数设置
- 中径、螺距、牙型角等

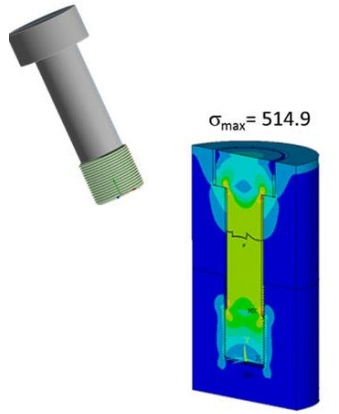




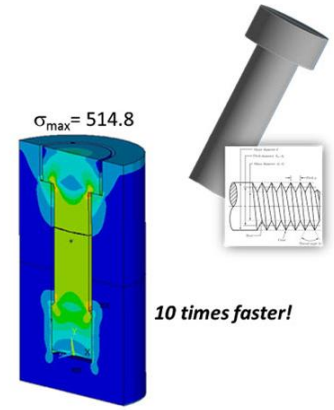
Details of "Frictional - Surface Body To Surface Body"

Scope	
Scoping Method	Geometry Selection
Contact	1 Edge
Target	1 Edge
Contact Bodies	Surface Body
Target Bodies	Surface Body
Shell Thickness Effect	No
Definition	
Type	Frictional
Friction Coefficient	0.2
Scope Mode	Automatic
Behavior	Program Controlled
Trim Contact	Program Controlled
Trim Tolerance	2.302 in
Suppressed	No

Geometric Modification	
Interface Treatment	Add Offset, Ramped Effects
Offset	0. in
Contact Geometry Correction	Bolt Thread
--Orientation	Revolute Axis
--Starting Point	Coordinate System
--Ending Point	Coordinate System 2
--Mean Pitch Diameter	0.4485 in
--Pitch Distance	7.6e-002 in
--Thread Angle	60. °
--Thread Type	Single-Thread
--Handedness	Right-Handed



True Thread Simulation



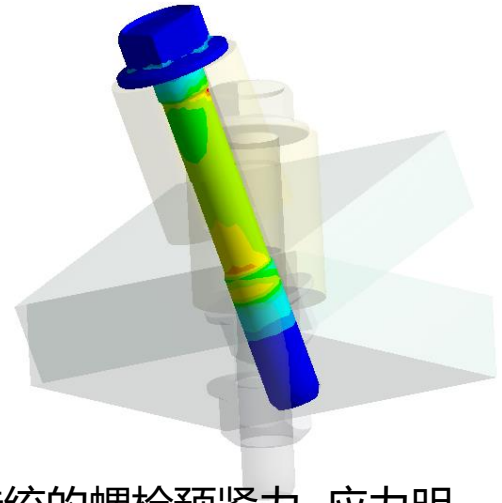
10 times faster!

Bolt Section Method

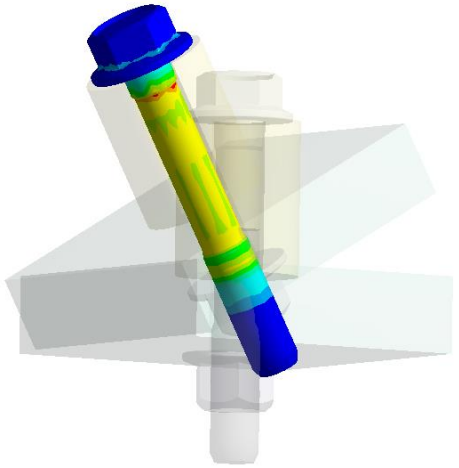
螺栓处理方式（5）

- 对于大挠度的应用,螺栓本身是要通过一个大的旋转,此时CEs可能变得无效。在这种情况下考虑使用圆柱副连接的设置作为一种替代。
  - 基于预紧力和预紧力矩的基础上支持大旋转
  - 支持在随后的载荷步中锁定
  - 在分析前需要切分预紧截面
  - 两个切开的面通过圆柱连接到一起

