

Stress Analysis of Tensioning Bolt based on MATLAB

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This paper conducts an analysis of stress of tensioning bolt. Bolt force equilibrium equation is established and solved. Then the stress tensor is gained at the danger point. The overall process is programmed by MATLAB. As a result, a quick-selection program of tensioning bolt is gained to overcome the tedious process of selection of multiple bolts of the modelling and finite element analysis. This program is also applied to an engineer case with good result. This program also gives a short-cut for engineers.

1. Introduction

M20 tension bolt is applied in the plate-chain conveyor in XXX Company's pipe-pile production line and its tension displacement is 0.1m. The tension bolt in the plate-chain conveyor has the obvious elastic deformation caused by the tension control. Therefore, it needs to use the bigger tension bolt. However, which type is suitable? Usually, finite element simulation (Liu, 2015) and numerical simulation (Yi, 2015) are carried out on the bolt strength calculation and checking. (Fukuda, 2015) have studied the bolt tensioning by the method mentioned above. However, the repeated modelling and analysis process are conducted by engineers for different specifications bolt. This paper adopts MATLAB-language to program the calculation and verification process about the tensioning bolt. The proper specification of tension bolt is gained directly, and the repeated verifications of all kinds of tensioning bolt are got rid of.

2. Force Analysis of the Bolt Tension Control

Figure 1 shows the transmission of plate-chain conveyor and Figure 2 shows the tensioning mechanism. In the process of bolt tension control, the force of hand acts on the wrench and then transmits to the tension bolt. While the tension bolt changes the torque into the tension axial force with the threaded connection. Therefore, we treat the bolt as the study object and carry out the force analysis of bolt with right hand thread.



Figure 1: Transmission of Plate-Chain Conveyor



Figure 2: Tensioning Mechanism

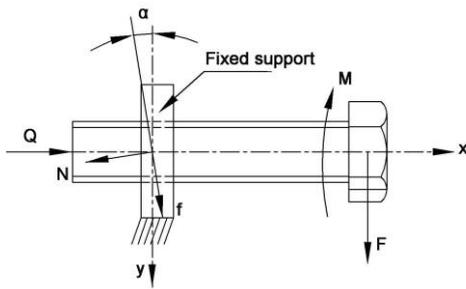


Figure 3: Force Analysis of Bolt

Figure 3 shows the force analysis of bolt. Seen from the Figure 3, tensioning load Q , tightening torque M and wrench pressure F are acting on the bolt, which are balanced by forces generated from the fixed support threads in the bolt (Xiang, 2010). Force N is the normal reaction of fixed support threads to the surface of bolt threads, f is the frictional resistance and α is the helix angle of thread. The formula is as follows:

$$f = N \times \mu \quad (1)$$

Where, μ is the coefficient of sliding friction. Assuming that the pitch of bolt is P and the minor diameter of bolt is D . It is concluded:

$$\cos \alpha = \frac{\pi \cdot D}{\sqrt{P^2 + \pi^2 \cdot D^2}}; \tan \alpha = \frac{P}{\pi \cdot D} \quad (2)$$

Force analysis of bolt obtains the following Equilibrium Equations:

$$\begin{cases} Q = N \cdot \cos \alpha - f \cdot \sin \alpha = \cos \alpha \cdot (N - f \cdot \tan \alpha) \\ M = (N \cdot \sin \alpha + f \cdot \cos \alpha) \cdot \frac{D}{2} = \cos \alpha \cdot (N \cdot \tan \alpha + f) \cdot \frac{D}{2} \end{cases} \quad (3)$$

Substitute (1), (2) into (3) and conclude:

$$\begin{cases} Q = \frac{N\pi D}{\sqrt{P^2 + \pi^2 D^2}} \left(1 - \mu \frac{P}{\pi D}\right) \\ M = \frac{N\pi D^2}{2\sqrt{P^2 + \pi^2 D^2}} \left(\frac{P}{\pi D} + \mu\right) \end{cases} \quad (4)$$

3. Stress Calculation

In the process of tension of bolt, both the wrench's torque M and manual vertical force F acting on the wrench are acting on the tension bolt. Therefore, the forces on the tension bolt are in a state of bending and twisting. The stress peril point is placed at point O, namely the top of bolt outer surface, which is shown in Figure 4 (Chen, 1991).

