Identification of real pitch difference in bolt-nut connection to improve anti-loosening performance and fatigue strength

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Abstract. In a wide industrial field, the bolt-nut joint is unitized as an important machine element and widely used. To ensure the safety of the structure and reduce cost, low-cost bolt-nut connections with good anti-loosening performance and high fatigue strength are always required. In our previous papers, the effect of pitch difference between a bolt and nut was studied. Under a small pitch difference, anti-loosening performance is not enough. Under a large pitch difference, fatigue strength is not good. Therefore, in order to improve both anti-fatigue and anti-loose performance, the choice of suitable pitch difference is very important although the manufacturing errors always appear in bolt-nut connection. Until now, the result of experiment and analysis without manufacturing error but is not match. Since even small manufacturing errors may affect anti-fatigue and anti-loose performance, in this paper how identification of real pitch difference is discussed after the pitch difference nut is produced. Also, the accuracy of the identified pitch difference is confirmed. By using the confirmed error, the machining accuracy may be improved to ensure the nut has good performance.

1. Introduction

The bolt-nut connections can be regarded as one of the most important materials joining techniques. They are widely used in various engineering fields, including aerospace, automotive and mechanical/civil engineering constructions. To ensure structures safety, high fatigue strength has been required, as well as anti-loosening performance. Many previous studies are focusing on the anti-loosening performance for newly developed bolt-nut connections [1-5], and several previous studies contribute toward improving fatigue strength [6-10]. This paper focuses on the effect of pitch difference between bolt-nut connection to improve the anti-looing performance and fatigue strength. Compared with other special nuts, pitch difference bolt-nuts can be manufactured with lower cost to have good anti-loosening performance and high fatigue strength. Here, several pitch differences between the bolt and nut are designed as shown in figure 1 where the nut pitch is larger than the bolt pitch. When screwing a nut with pitch difference, torque is necessary before the nut contact with the clamped body. This torque in this screwing process is called prevailing torque [8,11] as shown in figure 2.

In this paper, a three-dimensional FEM simulation will be performed to calculate the maximum prevailing torque when the pitch difference nut is screwed. Then, the effect of pitch difference on the prevailing torque will be discussed. In this experimental study, after the pitch difference nut is
manufactured, the accuracy of the pitch difference will be confirmed. By confirming correct pitch difference, the previous discussions [8] regarding anti-loosening and high fatigue strength can be more reliable. First, identify the nut rotating position where the prevailing torque appears during the nut screwing into bolt. This position can also be found theoretically by using axi-symmetric modelling of bolt-nut connection and also by using 3D modelling. In addition, the prevailing torque also can be focused to confirm the real pitch difference. Experimentally obtained $T_p^{\text{real}}$ using $\alpha$ and analytically obtained $T_p^{\text{FEM}}$ can be compared to confirm the corrected pitch difference.

![Figure 1](image1.png) Contact status when the prevailing torque appears between bolt and nut.  
![Figure 2](image2.png) Schematic illustration for screwing process.

2. Identification of real pitch difference $\alpha$ from the nut contact position $n_c$

2.1. Specimen geometry

In this study, the Japanese Industrial Standard (JIS) M10 bolt-nut connections with strength grade 8.8 are employed. The bolt material is chromium molybdenum steel SCM435, and the nut material is medium carbon steel S45C quenched and tempered. Table 1 shows material properties. The standard M10 bolt-nut connection has the same pitch dimension of 1500 μm. Here, the nut pitch is assumed to be equal or slightly larger than the bolt pitch as shown in figure 3[7-9]. Several types of pitch differences, namely $\alpha=20\mu m$, $\alpha=25\mu m$, $\alpha=30\mu m$, $\alpha=35\mu m$, $\alpha=40\mu m$ and $\alpha=45\mu m$ are considered in this study. In addition, the horizontal clearance between bolt and nut $C_x=60mm$. Figure 4 is a cross-sectional photograph of the M16 nut illustrating chamfer, which is usually used for standard nuts larger than M16 (JIS).

![Figure 3](image3.png) Pitch difference and clearance between bolt and nut threads.(unit:μm) in M10.  
![Figure 4](image4.png) Chamfer usually used for standard nuts larger than M6(JIS).

2.2. How to obtain nut contact position $n_c^{\text{theory}}$, $n_c^{\text{exp}}$ and prevailing torque $T_p^{\text{exp}}$

Figure 5 is a schematic illustration of nut screwing process. In figure 5, position A is the one where the nut screwing starts and position B is the one where prevailing torque appears. Notations $n_c^{\text{theory}}$ and $n_c^{\text{exp}}$ can be defined as the number of nut rotation from A to B obtained theoretically and experimentally. Position C is in the one when prevailing torque is increasing, position D is the one
where the nut is completely screwing into the bolt, and position E is the one where to continue to screw the nut for few turns after all the thread of nut is screwed into the bolt. Notation $T_{p}^{Exp}$ denotes the prevailing torque during the nut screwing process.

