Proposal of Loosening-Proof Nuts*
Stress Distribution in Bolted Joint and Pressure
Distribution on Bearing Surface of Nut

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The stress distribution in a bolted joint and the pressure distribution on the bearing surface of a nut have been examined by a three-dimensional photoelastic experiment. The experiment shows that the stress distribution in a bolted joint is axially unsymmetric, because the screw part has an axisymmetrical shape. The pressure distribution on the bearing surface of a nut has an unsymmetry corresponding to that stated above. It can be seen that the screw part of the bolted joint is acted upon by a bending moment due to the unsymmetric pressure distribution. In the case of a nut having some part without thread, the peripheral portion of the nut can bear the load pressure which has uniform distribution in all directions of circular angles.

Key Words : Fixing Element, Loosening-Proof Nut, Bolted Joint,
 Pressure Distribution on Bearing Surface of Nut

1. Introduction

Generally, as a means of joining plural parts a screw joint is widely used. But this screw joint can be loosened during use, and this loosening may cause a serious trouble or even an accident. The loosening of a screw is classified as follows.

(1) When there is a small unevenness or a fault in shape on a contact surface, such as those which can occur on the bearing surface of a nut which is produced in the working of a material after the clamping of a screw through the influence of external force, partial plastic deformation may proceed and the contact surface may be leveled. This is the character of looseness occurring without accompanying a restituting rotation. It is caused by fatigue of uneven spots on the contact surface, minute abrasion on the contact surface or heat.

(2) There is also a looseness accompanying a restituting rotation of a nut, caused by vibration or impulsive external force. The preventive measures against the former are comparatively simple but those against the latter are not and the latter kind of looseness is often found dangerous. Thus many kinds of preventive measures against this kind of looseness have been proposed.

But most of them have the inconvenience of requiring some anti-loosening parts and their constitution is complicated.

The cause of the looseness which comes about due to the restituting rotation of a nut is considered⁽¹⁾ to lie in the fact that when the pressure on the bearing surface has an unsymmetrical distribution, if a vibration at right angles to the axis is applied, the nut receives the force of restituting rotation. The unsymmetrical distribution of pressures on the bearing surface of a nut is caused not only by manufacturing error in the bearing surface or of the surface of the

parts to be joined, but it has also been confirmed and reported by us⁽²⁾⁽³⁾ previously that the stress condition of a threaded part shows an unsymmetrical character based on the unsymmetrical shape about its axis. A spiral shape, due to its function and the pressure distribution produced on the bearing surface of a nut also shows an unsymmetrical character about an axis due to the above-mentioned fact.

Even if, however, accurately the bolt, nut and the bearing surface of the parts to be joined are made, the pressure distribution of the bearing surface cannot be symmetrical, and there is the possibility that a rotating force could act on the nut and looseness is brought about due to vibration etc. Even when vibration perpendicular to the axis does not have the force of a rotating component, the parallel displacement to the axis is repeated as a reciprocating motion and the loosening can occur.⁽⁴⁾ By the fluctuation of the load in the axial direction, the nut can make a rotation in restituting direction, though it might be only a very small amount.⁽⁵⁾ The impact perpendicular to the axis⁽⁶⁾ and the impact parallel to the axis may cause a loosening reaction.⁽⁷⁾⁽⁸⁾

Considering the facts as mentioned above, in this study we aimed at obtaining a loosening-proof nut of a simple construction in which nut itself has a loosening-proof function.

According to this concept, any special anti-loosening parts would not be necessary and the cause of loosening would be eliminated. At first we confirmed the existence of the problematic unsymmetric-character of pressure distribution on the bearing surface of a nut, and tried to make the unsymmetrical character symmetrical, to eliminate the cause of the loosening of a nut, and also to establish a desirable increase in the friction moment. Moreover the development of a loosening-proof nut which is also effective for the loosening in which restituting rotation is not made was attempted in a three-dimensional photoelastic experiment. As a result, the shape of a nut which could be expected to be effective for the purpose was developed.

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2. Method of Experiment

In the bolt-nut joint, in the stress distribution of the threaded part and in the pressure distribution on the bearing surface, the difference of stress distribution according to the difference in starting positions of threading was studied. Namely, the difference was studied between the case in which threading starts corresponding to a corner of the hexagonal nut, and the one in which threading starts corresponding to a side of the hexagon. A study was then carried out providing a cylinder shaped part (hereinafter referred to as a skirt), with a diameter equivalent to the circumscribed circle of the hexagon, on the side of the bearing surface of the nut, as to how the pressure distribution was changed, that is, whether a symmetrical distribution of pressure was obtained or not. Moreover, the case in which the skirt was made in a hexagonal form was also studied.