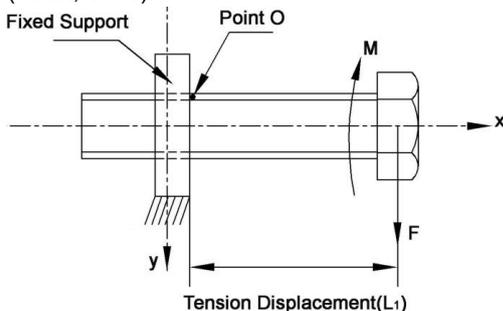


Figure 4: Stress Calculation

3.1 Distorting stress under the effect of torque M

The bolt generates the distorting stress at point O and the tension displacement is L_1 . Based on the torsion and deformation of shaft parts, the stress τ_1 at point O on the bolt and the rotating angles φ are:

$$\begin{cases} \tau_1 = \frac{16M}{\pi \cdot D^3} \\ \varphi = \frac{M \cdot L_1}{G \cdot I_p} \end{cases} \quad (5)$$

Where, G is the shear modulus of steel;

I_p is the resisting torsion moment of inertia in the bolt section, and equal to $(\pi D^4)/32$.

3.2 Shear stress under the effect of Wrench force F

The bolt generates the shear stress at point O . The shear stress τ_2 at point O is:

$$\tau_2 = \frac{4F}{\pi \cdot D^2} = \frac{4M}{L \cdot \pi \cdot D^2} \quad (6)$$

Where, L is the length of the wrench.

3.3 Bending stress under the effect of Wrench force F

The bolt generates the bending stress at point O . According to the bending and deformation equation of hanging stick, the bending stress σ at point O is:

$$\sigma = \frac{32M_1}{\pi \cdot D^3}, \quad (\text{where, } M_1 = F \cdot L_1) \quad (7)$$

3.4 Based on the above analysis

The stress matrix at point O is:

$$\sigma_{ij} = \begin{pmatrix} \sigma & \tau_2 & \tau_1 \\ \tau_2 & 0 & 0 \\ \tau_1 & 0 & 0 \end{pmatrix} \quad (8)$$

To diagonalize the above equation and conclude three principle stresses at point O :

$$\sigma_1 = 0; \sigma_{2,3} = \frac{\sigma \pm \sqrt{\sigma^2 + 4(\tau_1^2 + \tau_2^2)}}{2}; \quad (9)$$

Based on the fourth strength theory, the solution of simultaneous equations (1)~(9) is the Von-mises stress at point O .

$$\sigma_{\text{Von-mises}} = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - \sigma_1\sigma_2 - \sigma_2\sigma_3 - \sigma_1\sigma_3} \quad (10)$$

3.5 Strength Check

The allowable stress of given bolt is $[\sigma]$ and the allowable angle is $[\varphi]$. When the bolt fits the following criteria:

$$\begin{cases} \sigma_{\text{Von-mises}} < [\sigma] \\ \varphi < [\varphi] \end{cases} \quad (11)$$

The bolt conforms to the tension requirements.

4. Program Design

The stress calculation is complex. In order to improve the efficiency, the stress calculation and check needs the help of computer program. This paper adopts the MATLAB to design the program.

4.1 Initial Conditions

Check the strength of bolts. We need to determine the tension load Q , bolt minor diameter D , pitch P , tension displacement $L1$ and wrench arm length L . Friction coefficient is μ .

a. Input the tension load Q with the screen input form; (Unit: kg)

b. The nominal diameters M^t and pitches P of ordinary coarse threads (Unit: mm); The details are shown in Table 1.

