Conceptual Design Study on Bolts for Self-Loosing Preventable Threaded Fasteners

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Abstract. Threaded fasteners using bolts is widely applied in industrial field as well as various fields. However, threaded fasteners using bolts have loosening problems and cause many accidents. In this study, the purpose is to obtain self-loosing preventable threaded fasteners by applying spring characteristic effects on bolt structures. Helical-cutting applied bolt structures is introduced through three dimensional (3D) CAD modeling tools. Analytical approaches for evaluations on the spring characteristic effects helical-cutting applied bolt structures and self-loosing preventable performance of threaded fasteners were performed using finite element method and results are reported. Comparing slackness test results with analytical results and more details on evaluating mechanical properties will be executed in future study.

1. Introduction

Threaded fasteners using bolts are inexpensive and easy to be attached and detached. Therefore, they are used not only in industrial field but also in various fields such as precision instruments and medical field. There are various kinds of fastening methods using bolts, such as a method of using bolts and nuts together or a method of using tapping screws, and a designer can select assuming the environment in which different products are used.

However, loosening problems of threaded fasteners are unavoidable through the bolt tightening method, and many accidents are actually occurred and reported. For example, the railroad derailment accident occurred in the UK in 2002 is one of the most famous accident. This accident occurred because the screw used for the railroad switch was loosed and fatigue failure due to the vibration occurred. In order to prevent such kind of accidents, bolts or screws having locking functions are designed and developed.

In this study, spring characteristic effect as shown in figure 1 are interested. The purpose is to realize self-loosing preventable threaded fasteners by applying spring characteristics to bolts. Spring characteristic effects can be applied to bolt structures by introducing helical-cutting process to ready-made bolt to obtain self-loosing preventable threaded fasteners. The spring characteristic effects are swelling effect under rotating counter-clockwise (loosing direction) shown in figure 1 [a] and shrinking effect under rotating clockwise (tightening direction) shown in figure 1 [b].
2. Design of bolt structures for self-loosing preventable threaded fasteners

Structural design of bolts for self-loosing preventable threaded fasteners was investigated using 3D CAD software SolidWorks. Helical cutting with cross-sectional shape as cutting shape and cross thread turning in reverse direction to thread rotation direction of screw is introduced to the general hexagon bolt shown in figure 2(a) and (b). As the result, bolt structure provided by plurality of springs cross each other are designed with spring characteristic effects surposed to be imparted.

(a) Convetional bolt (b) Cutting shape & cross thread turning (c) Helical-cutting applied bolt

Figure 2. Image of helical-cutting applied bolt for self-loosing preventable threaded fasteners.

3. Analytical evaluation on spring characteristic effects of helical-cutting applied bolts

Analytical evaluation on spring characteristic effects of helical-cutting applied bolt structures with material properties of structural steel are carried out. Young’s modulus of 200.0 GPa and Poisson’s ratio of 0.3 of structural steel are applied to finite element analysis model of designed bolt structures through ANSYS software.

As loading and constraint conditions, the end of designed bolt was fixed and a torque of 5.4 Nm corresponding to 110% of 4.9 Nm fastening torque of general M6 bolt was applied. Finite element mesh of analytical model of helical-cutting applied bolt is shown in table 1. Figure 3 shows image of finite element mesh of bolt model for self-loosing preventable threaded fastener.

| Minimum Surface Size | 0.002mm |
|----------------------|---------|
| Maximum Surface Size | 0.35mm  |
| Maximum Size         | 0.40mm  |
| Number of Element    | 219695  |
| Number of Node       | 138410  |

Table 1. Finite element mesh of analytical bolt model.
Figure 3. Image of finite element mesh of bolt for self loosing-preventable threaded fastener.

Figure 4 shows the analytical result on spring characteristic effect of helical-cutting applied bolt structures with self-locking performance for threaded fastener application. From this result, spring characteristic effect is confirmed by the obtained swelling effect under rotating loads counterclockwise.

Figure 4. Analytical result on spring characteristic effect of helical-cutting applied bolt.