2.1 Model material, shapes of the bolt, nut and foundation

Epoxy resin was used as the model material, Alardite B and hardner (HT 901) were mixed to a weight ratio of 4:1. Considering the shapes and dimensions of the bolt, nut and the foundation which were used in the experiment, we made rather large blocks with, by pouring the mixed material into molds, and used them for experiment.

The shapes and dimensions of the bolt, nut and foundation used for the test are shown in Figs. 1 to 4.

The shape of the thread was made to specification M42, pitch was set rather large at 5 mm, and the roundness of the bottom of thread was made 0.5 mm.

2.2 Load condition and slicing

The bolt and nut coupled load test device used is shown in Fig. 5.

In the case of the elongation and the deformation of test pieces at the test temperature, the load was adjusted to a simple tensile one.

Slicing was carried out, considering the unsymmetrical character about the axis of a screw shape. The starting position of threading was established as the starting point shown in Fig. 6, with intervals of 45° at eight points on the periphery of the nut.

The foundation was also sliced at the same relative positions as the nut. In the case of the bolt, because of its size slicing was made at corresponding positions to those of the nut slice positions 1 (0°), 3 (90°), 5 (180°), 7 (270°). The thickness of a slice was 3 mm.

3. Results of experiment and consideration

The stress distribution conditions at each slice position of the bolt, nut and foundation are shown in Fig. 7.

As shown in Fig. 7 it is clear that the stress distributing conditions of the nut and the bolt differ in slice positions. This shows the unsymmetric distribution of stresses about the axis. Observing the pressure distribution conditions on the bearing surface in the case of (N): the coupling made

Fig. 1 Bolt

Fig. 2 Hexagonal nut

Fig. 3 Nut with skirt

Fig. 4 Foundation

Fig. 5 Load condition of the bolted joint model

1: Starting position of threading

Fig. 6 Slice position

by a hexagonal nut, and in the case of (NS): the coupling made by a nut with skirt, it is seen that in the case of (N) the magnitude of the pressure on the bearing surface at the inner part of the nut and that at the outer part differ slice by slice. Namely, this is an unsymmetric distribution (specific numerical values shall be given later).

In the case of (NS): utilizing a devised nut with skirt, the pressure on the bearing surface at the inner part of the nut was reduced to almost zero. While the pressure on the bearing surface was concentrated at the outer part the pressure of each slice showed an almost equal value. On account of this measure of the skirt being fixed on the nut the pressure distribution on the bearing surface was made symmetrical. Thus the cause of loosening due to unsymmetrical distribution of pressures on the bearing surface was eliminated. At the same time it was found that the measure also had a function of concentrating the pressure on the bearing surface of the skirt on the outer side of the bearing surface. This also resulted in a desirable increase in the bearing surface friction moment, and it was confirmed that the nut was positively effective for preventing the restituting rotation. It was also found that this measure is effective for preventing the nut from being overtightened by an external force.

The symmetrical distribution of the bearing surface pressures obtained, brought about a uniformity in the tightening force of screws. Moreover the skirt section performs a function of absorbing the rotating force of the material to be joined, and to absorb the loosening action when the parallel movement is repeated as a reciprocating motion or application of impact. When a nut is tightened, the construction of the skirt section has a compressive effect and at the same time the bolt can be elongated corresponding to the length of the axial part, equivalent to the height of the skirt. It means that this measure brings about the preventive effect of loosening without an accompanying nut rotation.

The external shape of the skirt section is not necessarily a cylinder form, but can be the same as the external shape of a nut. Two pitches of the thread (two threads) are sufficient for establishing a symmetrical distribution for the height of the skirt and for this increasing the outer peripheral bearing surface pressure. This was confirmed from the results of the experiment as shown in Fig. 7 (NS)₆. As for the increase in the bearing surface friction moment, the circumference cylinder of the hexagon is better.

By the construction of the skirt section, the thread coupling part becomes higher than the bearing surface by the height of the skirt, so that if the height of the skirt section plus the height of threaded part are made equal to the height of a normal nut (broken line in Fig. 7 (NS)₆) the load sharing of threaded part on the upper part of the nut is increased, and it is expected that the role of load would be reasonably played.

In this form the inner diameter part of the skirt section is useful to facilitate positioning in the fixing work. The use of a washer is considered unnecessary.

In Figs. 8 to 12 the stress values at each slice position of the bolt, nut and foundation are shown.

In Figs. 8 and 9 the ordinate expresses the number of threads and the abscissa expresses the maximum stress value at the bottom of threads.

