Fastener Expert 101

Angle Control Method: Combining with Torque Method to Improve Fastening Precision

by Toshimichi Fukuoka

Angle Control Method is divided into “Plastic Angle Control Method” where threads are fastened until plastic deformation takes place, and “Elastic Angle Control Method” where fastening is conducted within the range of elastic deformation. The former is basically suitable for bolted joints that won’t be disassembled again after the completion of fastening, like those high-strength bolts with small diameter employed to fasten critical components for car assembly. On the other hand, Elastic Angle Control Method is suitable for bolted joints that repeat periodical fastening and opening for the purpose of inspection, like crank pin bolts used for marine diesel engines. Elastic Angle Control Method utilizes the relation that the thread ridge proceeds 1 pitch as the nut rotates 1 turn. It is said that its advantage is that, when combining with Torque Method, the fastening precision can be improved comparing to a common Torque Method. The purpose of this article is to explain the fastening principles of Elastic Angle Control Method, and point out the effective range of application as well as the fastening guidelines for operations when combining with the common Torque Method.

Principles of Fastening

(Fig. 1)

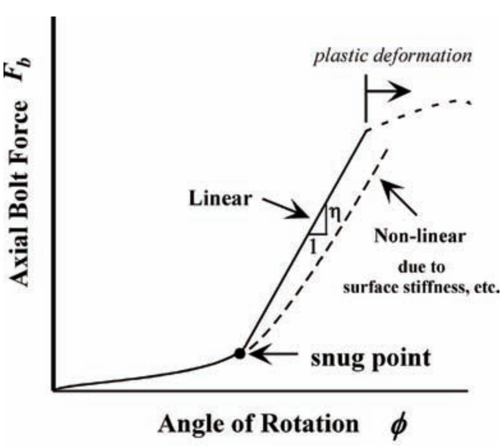


Figure 1 illustrates the relation between bolt axial force F_b and nut rotation angle ø. If we start measuring the angle at the moment when the bearing surface touches the surface of fastened object, in the range of small contact pressure at the bearing surface of nut, the axial force shows only a small increase even if the rotation angle increases. This is due to the effect of the surface roughness and the waviness of the interface, and the geometric error of the bolted joint. Then, as the bearing surface of nut adheres closely to the surface of fastened object, the relation between the axial force and rotation angle becomes almost linear. This specific point is called “snug point”. Until this point, “Torque Method” should be employed for fastening. Hereafter, one can utilize the relation that “thread ridge proceeds 1 pitch as nut rotates 1 turn”. In other words, the fastening procedure of Elastic Angle Control Method consists of the following 2 steps.

Step 1: Use Torque Method until the snug point and incur a certain amount of axial force. The torque applied here is called “Snug Torque”.

Step 2: Through controlling the nut rotation angle, apply the remaining axial force until the target axial force is reached. This step is so-called Elastic Angle Control Method and its fastening principle is as follows.

“As you turn the nut to fasten the bolt, for each rotation (2π) the nut proceeds 1 pitch in the axial direction. The amount of axial movement is equal to the sum of axial displacements that are derived by dividing axial force F_b by the spring constants of various portions consisting of the bolted joint.”

The spring constants of various portions of the bolted joint mentioned here are the 5 spring constants (k_{th}, k_s, k_{cyl}, k_{hd}, k_f) explained in Figure 1 in my first submitted article to Fastener World Magazine. The above mentioned relation between the two can be expressed in the following equation, in which P is thread pitch.

$$\phi = \frac{2\pi}{P} F_b \left(\frac{1}{k_{th}} + \frac{1}{k_s} + \frac{1}{k_{cyl}} + \frac{1}{k_{hd}} + \frac{1}{k_f} \right) = \frac{2\pi}{P} \frac{F_b}{k_{total}} \quad (1)$$

k_{total} in the above formula represents the stiffness of the whole bolted joint, as shown in equation (4) in my first submitted article.

From equation (1), it is found that the rotation angle ø required for obtaining the same axial force F_b becomes larger as the pitch and the stiffness of the bolted joint becomes smaller. As larger rotation angle expectantly produces higher fastening precision, we can say that Elastic Angle Control Method is not suitable for bolted joints with short grip length, i.e., short bolts.