Details of "Joint - Force"	
Scope	
Joint	Cylindrical - Solid To Solid
Definition	
DOF	Z Displacement
Type	Force
Magnitude	1000. lbf (ramped)
Lock at Load Step	2.
Suppressed	No



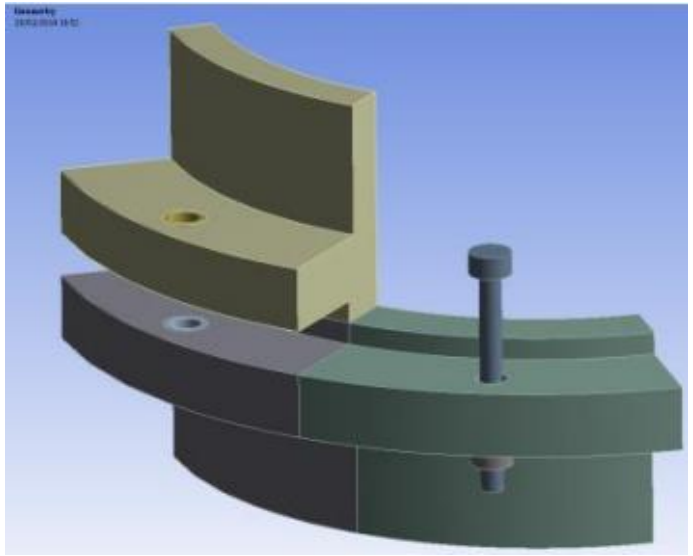
使用传统的螺栓预紧力, 应力明显的表现出弯曲应力来

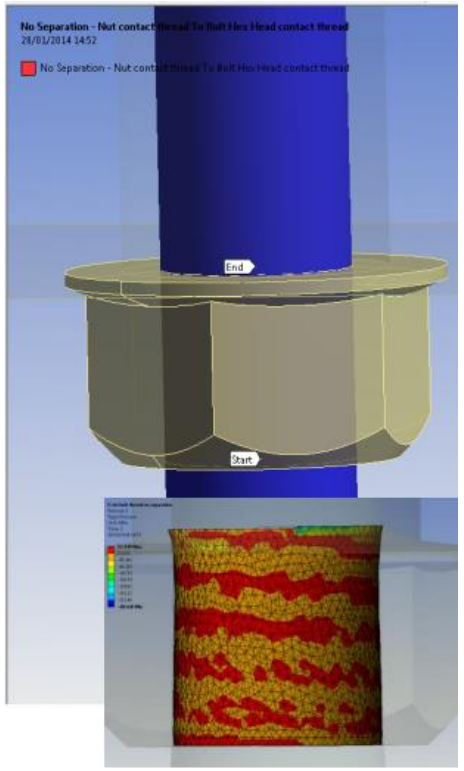


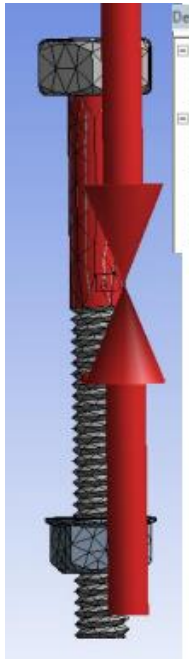
使用圆柱体连接，应力没有表现出弯曲应力

螺栓处理方式（6）

- 法兰结构，采用真实螺纹形式进行模拟
- 网格大部分情况下都是四面体网格，需要检查网格质量
- 如果想要得到准确的应力分布变形分布，网格必须足够的细密







Details of "Bolt Pretension full thread"

Scope	
Scoping Method	Geometry Selection
Geometry	1 Face
Definition	
ID (Beta)	902
Type	Bolt Pretension
Suppressed	No
Define By	Load
Preload	500. N

