Bolt

Xie Yu

1 介绍

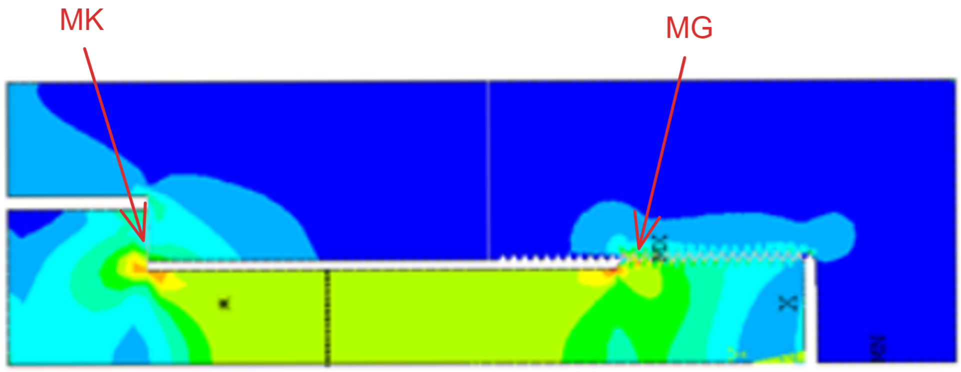
Bolt类参照VDI 2230 规范对螺栓进行分析建模.

2 原理

2.1 螺栓拧紧力矩

对于螺栓连接，其拧紧力矩M_A 用于克服螺纹副的螺纹阻力矩 M_G及螺母与被连接件（或垫圈）支承面间的端面摩擦力矩M_K 。

$$M_A = M_G + M_K \tag{1}$$



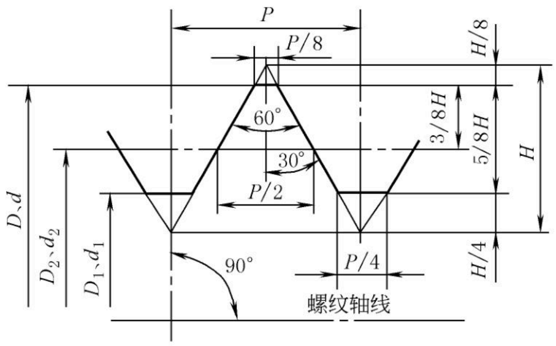
对于螺纹副的摩擦力矩它等于预紧力×螺纹中径面积×摩擦系数，可由下式表示：

$$M_G = F_M \frac{d_2}{2} tan(\phi + \rho') \tag{2}$$

式中，F_M为预紧力，d_2为螺纹中径，后面的则考虑了螺纹几何的一些参数，需要涉及一些螺纹力学的相关知识，可参考螺纹联接的理论与计算[41],对于普通螺纹α = 60 °，则上式可以简化为：

$$M_G = F_M(0.16P + 0.58 d_2 \mu_G) \tag{3}$$

式中，P为螺距，μ_G为螺纹处的摩擦系数。注意上式只针对普通螺纹，像多用于航空航天的MJ螺纹，或者管螺纹，螺纹处的力矩都需要重新考虑。



表中数值按下列公式计算，数值圆整到小数点后第三位数：

$$D_2 = D - 2\times\frac{3}{8}H = D - 0.6495P$$

$$d_2 = d - 2\times\frac{3}{8}H = d - 0.6495P$$

$$D_1 = D - 2\times\frac{5}{8}H = D - 1.0825P$$

$$d_1 = d - 2\times\frac{5}{8}H = d - 1.0825P$$

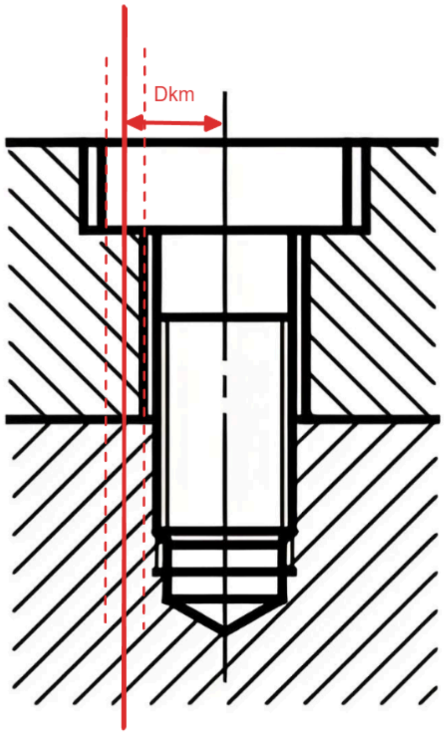
$$H = \frac{\sqrt{3}}{2}P = 0.866025404P$$