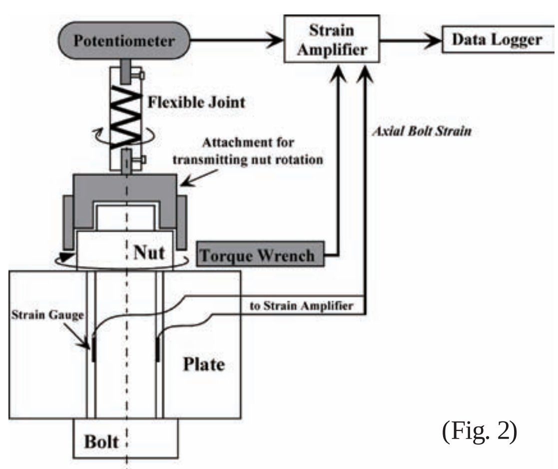
Equation Between Rotation Angle and Axial Force that Takes Account of Surface Roughness

In actual bolted joints, due to the effect of surface roughness, etc., even if the bearing surface of the nut is adhered to the bolt, the relation between bolt axial force and rotation angle does not become completely linear. When considering the effect of surface roughness, one must take "interface stiffness" into account. Interface stiffness indicates "the phenomenon of decreased stiffness due to the deformation of interface" driven by the collapse of micro-asperity on the interface that bears the contact pressure resulting from bolt axial force. Here I'll skip the details. Considering the effect of interface stiffness, equation (1) can be updated as follows.

$$\phi = \frac{2\pi}{P}\left(\frac{F_b}{k_{total}} + \zeta_{th} + \zeta_{nu} + \zeta_{hd} + \zeta_f\right) \quad (2)$$

ζ_{th}, ζ_{nu}, ζ_{hd}, ζ_f in the equation are the amounts of deformations resulting from the interface stiffness of thread surface, nut bearing surface, bolt head bearing surface, and the interface of the fastened object, respectively. In the case where the surface roughness of the interface is small, these deformations can be regarded as zero, and then equation (2) is approximately equal to equation (1). Accordingly, higher fastening precision is expected when Elastic Angle Control Method is applied to the bolted joint with smaller surface roughness.

Figure 2 illustrates the experimental device constructed to evaluate the fastening process of Elastic Angle Control Method. It can simultaneously measure torque, axial force, and nut rotation angle. With the use of potentiometer, the measurement of rotation angle is started at the moment when the nut is seated. Figure 3 is an example of the measured results. The ordinate is bolt axial stress σ_b, and the abscissa is nut rotation angle ø. If we shift the starting points of rotation angle measurement, the three experimental results agree well each other. This result supports the importance of snug torque mentioned in the previous section. Figure 4 compares the experiment results in Figure 3 with those of the calculation results obtained by equations (1) and (2) and Finite Element Analysis. Since the surface roughness of the target bolted joint used in the experiment is large, the calculation results by equation (2) is the most consistent. However, as the surface roughness becomes smaller, use of equation (1) may provide the calculation results with practically sufficient accuracy.



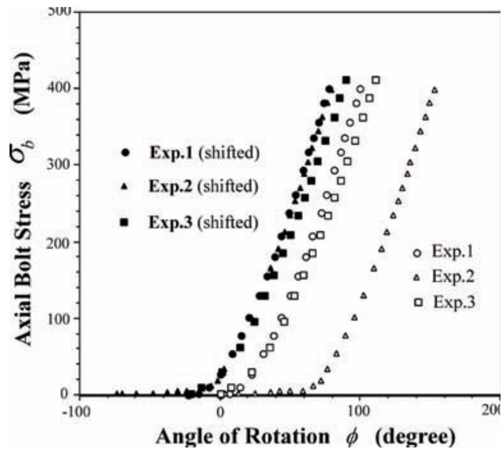
(Fig. 2)

Suggested Range of Application

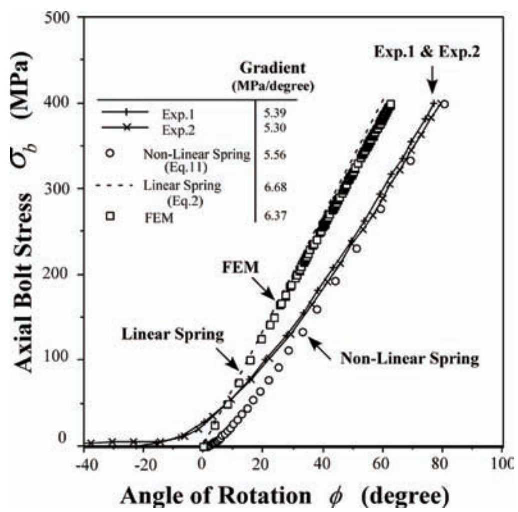
(1) Bolted joint with high target axial stress σ_b: When the axial stress is small, the effect of surface roughness on Rotation Angle/Axial Force Equation becomes larger. In addition, the fastening precision drops because the determination of appropriate snug torque is difficult. A target axial stress σ_b is preferably 300MPa and over.

