Fastener Expert 101

Thermal Expansion Method Simultaneous Fastening of Large Bolts

by Toshimichi Fukuoka

Introduction

Thermal Expansion Method is applied to simultaneous fastening of multiple bolts or large bolts which cannot be fastened with other methods. The target bolt is hollow, and a bar-shaped heater is inserted and heated to make the bolt elongate. It is therefore that Thermal Expansion Method is much similar to Tension Method, which utilizes hydraulic pressure to make the bolt elongate, in regard to the fastening characteristics. Additionally, it is not limited in the applicable bolt size and the tightening operation can be conducted with less expensive tools. Utilizing such advantages, it is widely applied to simultaneous fastening of multiple bolts used for the casing of power-generating turbines, as well as the fastening of hydroelectric power-generating mills and large pumps. This article explains the fastening principles of Thermal Expansion Method and proposes its effective applicable range and fastening guidelines.

Fastening Principles

Figure 1 shows a bolt heater mounted to a hollow bolt for the purpose of fastening experiments. The target bolt is placed vertically so that its engaging portion is facing upwards, and the heater is placed in the center of the bolt's hole. The fastening procedure with a bolt heater consists of 4 steps shown in **Figure 2**.

Figure 1

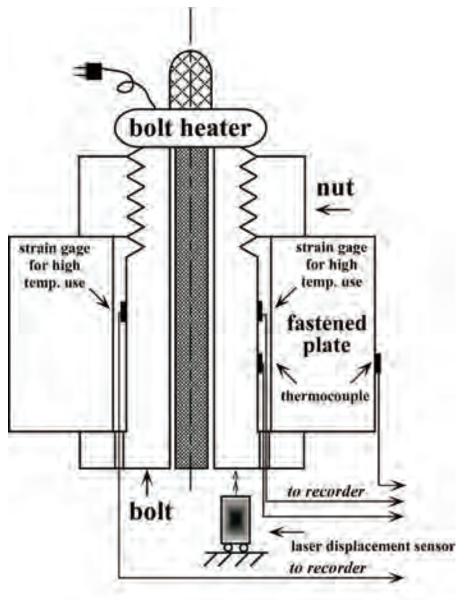
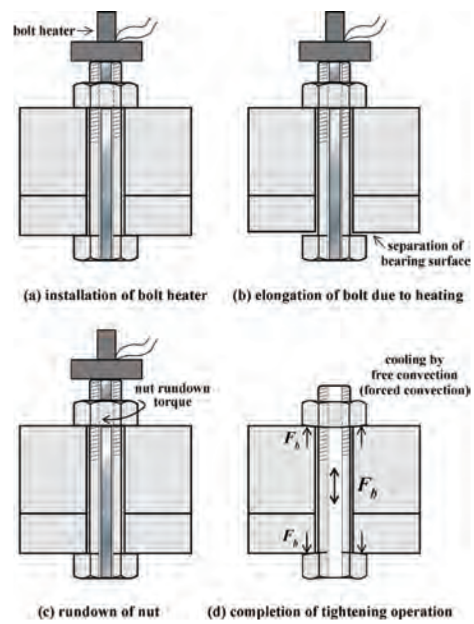


Figure 2



Step 1: Mount the target hollow bolt to the fastened object, and then insert the bolt heater.

Step 2: Switch on the bolt heater, and heat up the bolt until the bolt elongation reaches the target value. This will generate a gap equal to the amount of bolt elongation around the bolt head surface.

Step 3: Apply an appropriate amount of seating torque to bring the bolt head and fastened object in close contact.

Step 4: Axial force is generated by the bolt shrinkage due to natural cooling or forced cooling.

Bolt axial force occurs owing to the bolt shrinkage in step 4, which is equal to the bolt elongation generated in step 2. As in the case of Tension Method, the application of the seating torque, which results in the average contact pressure of 10 MPa and higher on the nut seating surface, will securely produce the objective axial force.

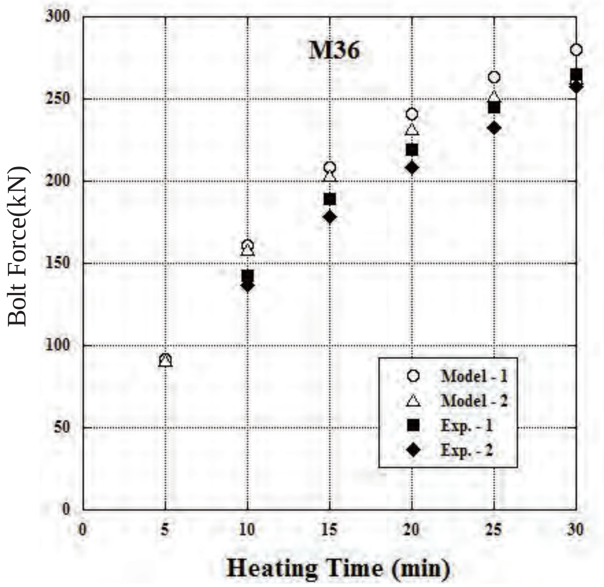
Relationship Between Axial Force & Heating Temperature

In order to apply axial force with high precision, an equation relating heating temperature and occurring axial force is necessary. We can derive the equation from the relation— "The amount of bolt elongation δ, which results from thermal expansion, is equal to the sum of axial deformations of all portions of fastening objects due to the generated bolt axial force F_b." If we set the coefficient of linear expansion of bolt material as α_b, the grip length of the bolted joint as L_f, and the amount of the bolt average temperature rise as ΔT_b, we can calculate the bolt elongation δ by the following equation.

$$\delta = \alpha_b \Delta T_b L_f \quad (1)$$

In the case of the bolted joint made of carbon steel, the coefficient of linear expansion is set to be 11.8×10-6, and we

Figure 4



the bolt elongation with the temperature distribution obtained above, and then you can derive the relation between the heating time and occurring axial force. **Figure 4** compares the numerical results with the experimental ones. It is found that both Model 1 and Model 2 can estimate the mutual relationships with fairly high precision.