螺栓处理方式

	Beam Connector	Line body	Solid body
+	• Easy to setup • No geometry required for bolt • Low computation time • Good simplification of bolt/flange stiffness	• Easy to setup • Low computation time • Good simplification of bolt/flange stiffness • Some post-processing tools available	• Most accurate/realistic representation of joint • Stresses available for all parts depending on how modelled • All contact details available, depending on how modelled • Post-processing tools available
-	• No contact detail between fastener and flange • No stress detail in flange • Need to know correct initial stress to achieve required pretension • APDL post-processing	• Requires line bodies in model • No contact detail between fastener and flange • No stress detail in flange	• Some geometry preparation liklely to be required • Mesh controls will be required • Large model / high computational time

目录

VDI2230准则

- 发展历程
  - VDI：德国工程师协会
  - VDI2230是以前的VDI设计组ADKI和现在的VDI联合会涉及分部的螺栓连接委员会多年工作的成果
  - 1974年12月版；1977年10月版；1986年7月版
  - 2001年10月修订版；2003年2月版

- 与常规方法的区别
  - 考虑了预紧时螺栓的松弛
  - 按照采用的拧紧工具，在计算中具体考虑了紧固力的变化范围
  - 用计算法按零件的材料和尺寸确定螺栓和被连接件的柔度
  - 考虑到力作用点对传力比的影响，引入载荷导入系数，力争通过科学计算求得各项参数，更大限度的把经验值进行理论化

