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Thread Fastening

Overview & Selection of Various Fastening Methods

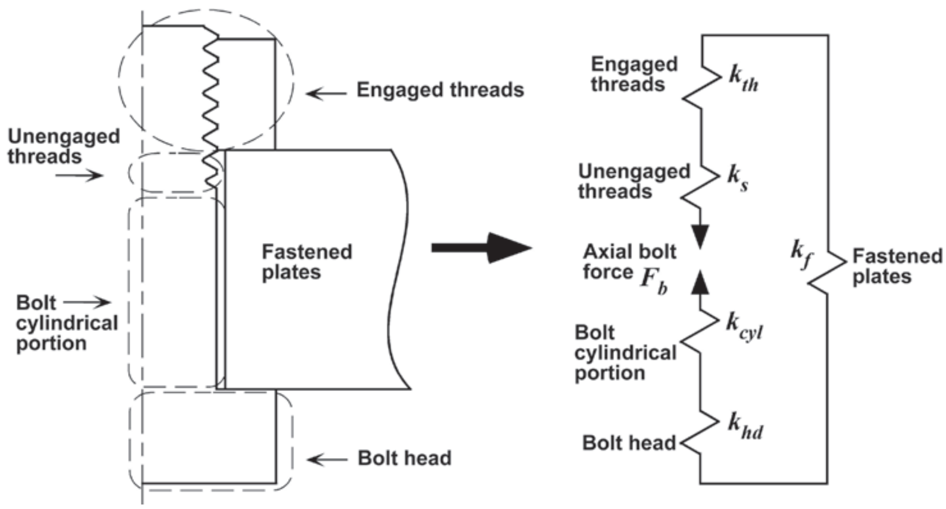
螺紋緊固 — 各種緊固法的概要與選擇

Toshimichi FUKUOKA is a renowned scholar in the Japanese fastener industry and is considered a pioneer of Japanese fastener research. In addition to writing many papers and publishing multiple books, he was invited by The Japan Research Institute for Screw Threads and Fasteners to write papers. Furthermore he was once interviewed by athome-academy.jp. He wrote many easy-to-comprehend works of knowledge for Japanese fastener technicians. We believe his contributions to Fastener World Magazine will bring Japanese fastener viewpoints to our broad American, European, and Asian readers.

Introduction

Threaded components are fastened by means of various methods, and the most widely applied method is "Torque Control Method". Another method, in which the torque is applied in like manner and the turn of nut is regarded as the indicator, is called "Turn-of-nut Method (Angle Control Method)". Other methods include the "Tension Method" which utilizes hydraulic tensioners, and "Thermal Expansion Method" utilizing bolt heaters. The choice of fastening method depends on the required axial force precision, applicable thread nominal diameter, price of the fastening device/tool, and costs including personnel expenses and working hours. In addition to the above-mentioned judging criteria, this article explains various fastening methods from the perspective of the joint stiffness, and offers some suggestions for choosing the method accordingly.

Fig. 1 Stiffness of the Bolted Joint



The precision of thread fastening can be considerably affected by the joint stiffness. A bolted joint with small grip length (the sum of the thickness of fastened plates) has high stiffness and therefore its fastening precision tends to decrease. **Figure 1** shows one-dimensional spring models representing the stiffness of bolt-nut connection in the axial direction. The spring constant "k" of the straight bar is expressed as " AE / L ", where "L" is the length under axial load, "A" is the area of cross section, and "E" is Young's Modulus. The spring constants, "k_{th}", "k_s", "k_{cyl}", "k_{hd}", which represent the stiffness of engaged threads, unengaged threads, bolt cylindrical portion and bolt head respectively, can all be expressed in the same form as follows.

$$k_{th} = \frac{A_S E_b}{L_{th}},\ k_s = \frac{A_S E_b}{L_s},\ k_{cyl} = \frac{AE_b}{L_{cyl}},\ k_{hd} = \frac{AE_b}{L_{hd}} \qquad (1)$$

"A_S" is the stress area; "A" is the cross section whose diameter is equal to nominal diameter "d"; "L_S" and "L_{cyl}" are the lengths of unengaged threads and bolt cylindrical portion; "E_b" is the Young's Modulus of bolt/nut material. "L_{th}" and "L_{hd}" are the equivalent lengths of the engaged threads and bolt head, and their approximate values can be calculated as follows.