Table 1: Comparisons of nominal diameters M^t and pitches P

Nominal Diameters	1	1.2	1.6	2	2.5	3	4	5	6	8
Pitch	0.25	0.25	0.35	0.4	0.45	0.5	0.7	0.8	1	1.25
Nominal Diameters	64	72	80	90	100	110	125	140	160	180
Pitch	6	6	6	6	6	6	6	6	8	8

Table 2: Comparisons of nominal diameters M^t and pitches P (continue)

Nominal Diameters	8	10	12	16	20	24	30	36	42	48	56
Pitch	1.25	1.5	1.75	2	2.5	3	3.5	4	4.5	5	5.5
Nominal Diameters	180	200	220	250	280	320	360	400	450	500	550
Pitch	8	8	8	8	8	6	6	6	6	6	6

Minor diameters of tension bolts $D \approx M^t - 2P$

c. Input the tension displacement $L1$ with the screen input form (Unit: m).

d. Wrench arm length $L = 0.3\text{m}$.

e. Friction coefficient $\mu = 0.2$.

4.2 Program Flow

Set the allowable stress as $[\sigma] = 3.5 \times 10^8 \text{Pa}$ and the allowable angle as $[\varphi] = 2^\circ$. According to the initial conditions, scan the tension bolts from $M1$ to $M550$. When checking conditions are all consistent, it needs to exit the program, record the current bolt's specification and show the results. The detail is shown in Figure 5 above.

4.3 Programming

The title of the program is defined as `zjls.m`. Firstly, input 'zjls' in the Matlab interface and press "Enter". Secondly, input the tension load and tension displacement according to the instruction on the screen and press "Enter". Finally, the specification of tension bolt will be obtained.

Make sure that the program can be invoked with the GUI interface and be operated independently (Liu, 2012).

The requirements are as follows:

- (1) The Calculation function should have input functions.
- (2) The Calculation function should have return values.
- (3) To ensure that the program can be called and operated independently, the beginning of program should have the selective identification of input parameters.

Therefore, the beginning of program is as follows:

```
function jiegou = zjls(Q, L1)% with parameter input function
```

```
if nargin < 1% to determine whether there is an argument
```

```
Q = input('Input the tension load: Unit (N)');
```

```
L1 = input('Input the tension displacement: m');
```

```
else
```

```
end
```

```
.....
```

```
Jiegou = LUCC(1, i); % Return the calculation results.
```

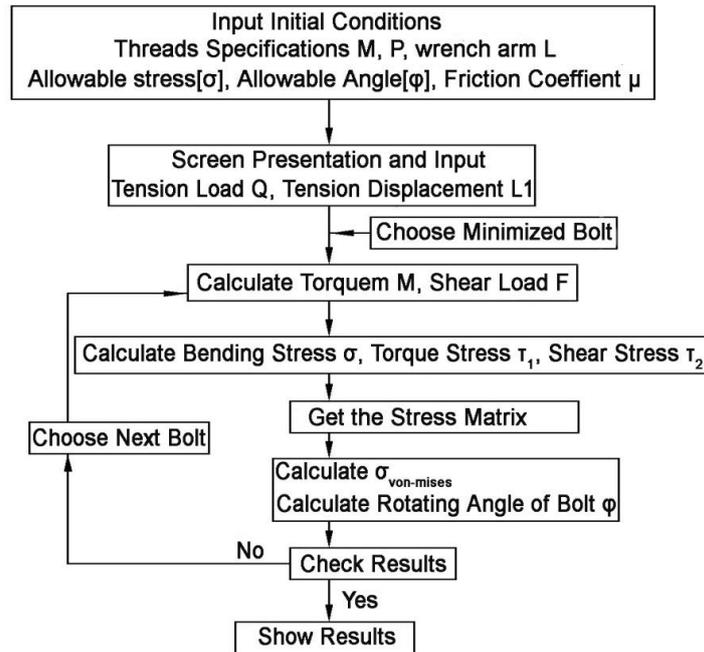


Figure 5: Program Design Flow Chart

4.4 GUI Mode of MATLAB

The above program adopts the function with input parameters. When there are no input parameters, it can input the parameters from the screen and calculate. Therefore, this program can be operated independently to calculate and be called by other functions. Set two input parameters: tension load and tension displacement. Meanwhile, the function set the return values, which can exchange the input and output data with other functions.