4. Analytical evaluation on self-loosing preventable performance of threaded fasteners

Self-loosing preventable performance of threaded fastener using helical-cutting applied bolts are analytically examined by comparison with general hexagon bolt. Junker vibration test under ISO 16130 standards are modeled including bolt, nut, fixed plate and vibration plate as shown in figure 5. Material properties of structural steel are also used for bolt structure in this model.

Figure 5. Analytical model of threaded fastener using different bolt structures.
General M6 hexagon bolts with or without helical-cutting processing are introduced for self-loosening preventable threaded fastener evaluation. The friction generated on the contact surface between the stationary plate and the diaphragm and nut was considered negligible and the friction coefficient was set to 0.17 by using experimental conditions of Yamamoto et al [1]. Contact of each surface was defined as contact element based on the penalty method [2, 3]. Table 2 shows the constraint conditions applied for analytical model of threaded fastener.

**Table 2.** Restraint conditions on self-loosening preventable threaded fastener model.

| Test Type                                      | Junker Vibration Test: ISO 16130 |
|-----------------------------------------------|----------------------------------|
| Number of Vibrations                          | 1000                             |
| Direction of Vibration                        | x Direction: ±0.3mm              |
| Fixed                                         | Side of Fixed Plate              |
| Bolt End: x and z Directions                  |                                  |
| Fastening Axial Force                         | 4330N                            |

Junker vibration test is a test in which a diaphragm and a fixing plate are fastened by using of bolt and vibration of the diaphragm is applied in the direction perpendicular to bolt axis. In this analytical model, fixations in x and z directions of the fixed plate and the end of the bolt were fixed, the fastening axial force was given in the first step, and then the diaphragm was oscillated with the amplitude of 0.3 mm in the x direction along perpendicular direction to bolt axis.

To analyzing the Junker vibration test, very long time calculation is needed because of the analysis type and model sizes. Analysis time can be shortened by increasing the element sizes of the diaphragm and fixing plate, which are considered having little influence on the analytical result. Table 3 shows the number of elements and nodes for self-loosing preventable threaded fastener model.

**Table 3.** Number of elements and nodes on threaded fastener model.

| Threaded fasteners using general Bolt          |                               |
|-----------------------------------------------|--------------------------------|
| Number of Elements                            | 16800                         |
| Number of Nodes                               | 36751                         |
| Self-loosing preventable threaded fasteners   |                               |
| Number of Elements                            | 15762                         |
| Number of Nodes                               | 36526                         |

**Figure 6.** Analytical results of Junker vibration test on threaded fasteners.
Figure 6 shows the change in fastening axial force for each number of oscillations obtained. Horizontal axis shows the number of vibration and vertical axis represents the fastening axial forces. Comparison between general and helical-cutting applied bolts are executed and self-loosing preventable performance is confirmed.

As shown in figure 6, unlike ordinary hexagon head bolts, for threaded fastener using helical-cutting applied bolt with self-locking effect, it is possible to maintain the initial fastening axial force even when the number of vibrations reaches 1000.

Figure 7 shows the hysteresis loop of translational load with translational displacement of 5 cycles, respectively. From the hysteresis loop of self-loosing preventable threaded fasteners shown in figure 7, almost gentle gradient portion in which slip occurs on the entire threaded surface can’t be confirmed. In addition, it can be seen that the flat part where the slip occurs over the entire surface of the bearing surface is minute.

![Figure 7](image)

**Figure 7.** Relationship between translational force and displacement of analytical results.

5. Summary
Self-loosing preventable threaded fasteners using helical-cutting applied bolt structures are designed in this study. Spring characteristic effects of helical-cutting applied bolts and self-loosing preventable performance of threaded fasteners are examined through finite element analysis. From analytical results,

(1) Spring characteristic effect of helical-cutting applied bolt is confirmed by the analytical results of swelling effect under rotating loads conterclockwise.

(2) Self-loosing preventable performance of threaded fasteners using helical-cutting applied bolts were performed using finite element method and confirmed. Comparing slackness test results with analytical results and more details on evaluating mechanical properties will be executed in future study.

6. References
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