$$L_{th} = 0.85d,\ L_{hd} = 0.55d \qquad (2)$$

In the case where the female screw is machined onto the main body side, "L_{th}" will slightly reduce to "0.75d". When evaluating the stiffness of fastened plates, they are categorized into "thin cylinder", "thick cylinder", and "plate" based on the ratio of grip length "L_f" to the outer diameter "D_0"of the fastened plates. In the case of "thin cylinder", in which "D_0" is roughly equal to the average diameter "B", its spring constant "k_f" is the product of the cross section area of hollow cylinder times Young's Modulus "E_f" of the joint material divided by grip length "L_f".

$$k_f = \frac{\pi\left(D_0^2 - d_h^2\right)}{4} \cdot \frac{E_f}{L_f} \qquad (3)$$

"d_h" is the bolt hole diameter. Additionally, if the fastened plates include gaskets having specific compression characteristics, it will be difficult to evaluate "k_f" correctly. The stiffness of each portion is summarized in the following.

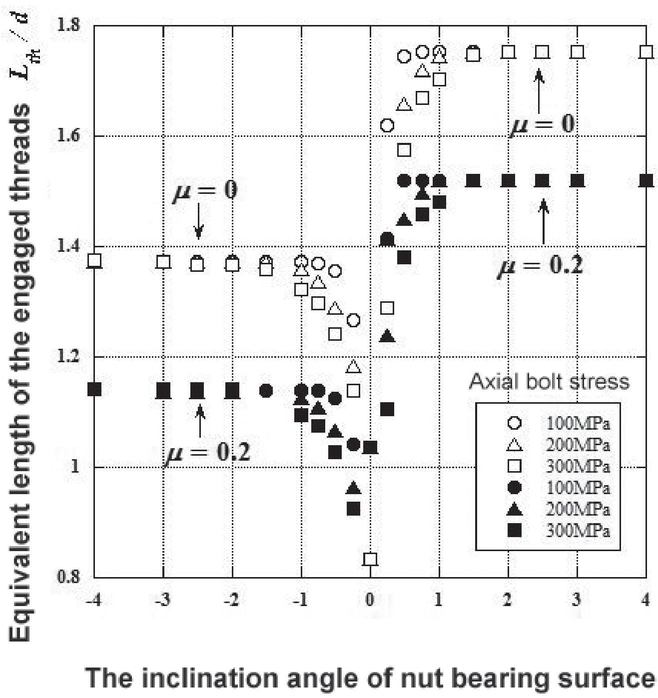
1) Regardless of grip length, the spring constants of the engaged threads and bolt head are constant.
2) The spring constants of the unengaged threads, bolt cylindrical portion, and the fastened plates are in inverse proportion to the targeted length.
3) The spring constant of each portion is in proportion to Young's Modulus.

The spring constant "k_{total}", which represents the total stiffness of the bolted joint, is in a series connection of 5 spring constants.

$$\frac{1}{k_{total}} = \frac{1}{k_{th}} + \frac{1}{k_s} + \frac{1}{k_{cyl}} + \frac{1}{k_{hd}} + \frac{1}{k_f} \qquad (4)$$

Since "k_{total}" is roughly in inverse proportion to the grip length "L_f", in case of "L_f" being small, the value of "k_{total}" will greatly depend on the evaluation accuracy of "L_{th}" and "L_{hd}". **Figure 2** shows the value of "L_{th}" obtained by finite element analysis. Because a small degree of inclination can occur on the nut bearing surface due to the problem of plastic working, the horizontal axis is set to be the angle of inclination. The symbol "μ" is the coefficient of friction on the contact surface. As shown in the figure, "L_{th}" will be more than two times larger than that of the nut bearing surface being flat (0.85d). It can therefore be concluded that the fastening methods, which are greatly affected by the joint stiffness, do not work well for the bolted joints with small grip length.