Finishing the calculating program, we can design the GUI interface of MATLAB (Yang, 2012), namely the Human-Machine Interface. Seen from Figure 6, the choice depends on the units in the interface. Choosing the international unit system, the unit of tension load is Newton (N) and the unit of tension displacement is Meter (M). Choosing other unit system, the unit of tension load is *kgf* and the unit of tension displacement is *mm*, which is shown in the Figure 7. When the interface is ready, the assignments of input and output can be set in the M-file of interface. The main program adopts the international unit system. So it results in the conversion for other unit system. Meanwhile, it needs to call *zjls* (Q, L1) function in the feedback function that displays the results of bolts selections and assign the main function's variables with input values. It will realize the calling bolt selections' main program function by the interface function and the operation of human-machine interface.

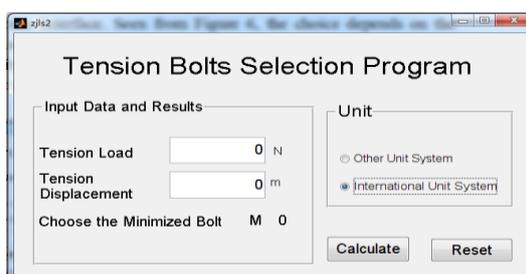


Figure 6: Program Interface of Bolt with International Unit System

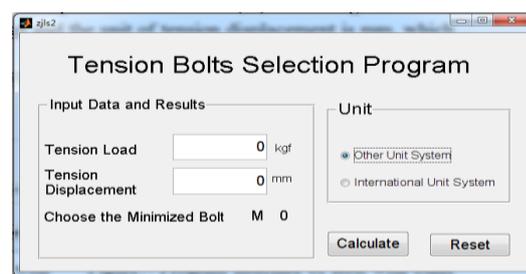


Figure 7: Program Interface of Bolt with other Unit System

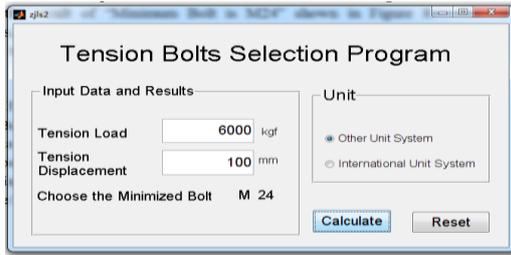


Figure 8: Results of Bolt Selections

5. Examples of Engineering Application

In XXX pipe-pile production line, the tension load of plate chain conveyor is 60kN and the tension displacement is 0.1m. It is found that the initial M20 bolt has an obvious deformation which is disadvantageous for the tension control. Therefore, it needs to change a larger bolt.

Filling the tension loads and tension displacements into the interface shown in Figure 7, clicking “Calculate”, then the result of “Minimum Bolt is M24” is shown in Figure 8. Considering the safety factors, it needs to choose the bigger bolt. Therefore, tension bolt M30 is applied in the field and the tensioning effect is good in fact.

Conclusion and Prospect

This paper mainly analyzes the tension bolt’s force and designs the calculation programming. The tension load of plate-chain conveyor is 60kN. With the calculation program, the minimized bolt is M24. Considering the security, M30 bolt is applied in field and the tensioning effect is good in fact.

Finally, it can be converted into an executable file by MCC and runs independently without the MATLAB environment, which provides the fast and easy design data for mechanical designers.

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