(a) (N): Hexagonal nut coupling

(b) (NS): Coupling of a nut with a cylinder type skirt ($H_s=H_t/2$)

(c) (NS)₆: Coupling by a nut with a hexagonal type skirt ($H_s=2p$)

Fig. 7 Stress distributing conditions at each slice position of bolt, nut and foundation

It is clearly observed in this figure that the stress distributing conditions of the threaded part of a bolt differ in the slice position. Thus an unsymmetrical distribution about the axis is shown. The maximum stress of the threaded part appears at the first thread bottom, counting from the bearing surface of the nut coupling part and when the starting position of threading corresponds to the center of a side of the hexagon it is found that the maximum stress appears at $\theta=135^\circ$ to 225° counterclockwise from the starting position of threading.

From this data the position at which a crack caused by fatigue occurs can be deduced. The maximum stress which occurs at the thread bottom of a nut about each slice is shown in Figs. 10 and 11.

Fig. 8 Maximum stress distribution of bolt threads coupling hexagonal nut

Fig. 9 Maximum stress distribution at the bottom of threads of a bolt coupling by a nut with skirt

Fig. 10 Maximum stress distribution at the bottom of threads of a hexagonal nut

Fig. 11 Maximum stress distribution at the bottom of threads of a nut with skirt

Slices were taken at intervals of 45° but in these figures only slices Nos. 1, 3, 5, 7 are shown. The stress distribution of the threaded part of a nut, in the case of a hexagonal nut, corresponds to the threaded part of a bolt, but in the case of a nut with the skirt the correspondence between the bolt and the nut is not seen.

The reason, we can consider, is that with the existence of the skirt the rigidity of the nut is relieved, and between the coupling threads of the bolt and the nut a slipping can occur.

Figure 12 shows pressure distribution on the bearing surface.

In the case of an ordinary hexagonal nut, the maximum contact pressure condition is comparable between inner side and outer side of a nut, but in the case of a nut with skirt on the inner side, the bearing surface pressure is almost zero and is concentrated

on the outer peripheral part. Moreover in what was considered the most desirable phenomenon of pressure distribution, pressure values at the outer periphery show almost an identical value. This is because at the inner peripheral part stress acts from the point which deviates from the bearing surface by the height of the skirt to the top side surface and furthermore, the thread surface itself has the inclination of half an angle of the thread, so that the load applied on the thread surface is directed outwards of the axial line.

4. Conclusions

It was made clear that in the from of ordinary nuts the cause of the occurrence of

looseness by restituting rotation of nuts is in the unsymmetrical shape of nuts about an axis, which comes from the fact that nuts are made helical for reason of their function. Furthermore, to work out the form of a loosening-proof nut the bolted joint and pressure distributing conditions on the bearing surface were investigated by a three-dimensional photoelastic experiment.

The following are the summary of the investigation.

(1) It was confirmed that the stress distribution condition of the bolted joint presents an unsymmetrical character based on the helical shape of the threaded part which for reason of its function naturally is made unsymmetrical about its axis.

(1-a) The maximum stress in the threaded part appears at the first thread from the bottom, counting from the bearing surface of the coupling nut. When the starting position of threading corresponds to the center of a side of the hexagon it is found that the maximum stress appears at $\theta = 135^\circ$ to 225° , counterclockwise from the starting position of threading. From these data the position at which a crack can be presumed to be caused by fatigue.

(1-b) The load bearings of a bolt and a nut do not coincide with each other because of the helical construction of a screw, a construction unavoidable from its functional point of view, and also a bolt and nut coupling, influenced by the incomplete threading part of a nut.

(2) The degree of stress concentration is large at the bottom of the threading part of a bolt close to the bearing surface of nut coupling part. The load bearing becomes largest between threads No.1 and No.2, but from this point towards the top it rapidly decreases hyperbolically.

(3) The nut with skirt of this form has a skirt section in which the bearing surface is scraped off to the depth of two thread pitches. It brings about a symmetric pressure distribution on the bearing surface and moreover it is confirmed that the pressure is concentrated on the outer peripheral part.

It was made clear that this phenomenon eliminated the cause of loosening of a nut and furthermore caused a desirable increase in the friction moment on the bearing surface. It also prevented the loosening of a nut caused by its rotation. An increase in tightening allowance is obtained by the construction of the skirt section. Thus this construction is effective for preventing loosening without an accompanying nut rotation.

The inner diameter part (central hole) of the skirt is useful for facilitating the positioning in the fixing work. The use of general type washers is not necessary and the saving of material can be realized.

Fig. 12 Pressure distribution on the bearing surface

Summarizing the above, a nut with a skirt is reasonable from the dynamical point of view and its construction is so simple that it has, itself, a loosening-proof function. The author proposes this nut with skirt*¹ as an ideal nut.

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*¹ Patent pending