D —内螺纹的基本大径；d —外螺纹的基本大径；D_2 —内螺纹的基本中径；
d_2 —外螺纹的基本中径；D_1 —内螺纹的基本小径；d_1 —外螺纹的基本小径；
P —螺距；H —原始三角形高度

接着需要计算螺栓头处的力矩，可由下式计算:

$$M_K = F_M \frac{D_{Km}}{2} \mu_k \tag{4}$$

式中，μ_G为螺栓头处的摩擦系数，D_{Km}为受压承载面的中径，如下图所示，因此不同规范螺栓、垫片以及开孔大小都会对其有所影响。



在Baffalo bolt中已经集成ISO 4762、ISO4032和DIN ISO 7089规范下的螺栓、螺母和垫片几何。

在计算螺栓拧紧力矩时，需要额外关注预紧力的损失，不同预紧方法会有不同的离散系数，比如参照VDI 2230规范，使用力矩扳手时离散系数为1.6~2.0，如下图所示，也就意味着，原先比如打90% 屈服强度的预紧力，实际只有45% ~56.25%屈服强度的预紧，所以我们不仅要关注在最大预紧力作用下的夹持件和螺栓的应力强度，也应关注在最小预紧力作用下螺栓的松动等问题。

Tightening factor α_A	Scatter $\frac{\Delta F_M}{2 \cdot F_{Mm}} = \frac{\alpha_A - 1}{\alpha_A + 1}$	Tightening method	Setting method	Comments	
1,4 to 1,6	±17 % to ±23 %	torque-controlled tightening with torque wrench, signalling wrench or motorized nut-runner with dynamic torque measurement	experimental determination of the setpoint torques at the original joint member, for example, by elongation measurement of the bolt	low values: large number of setting or monitoring attempts required (20, for example); low scatter of the output moment (for example, ±5 %) required	low values for: • small rotation angles, in other words, relatively stiff joints • relatively low hardness of the countersurface[a)] • countersurfaces which do not have a “galling” tendency, for example, phosphated or adequately lubricated
1,6 to 2,0 (coefficient of friction class B) 1,7 to 2,5 (coefficient of friction class A)	±23 % to ±33 % ±26 % to ±43 %	torque-controlled tightening with torque wrench, signalling wrench or motorized nut-runner with dynamic torque measurement	determination of the setpoint tightening moment by estimating the coefficient of friction (surface and lubrication conditions are a great influence)	low values for: measuring torque wrenches with even tightening and for precision nut-runners high values for: signalling or buckling torque wrenches	high values for: • large rotation angle, in other words, relatively resilient joints as well as fine thread • great hardness of the countersurface, combined with a rough surface
2,5 to 4	±43 % to ±60 %	tightening with impact wrench, “stalling driver” or impulse driver; tightening by hand	setting the driver via retightening moment, which is formed from the required tightening moment (for the estimated coefficient of friction) plus a supplement; manual tightening based on subjective assessment	low values for: • large number of setting attempts (retightening moment) • on horizontal branch of the driver characteristic • backlash-free impulse transmission method only suitable for preliminary tightening, in the case of tightening by hand risk of overstretching with M10 and smaller	