Fig. 2



Overview of Fastening Principles & Suggestions for Method Selection

(1) Torque Control Method: This method utilizes the wedge effect, which occurs on the inclined surface of threads, to convert the torque into the axial force. The applied torque is consumed to generate the axial force as well as the frictional torques on the thread surface and nut bearing surface. As 90% of the total torque is consumed in the friction work, even if the same torque is applied for fastening, the variation of axial force between 25% and 35% is inevitable due to the scatter in coefficient of friction. Torque applying devices like hydraulic/pneumatic/electric motors, as well as impact wrenches that utilize air impact, are all regarded as the Torque Control Method.

(2) Torque Gradient Control Method: This method detects "the drop of torque variation rate in relation to the turn of nut" resulting from partial plastic deformation around the thread root immediately after the axial force increases. Although this method has higher precision than Torque Control Method, it still requires the use of the tools especially designed for this method.

(3) "Turn-of-nut Method (Angle Control Method)": This method includes the "Elastic Angle Control Method", where the bolt is fastened within the elastic zone, and "Plastic Angle Control Method" that increases the axial force to the plastic zone. In both methods, the target axial force is given by controlling the nut rotation angle. The latter one utilizes the drop of torque variation rate in relation to the turn of nut in the process of plastic deformation. As the turn of nut in "Plastic Angle Control Method" is larger than that in "Torque Gradient Control Method", axial force control is easier. Therefore, "Plastic Angle Control Method" is sometimes applied to the bolts with small diameter and high strength used in the automotive industry. The former one, namely "Elastic Angle Control Method", is applied to the fastening of critical components in the marine engineering field. The principle of fastening - "The movement of thread driven by one nut rotation equals to the amount of deformation of the whole fastening portion caused by the targeted axial force". The amount of turn, required for the bolts with same nominal diameter, is roughly in proportion to the grip length.

(4) Tension Method: This method uses a special device called hydraulic tensioner to directly apply tension to the bolt for fastening. Basically, this method is not affected by the friction on the contact surface, and therefore it is used for the joint that requires high fastening precision. On the other hand, the equipment is expensive and it needs some setting space around the threaded component. The principle of fastening - "The amount of the deformations of bolt (excluding the engaged threads) and fastened plates during the initial tension process equals to the amount of deformation of the whole fastening portion caused by the targeted axial force". The fastening precision could significantly decrease if the grip length is short. Additionally, since the initial tension is higher than the targeted axial force, special attention must be paid if the magnitude of axial bolt stress is close to the yield point.

(5) Thermal Expansion Method: This method heats up the hollow bolt with a bolt heater to elongate the bolt, and then the operator turns the nut, seats the nut onto the bearing surface of the bolt head, and utilizes the contraction during cooldown to fasten. The application of this method is not limited to bolt size, and the equipment is less expensive and compact; therefore it is suitable for tight space. On the other hand, the drawback is that it requires much operating time. Additionally, in order to apply axial force with high precision, it is required to correctly estimate the relation between the heating time and the axial force to be generated. The principle of fastening - "The elongation of bolt occurring on the portion of grip length caused by the bolt heater equals to the amount of deformation of the whole fastening portion generated by the targeted axial force". This method is suitable for the joint having rather large grip length.

Figure 3 is an example of hydraulic tensioner and bolt heater used for "Tension Method" and "Thermal Expansion Method". In the following, the suggestions for method selection are given.

1) When using the "Turn-of-nut Method", "Tension Method" and "Thermal Expansion Method", high fastening precision is not always expected if the joint has short grip length (e.g., Lf /d < 3). Furthermore, it is suggested that you refrain from applying those methods to thin plates. If the fastened plates contain components like gaskets, the fastening precision could dramatically decrease.
2) When using the "Torque Control Method", since the relation between applied torque and axial force is not affected by the joint stiffness, even in the case of short grip length, and the problem of joint waviness being involved, the decrease in fastening precision will be smaller compared to the other fastening methods.

Conclusion

This article briefly introduces various fastening methods and offers some suggestions for choosing an appropriate fastening method from the perspective of the joint stiffness. Next time, I would like to explain the widely-used Torque Control Method, Turn-of-nut Method, Tension Method and Thermal Expansion Method in more detail.


Hydraulic tensioner


Bolt heater

Fig. 3

Reference:
Toshimichi FUKUOKA, "Threaded Fasteners for Engineers and Design – Solid Mechanics and Numerical Analysis –", pp.73-125, CORONA Publishing Co. Ltd. (2015)