INPUTS

- R0:初步确定螺栓公称直径，核算其使用范围
- R1:确定扭紧系数
- R2:确定最小残余夹紧力

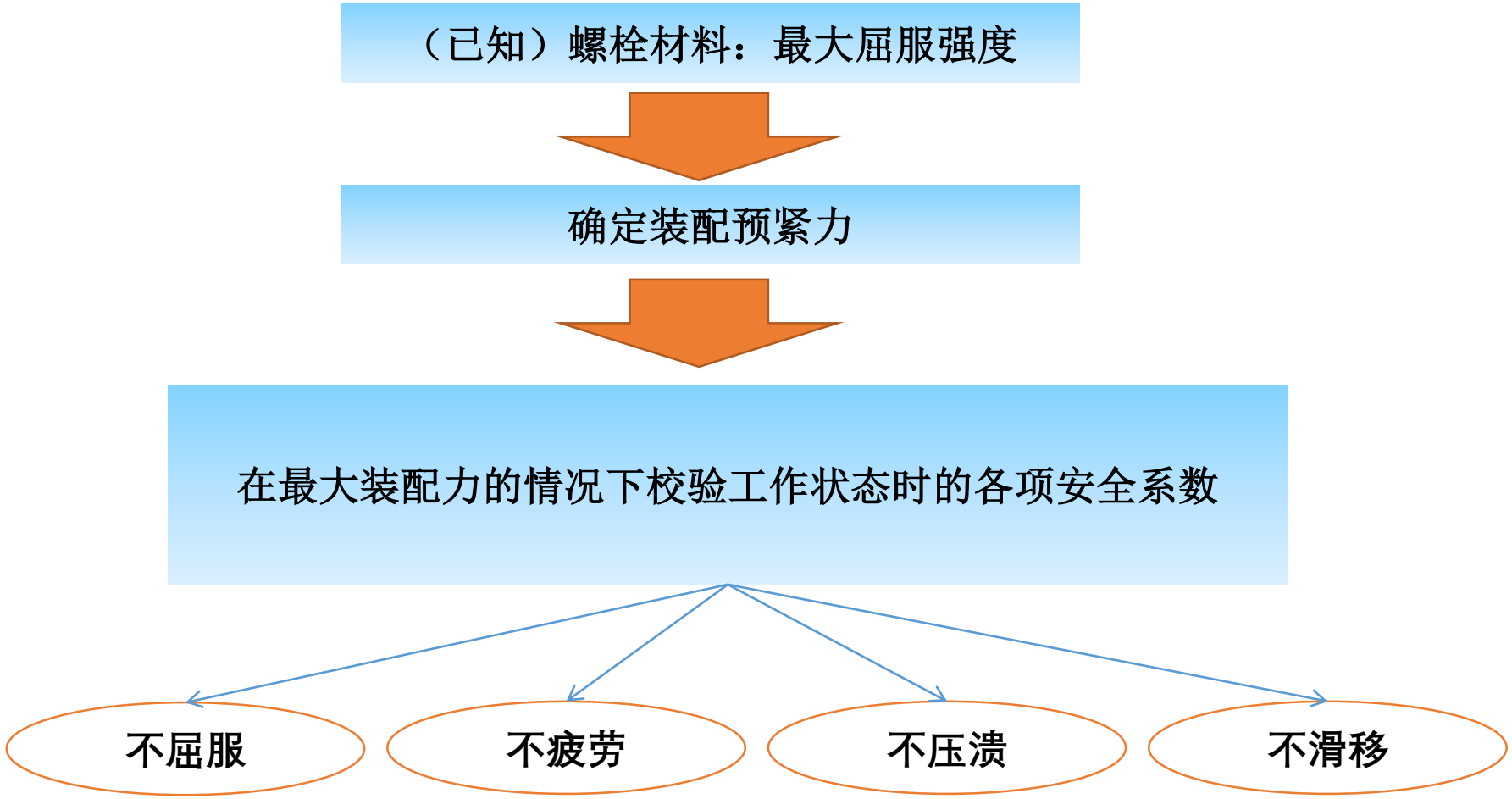
Joint diagram

- R3:求工作载荷、弹性柔度、弹性回复和载荷导出系数
- R4:计算因嵌入产生的预紧力损失量FZ
- R5:计算最小装配预紧力
- R6:计算最大装配预紧力

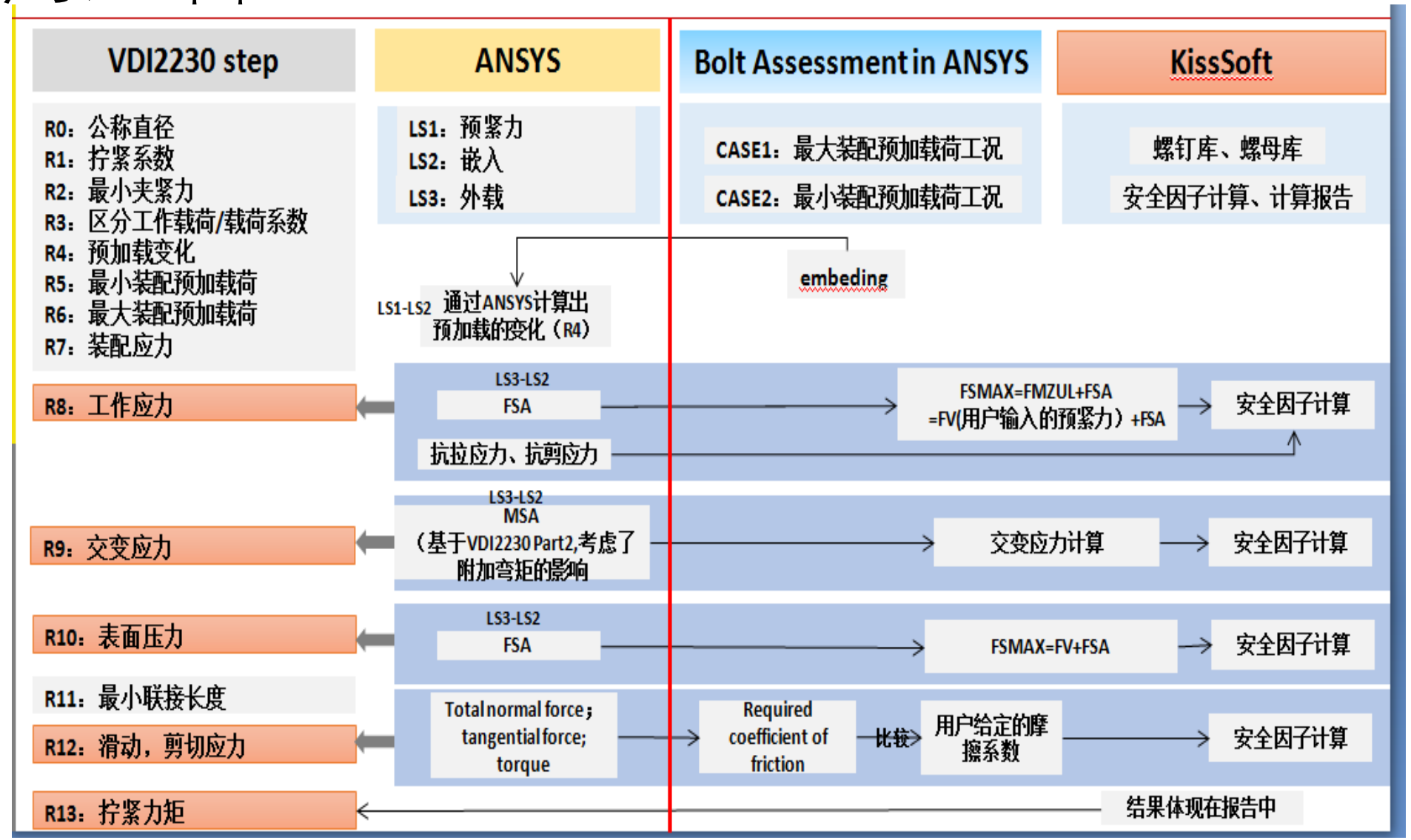
Stress analysis

- R7:装配应力
- R8:工作应力
- R9:变应力
- R10:表面压强
- R11:最小拧入深度
- R12:抵抗滑动的安全限度
- R13:求扭紧力矩

VDI2230螺栓设计思路

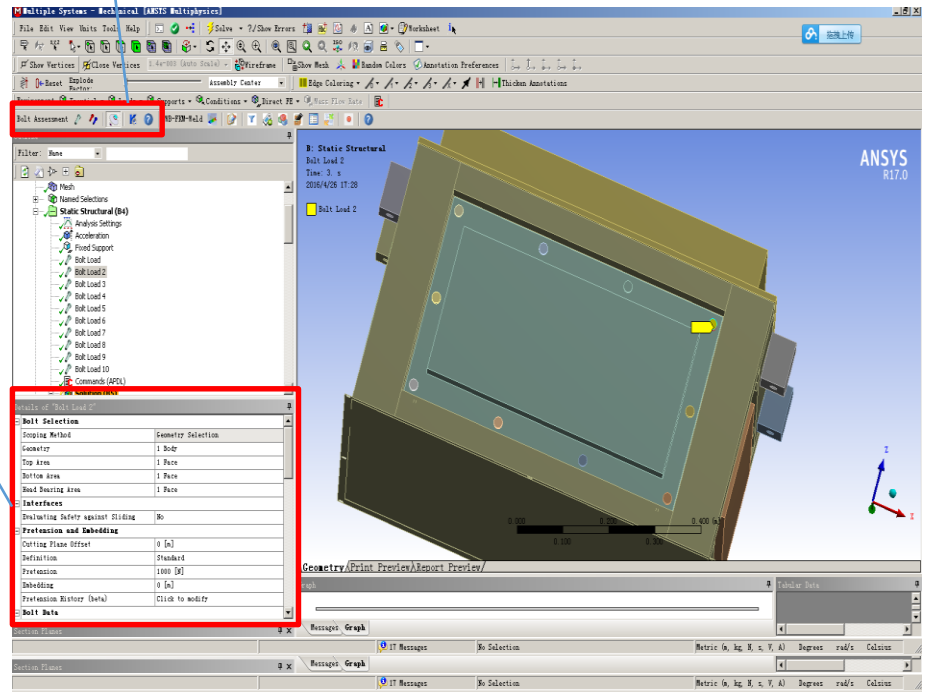


应用逻辑


VDI2230 step
ANSYS
