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Loosening-resistance evaluation of double-nut tightening method and spring washer by three-dimensional finite element analysis

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ABSTRACT

The mechanisms of loosening-resistance components are investigated within the framework of the three-dimensional finite element method (FEM). In this paper, we have evaluated the ability of double-nut tightening method (DN) and spring washer (SW) to resist self-loosening due to transverse loading. We have found that if locking state is properly achieved in the tightening process, DN shows significant loosening resistance regardless of the magnitude of locking force. It was observed in this case that thread surface on the upper nut retains stuck state even if bearing-surface undergoes complete slip. However, if the locking process is not performed properly, the ability to resist loosening completely disappears. On the other hand, it is shown that SW accelerates loosening rotation of nut. The stuck area on the contact surfaces is reduced to two corner edges of the SW and the rotational force around these edges thus drastically leads to loosening before complete bearing-surface slip.

1. Introduction

Bolted joints are widely used in mechanical structures due to the joints' ease of disassembly for maintenance and their relatively low cost. However, vibration-induced loosening due to dynamic loading has remained unsolved, and fatal accidents due to joint loosening still frequently take place every year in Japan. As a response to these problems, numerous kinds of loosening-resistance components have been developed and used. Double-nut tightening method is a classical one. It is well-known that the correct tightening procedure is necessary to bring out its potential performance. Although washers such as plain washers and spring washers also have been used in many industries in attempts to resist bolt loosening, it has been shown experimentally that their effect on preventing loosening rotation does not appear in every case [1–4].

Three-dimensional finite element models considering the helical profile specific to threads can represent the loosening of bolted joint. In previous work [5], the authors performed FE analysis on bolt loosening due to external loading perpendicular to the bolt axis (transverse loading) and obtained close qualitative agreement with the experimental results reported by Yamamoto and Kasei [6]. In addition, we investigated the mechanisms of a self-loosening prior to the complete bearing-surface slip (loosening rotation due to micro bearing-surface slip) suggested by Kasei [7] and Pai and Hess [8] and showed that a small degree of loosening occurs when the transverse load reaches about 50–60% of that of bearing-surface slip [9]. This modeling method using FEM enables us to examine the effects of loosening-resistance components on the prevention of loosening.

In the present study, the effects of double-nut tightening method (DN) and a spring washer (SW) on loosening resistance were investigated using the three-dimensional finite element modeling method. We focus on the loosening due to both complete and micro bearing-surface slips in this study.

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2. Analysis method

2.1. Overview of finite element model

Historically, Junker's loosening apparatus, in which roller bearings are placed between a movable top plate and a fixed plate to minimize sliding friction, has been widely used to observe loosening behavior [10]. In the present study, we model part of Junker's loosening apparatus which includes a bolted joint employing a loosening-resistance component, and examine the effect by observing the progress of loosening rotation and the decrease in bolt tension. The FEM model for reproducing Junker's loosening apparatus is shown in Fig. 1. We use a general-purpose finite element method software, ANSYS 10.0. Details of modeling are shown in [5]. The model reproduces a helical profile of the internal and external threads, but detailed shapes such as the curvature of the bottom of thread are not taken into account since a detailed evaluation of stress distribution is beyond the scope of the present study. The bolt–nut size is M10, and the grade and position of the crossover is 6H/6g (expressed in terms of the Japanese Industrial Standards). Because the friction between the movable top plate and the fixed plate can be ignored in the loosening apparatus, only part of the movable plate is modeled, and the displacement of the bottom of the movable plate in the vertical (y) direction is fixed.

Contact elements are used to incorporate contact behavior at all the interfaces such as between the mating threads, under the nut bearing-surface, and so on. In this model created using ANSYS, contact element pairs TARGE170 and CONTA174, which realizes surface–surface contact between three-dimensional objects and can deal with the Coulomb friction, are used. The pure penalty method is employed as a contact algorithm. To reduce calculation costs, bolt tension is generated by allowing initial interference between the movable plate and the lower nut (in the case of a DN joint), or between the movable plate and the washer (in the case of a SW joint). The transverse load is applied to the end surface of the movable plate as constrained displacement or force. A displacement-constrained boundary condition is employed in order to observe the loosening due to complete bearing-surface slip, while a force-constrained boundary condition is employed to observe the loosening due to micro bearing-surface slip. The Young's modulus and Poisson's ratio for all the components (bolt, nut, SW, and movable top plate) are 205 GPa and 0.3, respectively. The friction coefficient of the contact surfaces is set to 0.15. The performed FEM analysis is quasi-static and elastic. Geometric nonlinearities are taken into account.

Detailed analysis conditions for each case of DN and SW joints are explained in the sections below. For each case, a progress of loosening is compared to the case of a standard joint. The progress in loosening is evaluated from two viewpoints. One is the relative rotation angle of nut with respect to bolt (loosening rotation angle). The other is the decrease in bolt tension.

2.2. Double-nut (DN) joint

Two methods are well-known to set up the double-nut joint, that is, the upper nut rotation method and the lower nut reverse rotation method. This study is intended for the latter. After the processes of lower nut reverse rotation method, thread of the lower nut comes in contact on the surface opposite to the one that is in contact in the standard tightening process. This state is called as "locking state", and the force produced on the thread of lower nut is called as locking force. The details of FEM analysis for the tightening process are shown elsewhere [11]. Here, in order to reduce calculation costs, bolt tension and locking force are generated by using an initial interference scheme. The bolt tension and the locking force are generated by the interference between the movable plate and the lower nut and that between the upper nut and the lower

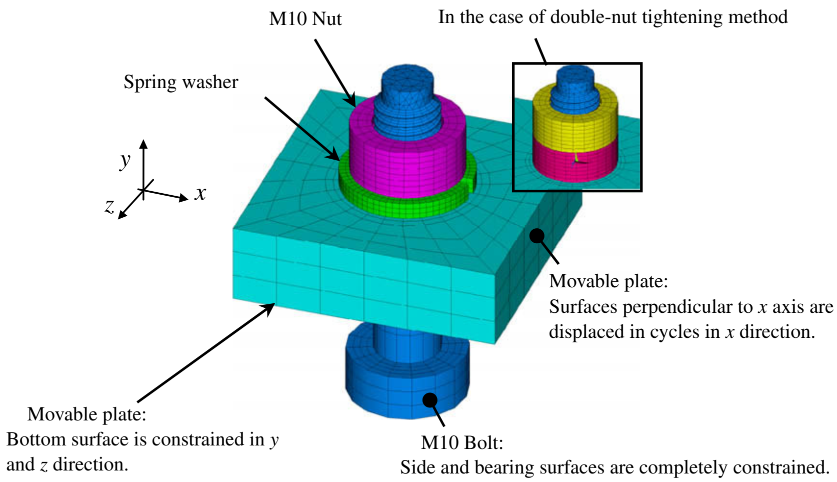

Fig. 1. Finite element model for loosening analysis of bolted joint.