2.2 螺栓有限元分析

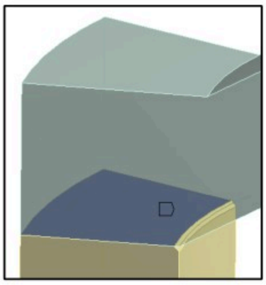
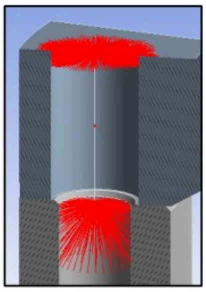
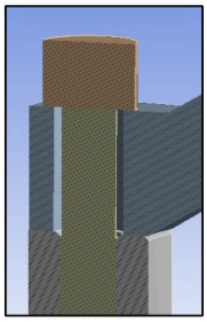
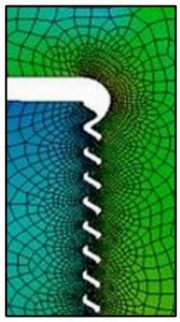
在了解了螺栓预紧机制，制定好螺栓的预紧力，便可以对其进行有限元分析，在VDI 2230中，规定了4种计算等级

Class 1: 螺栓和接触都未考虑，此时考虑建立局部的刚性连接来传递载荷；

Class 2: 用梁单元建立螺栓，螺栓头和螺纹处采用刚性连接；

Class 3: 螺栓采用实体连接；

Class 4: 螺栓和螺纹都采用实体连接。

	Class I	Class II	Class III	Class IV
				
Characteristic	Bolt and interface are not taken into consideration. Preload is not included in representation	Bolt is represented by a beam. Preload and interface contact can be included	Bolt is represented by a volume body. Preload and interface contact can be included	Bolt is fully modelled and include threads, preload, and contact on all surfaces

显然Class 2这种方式适合做参数化的处理并进行螺栓相关的校核，Baffalo Bolt可以根据输入的螺栓尺寸直接生成相应的网格。

3　类结构

输入 input：

- dha : 去除倒角后的螺栓孔直径
- dh : 螺栓孔直径
- lk : 夹持长度
- l1 : 螺栓光杆长度
- l : 螺栓总长

参数 params:

- v : 螺栓利用系数
- alphaA: 离散系数
- WasherType : 垫片类型
- Washer : 是否含有垫片
- Type : 预紧工况 (最大预紧，最小预紧)
- ThreadType : 螺纹类型
- Strength : 螺栓强度，默认10.9
- Order : 网格阶数
- NutType : 螺母种类
- Nut : 是否含有螺母
- Name : 名称
- MuK : 螺栓头处的摩擦系数
- MuG : 螺纹处的摩擦系数
- BoltType : 螺栓类型
- Material : 材料

输出 output :

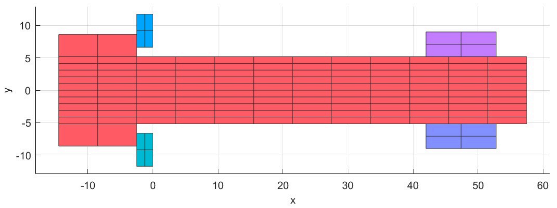
- di: 螺杆直径
- P : 螺距
- d1 : 螺纹外径
- d2 : 螺纹中径
- d3 : 螺纹小径
- H : 螺纹几何参数
- ds : 螺纹受力面积对应直径
- dw : 螺栓头外径
- da : 螺栓头内径
- Dkm : 有效受力面积对应直径
- As : 螺纹有效受力面积
- SigmaM : 预紧力下螺栓受拉应力
- FMmax : 最大预紧力
- FMmin : 最小预紧力
- MG : 螺纹处的扭矩
- MK : 螺栓头处的扭矩
- MA : 螺栓的拧紧力矩
- Fhmax : 最大允许拉力
- Fh : 拉力
- Surface : 螺栓截面
- lk : 夹持长度
- Assembly : 螺栓网格装配

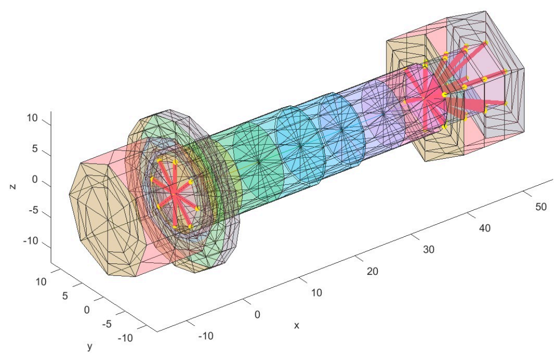
4 案例

4.1 Create Bolt with Nut (Flag=1)

```
inputStruct.d=12;
inputStruct.l=60;
inputStruct.lk=42;
paramsStruct.ThreadType=1;
paramsStruct.MuG=0.1;
paramsStruct.MuK=0.1;
paramsStruct.Nut=1;
obj= bolt.Bolt(paramsStruct, inputStruct);
obj= obj.solve();
Plot2D(obj);
Plot3D(obj);
ANSYS_Output(obj.output.Assembly);
```