Bolt Assessment in ANSYS
KissSoft
R0：公称直径
R1：拧紧系数
R2：最小夹紧力
R3：区分工作载荷/载荷系数
R4：预加载变化
R5：最小装配预加载荷
R6：最大装配预加载荷
R7：装配应力
LS1：预紧力
LS2：嵌入
LS3：外载
CASE1：最大装配预加载荷工况
CASE2：最小装配预加载荷工况
螺钉库、螺母库
安全因子计算、计算报告
embeding
LS1-LS2 通过ANSYS计算出预加载的变化（R4）
R8：工作应力
LS3-LS2
FSA
FSMAX=FMZUL+FSA
=FV(用户输入的预紧力）+FSA
安全因子计算
抗拉应力、抗剪应力
R9：交变应力
LS3-LS2
MSA
（基于VDI2230 Part2,考虑了附加弯矩的影响
交变应力计算
安全因子计算
R10：表面压力
LS3-LS2
FSA
FSMAX=FV+FSA
安全因子计算
R11：最小联接长度
R12：滑动，剪切应力
Total normal force；tangential force; torque
Required coefficient of friction
比较
用户给定的摩擦系数
安全因子计算
R13：拧紧力矩
结果体现在报告中

操作流程

1. 有限元模型处理
2. 载荷及边界条件设置
3. 插入螺栓载荷
4. 设置相关参数
5. 求解计算
6. 查看螺栓安全因子/计算报告



参数设置

- 选择螺栓实体
- 定义相关表面
- 预紧力大小
- 嵌入量大小
- 螺栓规格
- 螺栓类型
  - 通孔 → 定义螺母类型
  - 盲孔
- 其他参数

需包含螺栓实体模型；梁模型下一版本支持（预计2016年8月份发布）

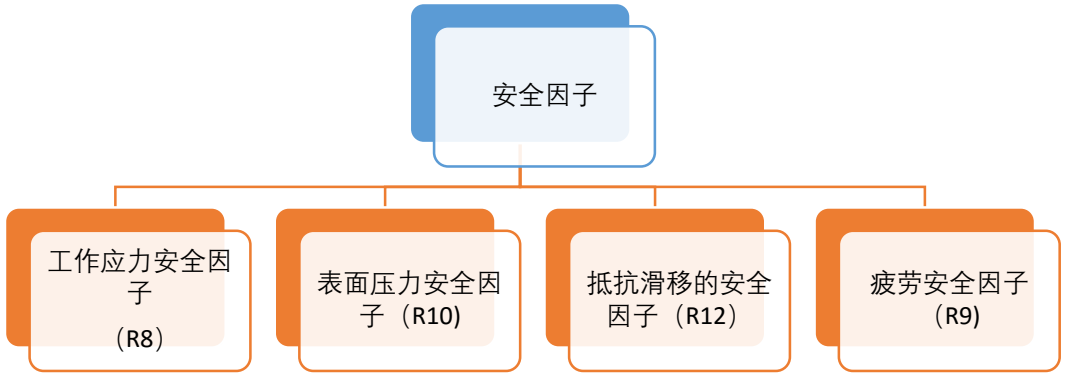
螺栓及螺母基于数据库直接选择

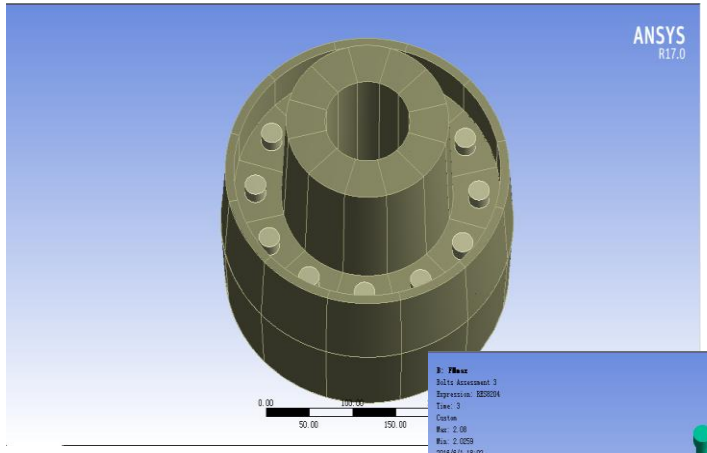
Details of "Bolt Load"