(2) Bolted joint with large grip length: Because the rotation angle ø required for the target axial stress σ_b becomes larger, high fastening precision is expected.

(Fig. 3)



(Fig. 4)



(3) Bolted joint employing fine threads: The rotation angle ø required for the same axial stress is in inverse proportion to the pitch *P*. The required rotation angle ø in case of fine threads is larger than course threads, so high fastening precision is expected.

(4) Bolted joint having small surface roughness: The effect of surface roughness on Rotation Angle/Axial Force Equation is relatively small, so high fastening precision is expected.

(5) Bolted joint composed of low stiffness materials: As Young's Modulus of the material of the bolted joint gets smaller, the required rotation angle ø necessarily becomes larger. Owing to the same reasons stated in 2) and 3), high fastening precision is expected.

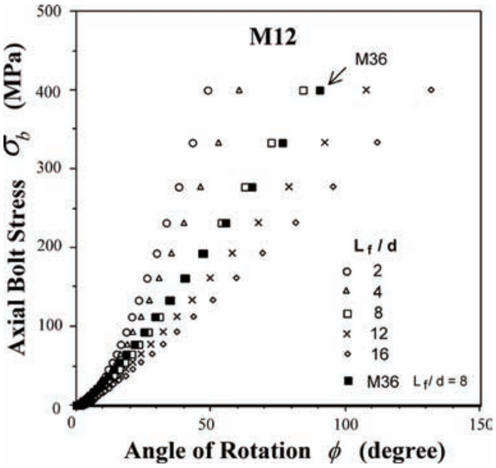
Regarding the above 2), it is considered that smaller grip length causes substantially large scatter in the axial force due to the effect of surface roughness, geometric error of the bolted joint and other factors. Accordingly, the application of Elastic Angle Control Method is not recommended for such bolted joints stated above.

Fastening Guidelines:

(1) Set the Snug Torque that produces typically 50-100MPa of axial stress. Convert the axial stress into bolt axial force F_b. Then, determine Snug Torque T_{sng} using the Torque/Axial Force Equation that I explained in my third submitted article, and fasten the joint with that amount of torque.

(2) Then, based on Rotation Angle/Axial Force Equation, fasten the joint to the target axial force. Use equation (2) or equation (1) in order to calculate the required rotation angle. Furthermore, the value of axial force F_b substituted into these equations is obtained by subtracting the axial force generated by Snug Torque explained in Guideline 1) from the target axial force.

Figure 5 shows an example for the case of M12, in which the relation between the axial stress σ_b and nut rotation angle ø is calculated by utilizing equation (2). As the ratio of the grip length L_f to nominal diameter d, L_f/d, increases, the rotation angle required for the same axial stress becomes larger. Therefore, it is found that the fastening precision is to be improved. The results of M36, shown in the figure, indicate a small effect of nominal diameter.



Conclusion

A fairly high fastening precision is expected if we use Elastic Angle Control Method along with Torque Method in a proper manner. In case of application, bolted joints with low stiffness are recommended. On the other hand, for the case of such structures as pipe flanges with low stiffness gaskets being inserted between two metal plates, it is difficult to correctly evaluate the spring constant k_f of the fastened object which appears in equation (1). In those cases, therefore, the application of Elastic Control method is not recommended.

Reference:

1. Toshimichi Fukuoka, "Threaded Fasteners for Engineers and Design – Solid Mechanics and Numerical Analysis –", pp.100-107, Corona Publishing Co., Ltd. (2015)

2. Fukuoka, T. and Takaki, T., 2004, "Evaluation of the Tightening Process of Bolted Joint with Elastic Angle Control Method", Analysis of Bolted Joints, PVP-Vol. 478, pp.11-18