由平面拉伸为平板。

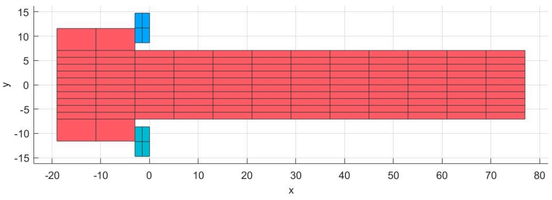


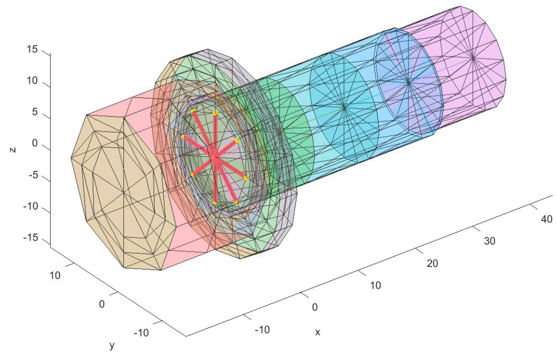


4.2 Create Bolt without Nut (Flag=2)

```
inputStruct.d=16;
inputStruct.l=80;
inputStruct.lk=42;
paramsStruct.ThreadType=1;
paramsStruct.MuG=0.1;
paramsStruct.MuK=0.1;
paramsStruct.Nut=0;
obj= bolt.Bolt(paramsStruct, inputStruct);
obj= obj.solve();
Plot2D(obj);
Plot3D(obj);
ANSYS_Output(obj.output.Assembly);
```

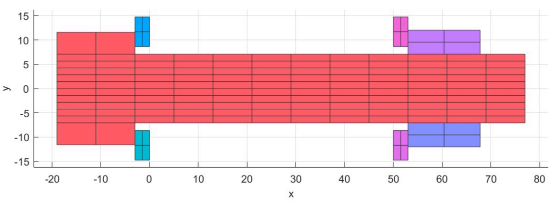
注意此处螺栓2D截面图和3D网格图是不一样的，这是因为在有限元分析中，只需要将螺栓加持长度部分建立出来即可，旋合部分通过Rbe2刚性连接与螺栓孔连接。

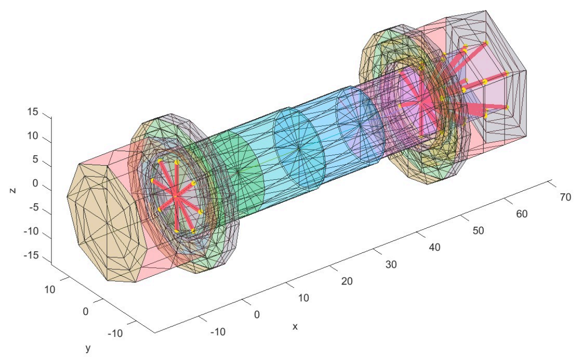




4.3 Create Bolt with Nut and NutWasher (Flag=3)

```
inputStruct.d=16;
inputStruct.l=80;
inputStruct.lk=50;
paramsStruct.ThreadType=1;
paramsStruct.MuG=0.1;
paramsStruct.MuK=0.1;
paramsStruct.Nut=1;
paramsStruct.NutWasher=1;
obj= bolt.Bolt(paramsStruct, inputStruct);
obj= obj.solve();
Plot2D(obj);
Plot3D(obj);
ANSYS_Output(obj.output.Assembly);
```





5　参考文献

[1] VDI2230_blatt_1_2015

[2] VDI2230_blatt_2_2014