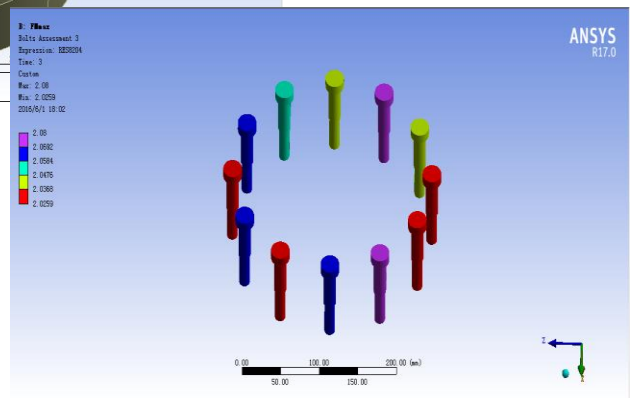
Bolt Selection	
Scoping Method	Geometry Selection
Geometry	1 Body
Top Area	1 Face
Bottom Area	1 Face
Head Bearing Area	1 Face
Interfaces	
Evaluating Safety against Sliding	Yes
Number of Interfaces to evaluate	1
Interface 1	4 Faces
Friction Coefficient 1	0.1
Pinball Parameter 1	0.9
Pretension and Embedding	
Cutting Plane Offset	0 [mm]
Definition	Standard
Pretension	64800 [N]
Embedding	0.008 [mm]
Pretension History (beta)	Click to modify
Bolt Data	
Bolt Type	Cylindrical screw with socket ...
Strength Grade	10.9
Nominal Diameter	12 [mm]
Bolt Length	60 [mm]
Thread Manufacturing	Final heat treated
Type of Bolting	
Type of Bolting	Blind Hole
Material (beta)	C45 (1)
Bore Definition	
Standard	ISO 273:1979 (DIN 273) medium
Chamfer at Head	0 [mm]
Basic Data	
Friction Factor in the Thread	0.1
Friction Factor in the Bearing Surface	0.1
Limiting Surface Pressure (Head)	1300 [MPa]
Number of Load Cycles	2000000
Report Units (beta)	Metric
Reduction Coefficient (beta)	0.5
Data used by KISSsoft	
Bolt Type	
Strength Grade	
Reference Diameter	
Bolt Length	
Thread Manufacturing	

结果评估

Details of "Bolts Assessment"	
Geometry	
Scoping Method	Geometry Selection
Geometry	9 Bodies
Definition	
Safety	Sliding
Type (beta)	Standard
Select Bolts	Click to modify
By	Time
Display Time	Last
Display	
Auto Scale	Yes
Results	
Minimum	0.
Maximum	0.
Minimum Occurs On	bolt5
Maximum Occurs On	bolt4







R13对应的扭紧力矩体现在计算报告中

计算报告

CADFEM KISSSOFT

KISSsoft - Bolt Assessment inside ANSYS

Non commercial version for demo and support purposes only !

File

Name : Bolt Load_1

Changed by: VCD on: 02.02.2016 at: 16:55:16

Bolt calculation according to VDI 2230:2014

INPUT:

Configuration: Proof for bolts with FEM results

Modeling in FEM:

Model class III (only forces and torques, without resilience)

Calculation using assembly temperature

Assembly temperature (°C)	[TM]	20.00
Operating temperature, bolt (°C)	[TS]	20.00
Operating temperature of parts (°C)	[TP]	20.00

Thread standard		Standard thread
Label		M12
Pitch (mm)	[P]	1.75
Flank angle (°)	[β]	60.00
Reference diameter (mm)	[d]	12.00
Flank diameter (mm)	[d2]	10.86
Core diameter (mm)	[d3]	9.85
Nominal cross section of thread (mm²)	[AN]	113.10
Core cross section of the thread (mm²)	[As3]	76.25
Thread manufacturing		Final heat treated