Applicable Range & Fastening Guidelines

Applicable Range:

1. Bolted joint using the bolt with large nominal diameter: Thermal Expansion Method is the only method that can fasten the bolts with very large nominal diameter. Although a hollow bolt is used in Thermal Expansion Method, there is no problem concerning its strength since the hollow bolt's diameter is small.

2. Bolted joint requiring simultaneous fastening of multiple bolts: Simultaneous fastening of multiple bolts with large nominal diameter is possible if you use the bolts and the same number of heaters. In that case, you can eliminate the scatter in bolt axial force which occurs during the successive bolt fastening. I will explain the phenomenon in the next section.

3. Bolted joint with large grip length: Since Thermal Expansion Method utilizes the difference between the elongation during heating and the contraction during cooldown of the bolt's grip length portion, we can expect high fastening precision for the bolted joints with large grip length.

Fastening Guidelines:

1. Based on the specifications of the target bolted joint, use Equation (2) to calculate the bolt's heating temperature ΔT_b required for obtaining the target axial force F_b. If possible, calculate the approximate heating time in advance by means of simple numerical analysis.

2. Use Equation (1) to calculate the bolt elongation δ corresponding to the heating temperature ΔT_b. Divide δ by thread pitch P and multiply it by 360°, and then convert it into the angle of nut rotation, which is to be the indicator for the fastening operations.

3. Mount the bolt to the bolted joint and start heating. Measure the temperature of a specific bolt portion, such as the far end of the bolt threads, and as the temperature rise approaches ΔT_b, start seating the nut.

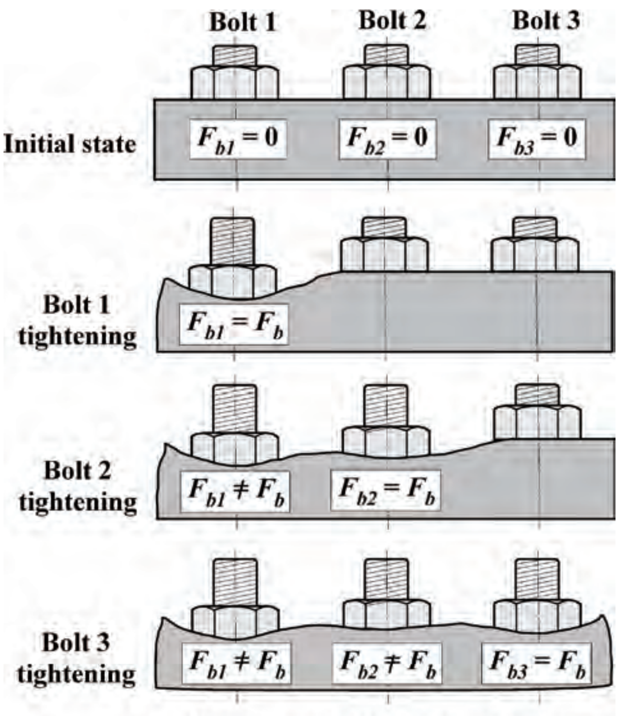
4. Keep the heater inserted during the nut seating process until the rotation angle reaches the value derived in Guideline 2). The seating torque is selected as the value that causes the average contact pressure of 10 MPa and higher on the nut seating surface.

You must pay attention that if you start fastening after removing the heater, the drastic cooldown will cause the bolt to shrink and result in the reduction of axial force. As ΔT_b measured in Guideline 3) differs depending on the measuring position it should be regarded as just a reference value. As far as the operating guideline is concerned, use the angle of nut rotation or bolt elongation.

Multiple Bolt Fastening & Elastic Interaction

When you fasten multiple bolts successively, the axial forces of the already fastened bolts may change. This phenomenon is called "elastic interaction". **Figure 5** illustrates the enlarged deformation patterns obtained by Finite Element Method, in which 3 bolts are fastened successively with the same axial force F_b. When fastening Bolt 1, Bolt 2 and Bolt 3 successively, even if you fasten every bolt with the target value, it is observed that the axial forces vary because of the interaction among the deformations around the objective bolts. Elastic interaction significantly occurs when, just like pipe flange connections, the bolted joint contains low-stiffness materials like gaskets, or when all bolts are positioned on a concentric circle. A method is proposed for a countermeasure to the elastic interaction. By using finite element analysis, the axial force variations can be estimated for any fastening sequence and the initial bolt axial forces, which result in the uniform final axial forces, can be obtained.

Figure 5



Completion of Tightening Operation

Conclusion

At present, Thermal Expansion Method is applied to some specific bolted joints. Besides, recent studies reveal that it is also applicable for situations where the bolt is placed horizontally or inclined. Furthermore, a new bolt heater has been developed, which utilizes high frequency to reduce the time required for heating. It would be much appreciated if this article can help expand the use of Thermal Expansion Method.

Reference

1. Toshimichi Fukuoka, "Threaded Fasteners for Engineers and Design – Solid Mechanics and Numerical Analysis –", pp.117-132, CORONA Publishing Co. Ltd. (2015).

2. Fukuoka, T. and Xu, Q., 2002, "Finite Element Simulation of the Tightening Process of Bolted Joint with a Bolt Heater," Journal of Pressure Vessel Technology, Vol.124, pp.457-464.

3. Fukuoka, T. and Takaki, T., 2003, "Finite Element Simulation of Bolt-Up Process of Pipe Flange Connections with Spiral Wound Gasket," Journal of Pressure Vessel Technology, Vol.125, pp.371-378.