In figure 5, the red arrow shows the contact force between bolt and nut threads during the screwing process. At position B in figure 5, the threads contact starts. As shown in figure 1, $\delta$ is defined as the distance where the contact takes place. The following Equations (1) and (2) can be obtained from the thread geometry.

$$n_{c}^{Theory} = 2C_{x}, C_{x} = \frac{C_{y}}{\tan \theta} \quad (1)$$

$$\delta = n_{c}^{Theory} p \quad (2)$$

To obtain $n_{c}^{Exp}$ during screwing the nut in the experiment, a dial type torque wrench whose product name TOHNICHI DB 50N is used as shown in figure 6. Then, $n_{c}^{Exp}$ is defined as the position when $T_{p}^{Exp} = 0.1N\text{m}$ appears. To obtain the relation between $T_{p}^{Exp}$ and the nut rotation angle $\theta$ experimentally, head of bolt fixed, $T_{p}^{Exp}$ is measured to rotate the nut by using torque wrench at the interval of 45 degree. By considering both bolt and nut always have incomplete threads at the locations where the threads start, these thread starting positions are adjusted at position A as shown in figure 5 in this experiment. Then, this position is defined as $\theta = 0$. This screwing experiment is conducted under lubrication surface state of Molybdenum disulfide grease spray PRO (manufactured by Azette Co., Ltd.) figure 7 shows $T_{p}^{Exp}$ measured for M10 with $\alpha=35\mu\text{m}$.

2.3. Relationship between $n_{c}^{Theory}$ and $\alpha$

Figure 8 shows the relationship between $n_{c}^{Theory}$ and pitch difference $\alpha$. The blue line shows the result of Equation (1) and the red line shows the result of 3D CAD modelling. Figure 8 shows the blue line and the red line coincide with each other within 5%. Therefore it may be concluded that Equation (1) can estimate $n_{c}^{Theory}$ accurately without considering 3D chamfer geometry. Since the result of Equation (1) is almost consistent with 3D CAD model result, Equation (1) can be used as the theoretical result.

Figure 9 shows the result of $n_{c}^{Exp}$ as green line. As shown in figure 9, $n_{c}^{Exp}$ and $n_{c}^{Theory}$ have some difference. This is because the bolt-nut connection experimentally used has some manufacturing error regarding the pitch difference $\alpha$. As shown in figure 9, for example, the result of $\alpha = 20\mu\text{m}$ should be regarded as $\alpha = 30\mu\text{m}$ by considering $n_{c}^{Exp} = 4.25$. Therefore, the black line can be drawn as the result of $n_{c}^{real}$ by correcting $\alpha$.

![Figure 5. Screwing process of nut.](image)
3. Confirmation of real pitch difference by calculating $T_p^{FEM}$

3.1. How to obtain $T_p^{FEM}$

From section 2, how to obtain real pitch difference $\alpha$ has been discussed in terms of $n_c^{Theory}$. To confirm the corrected value of $\alpha$, in this section the prevailing torque $T_p^{exp}$ will be confirmed experimentally. A precise three-dimensional FEM model as shown in figure 10 is used for finite element analysis. To simplify the calculation, the hexagonal part of the bolt and the nut shapes are replaced by two cylinders. Especially, the helical thread of the bolt and nut were subdivided into smaller elements compared with other parts [4]. Contact types and material non-linearity are considered in the analysis. Boundary conditions are set as follows, one side of the bolt is fixed, a small screwing angel is applied on the side surface of the nut as shown in figure 11. The connecting method of the nut and the bolt is frictional contact. Then, $T_p^{FEM}$ is calculated by FEM simulation.
3.2. Analytical result of $T_p^{FEM}$

Figure 12 shows that the relation between prevailing torque $T_p^{FEM}$ and the nut rotation angle $\theta$. When the nut screwing starts from position A in figure 5, the prevailing torque $T_p^{FEM}$ increases from $T_p = 0$. With increasing the prevailing torque $T_p^{FEM}$, the bolt is twisted with a small torsion angle. The prevailing torque $T_p(\alpha)$ can be defined as the saturated value in figure 12. The saturated point $T_p(\alpha)$ in figure 12 is proportional to the nut rotation angle $\theta$ as shown in the red dotted line.

Figure 13 shows the relationship between the prevailing torque and pitch difference $\alpha$. The red line shows the result of $T_p^{FEM}$. The green line shows the result of $T_p^{Exp}$, which does not coincide with result of $T_p^{FEM}$. By collecting $\alpha$ as explained in figure 13, the black line show the result of $T_p^{Real}$. For example, the result of $T_p^{Exp}$ when $\alpha = 20\mu m$ should be regarded as $T_p^{Real}$ when $\alpha = 30\mu m$ by using $n_c^{Real}$. It is seen that $T_p^{Real}$ coincide with $T_p^{FEM}$ within a few percent error. It is confirmed that correct $\alpha$ can be obtained in terms of the prevailing torque.

![Figure 12. Prevailing torque $T_p^{FEM}(\alpha)$ in M10.](image)

![Figure 13. Comparison of prevailing torque $T_p^{Exp}(\alpha)$, $T_p^{Real}(\alpha)$ and $T_p^{FEM}(\alpha)$ in M10.](image)

4. Conclusion

1. The nut contact position $n_c^{Theory}$ can be obtained by using Equation (1) assuming axi-symmetric geometry. Since the results of Equation (1) coincides with the results of 3D CAD model considering nut chamfering, the nut chamfer geometry does not affect the contact position very largely.

2. Since bolt-nut connections have some manufacturing error, the real pitch difference can be obtained from the comparison between the experimentally obtained the contact position $n_c^{Exp}$ and analytically obtained $n_c^{Theory}$. The difference can be regarded as the pitch difference error.

3. To confirm the corrected value of the pitch difference, the prevailing torque was confirmed in the experiment. By using the corrected pitch difference, the obtained $T_p^{Real}$ relation coincides with $T_p^{FEM}$ obtained by FEM simulation.

4. In the future, this method is used for calculating the real pitch difference of nuts and reflects the result of experiment considered manufacturing error.

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