Coefficient of friction between parts	[μ]	0.100
Additional bolt load (N)	[FSA]	1423.595
Maximum additional bolt torque (Nm)	[MSAs]	0.000
Minimum additional bolt torque (Nm)	[MSAu]	0.000
Minimum residual clamp load (N)	[FKR]	26592.253
Maximum achievable mounting prelaseon force (N)	[FM]	64799.05
Maximum bolt load (N)	[FSmax]	88222.64
Limiting surface pressure (under head) (N/mm²)	[pGRmax]	1300.00

Coef. of friction in thread	[μG]	0.100
Coef. of friction at head support	[μK]	0.100

Bolt type		Cylindrical screw with socket head bolt DIN EN ISO 4762:2004
Reference diameter (mm)	[d]	12.00
Bolt length (mm)	[l]	60.00
Shank diameter (mm)	[d1]	12.00
Shank length (mm)	[l1]	34.00
Thread length (mm)	[b]	38.00
Outer diameter of head support (mm)	[dw]	17.23
Inner diameter of head support (mm)	[de]	13.70
Surface roughness (tip support) (µm)	[Rz]	16.00

Stressed cross section of screw (mm²)	[As]	84.27
Height of bolt head (mm)	[k]	12.00
Diameter of screw head (mm)	[dk]	18.00
Free thread length (mm)	[lG]	0.00

CADFEM KISSSOFT

Width across flats (mm)	[s]	10.00
Reduction coefficient	[kr]	0.50

Strength class		10.9
Tensile strength (N/mm²)	[Rm]	1040.00
Yield point (N/mm²)	[Rp0.2]	940.00
Maximum yield point (N/mm²)	[Rp.max]	940.00

Thread with pocket hole

Through hole standard		ISO 273:1979 (DIN 273) medium
Diameter through hole (mm)	[dh]	13.50
Chamfer at head (mm)	[cK]	0.00

No washer below screw head

Blind hole

Material		C45 (1)
Counter bore depth (mm)	[tk]	0.00
Surface roughness (µm)	[Rz]	16.00

RESULTS:

-maximum (N)	[FM]	64799.05
Fatigue load (N/mm²)	[σa]	8.45
Fatigue life (N/mm²)	[σAzul]	45.55
Number of load cycles	[NZ]	** 2000000

Calculation with maximum attained prelaseon force:

Mounting-Prelaseon force (N)	[FM]	64799.05
Equivalent stress (N/mm²)	[σred.M]	844.62
Equivalent stress (N/mm²)	[σred.B]	819.66

Tightening torque (Nm)	[MA]	109.14
Loose torque (Nm)	[ML]	89.78
Surface pressure		
(below screw head) (N/mm²)	[pK]	772.26

Permissible equivalent stress (N/mm²)	[σ.Mzul]	846.00
Permissible equivalent stress (N/mm²)	[σ.Bzul]	940.00
Support area		
(below screw head) (mm²)	[ApK]	85.75
Permissible surface pressure		
(below screw head) (N/mm²)	[pKzul]	1300

SUMMARY:

It is not permitted to exceed the yield point.

Calculation with the maximum required assembly preload with tightening factor 1.00

Safety against yield point	[SF]	1000.00
Safety against fatigue	[SD]	5.79
Safety against pressure	[SP]	1.65

Calculation with maximum attained prelaseon force:

Safety against yield point	[SF]	1.15

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Safety against fatigue	[SD]	5.79
Safety against pressure	[SP]	1.65

Calculation with minimum attained prelaseon force:

Safety against sliding	[SG]	1000.00

Force [N]

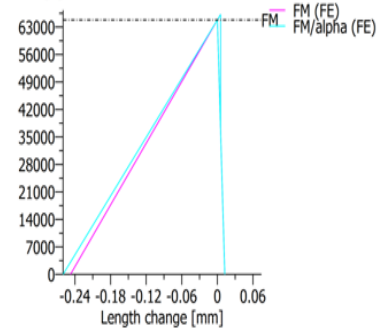

Figure: Display of restraint-diagram

Remarks:

-The safeties (SF, SD, SP) are calculated according to VDI2230.

End of Report lines: 127

每个螺栓一个计算报告

感谢聆听