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# Research on Anti-loosening Technology of Transmission Line Bolts

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**Abstract.** Transmission lines are affected by the natural environment for a long time, and bolts are prone to frequent vibration, resulting in loosening or falling off. In this paper, the loose mechanism of transmission line threaded connection is analysed, and the transverse vibration comparative test of bolt locking method is carried out. A new type of locking nut has been developed, which has good locking performance and convenient installation. According to different operating environments, the principle of differential bolt locking is proposed.

## 1. Introduction

Loosening of bolts is a long-standing pain point in transmission lines, especially in region where bolts are prone to loosening such as galloping, strong wind, and ice-shedding. In 2021, there are more than 230,000 base towers in China to carry out the bolt tightening operation, and the high-altitude operation poses great personal safety hazards and high operation and maintenance costs. At present, the bolts of transmission towers mainly adopt anti-loosening methods such as spring washers, fastening nuts, double nuts, etc. The anti-loosening effect is greatly affected by the installation quality [2], and the anti-loosening durability is insufficient.

In the relevant standards for fasteners in the power industry, the technical requirements for locking nuts are currently not included, which restricts the improvement of the anti-loosening level of transmission line bolts. This paper analyzes the current transmission line bolt loosening mechanism, introduces a new type of transmission line anti-loosening nut, conducts a lateral vibration comparison test of anti-loosening performance, and puts forward differentiated anti-loosening suggestions for transmission line bolts.

## 2. Current status of bolt loosening in transmission lines

The threaded connection generally adopts a single-line common thread, and the thread lift angle is less than the equivalent friction angle of the screw pair, so the threaded connection meets the self-locking requirements. In addition, the friction force on the supporting surfaces such as the nut and the bolt head after tightening also has an anti-loosening effect, so the threaded connection will not automatically loosen when the static load and working temperature are small.

However, in the case of shock, vibration or variable load, or large temperature changes, the friction between the screw pairs may decrease or disappear instantaneously. After this phenomenon is repeated many times, the connection will be loosened [3-5]. The loosening of bolts results in a significant drop in connection strength, resulting in serious accidents such as missing tower members, connection failures, and structural damage. At the same time, due to the lack of automatic monitoring methods for bolt loosening, it is difficult to eliminate the hidden danger of bolt loosening in time, which directly threatens the safety of power grid operation.

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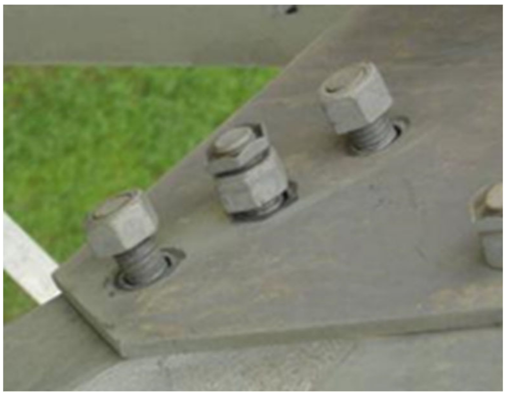


Figure 1. Loosening and falling off of transmission tower bolts.

The transmission line defect record table of each provincial company from January 2015 to April 2020 derived from the PMS system of SGCC shows that the proportion of bolt loosening defects in strong wind and galloping region exceeds 15%. Table 1 shows that the proportion of bolt loosening is relatively high provincial power company statistics.

Table 1. Statistics on loose bolts of transmission towers.

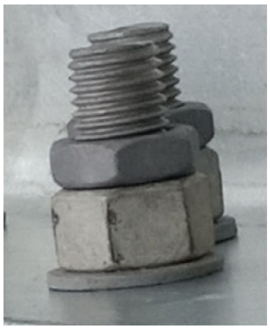
| Provincial power company | Number of tower defects | Number of loose bolts | Bolt loose ratio |
|---|---|---|---|
| Tibet Electric Power Co. | 1647 | 315 | 19.1% |
| Heilongjiang Electric Power Co. | 10840 | 1920 | 17.7% |
| Liaoning Electric Power Co. | 16399 | 2602 | 15.9% |
| Xinjiang Electric Power Co. | 44669 | 5410 | 12.1% |
| Shandong Electric Power Co. | 12561 | 1134 | 9.0% |
| Nei monggol Electric Power Co. | 34876 | 3064 | 8.8% |
| Jiangsu Electric Power Co. | 4266 | 353 | 8.3% |
| Jilin Electric Power Co. | 35554 | 2799 | 7.9% |
| Shanxi Electric Power Co. | 29492 | 2193 | 7.4% |
| Hebei Electric Power Co. | 11532 | 828 | 7.2% |

## 3. Commonly used bolt anti-loosening methods for transmission lines

### 3.1 Anti-loosening method of transmission tower bolts

The essence of the bolted connection is to prevent the relative movement between the bolt and the nut. There are many different kinds of anti-loosening bolts, nuts, gaskets and other anti-loosening types that are used in different industries. However, due to the characteristics of transmission line processing, installation, and field operation, and considering the economy and installation convenience, the current transmission line mainly use spring washers, fastening nuts, double nuts to fasten bolts.

(a)Spring washer (b)Tightening nut



(c) Double nuts (d) Thin nut

Figure 2. Anti-loosening methods for transmission lines.

The above-mentioned bolt anti-loosening methods are all friction-proof and need to ensure a certain bolt clamp force. However, due to the inability to ensure that the construction tightening torque of each bolt reaches the expected value during bolt installation, as well as the deformation of the bolt connection surface and long-term vibration, it is easy to cause the reduction or even disappearance of the bolt preload. The weakening or even disappearance of the clamp force of the bolted connection leads to the loosening of the bolts, mainly in the following situations:

(1) Creep occurs in the screw thread of bolted connection: the common problems of bolted connection, including thread plastic deformation and bolt rebound torque.

(2)Looseness caused by the collapse of the bearing surface: including the gap of multi-layer connectors, the gap of bolt holes, and the corrosion of the galvanized layer.

(3) Long-term exposure to vibration loads is the main cause of bolt loosening: including continuous and stable strong wind, galloping, and ice-shedding.

### 3.2 Bolt tightening torque

Check the standards for the design and construction of transmission lines, the relevant provisions of bolt tightening torque[6-7], the bolt tightening torque of each standard is slightly different, and the installation torque is mainly given according to the shear and tension bolts,

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respectively. Table 2 only contains the installation torques of M16, M20, and M24 bolts that are most commonly used in transmission lines.

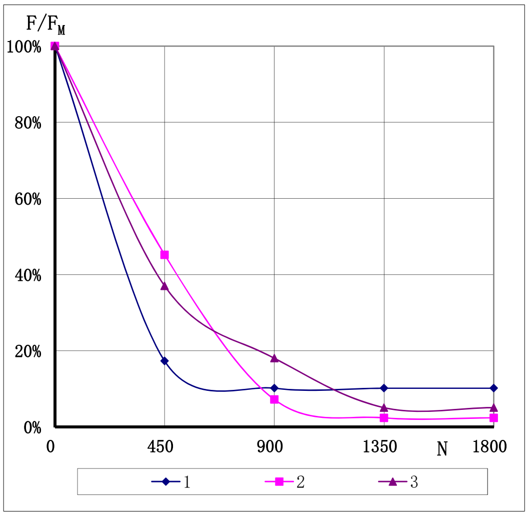
For double nuts, the installation torque of the inner nut is implemented according to the standard, while the torque of the outer nut is mostly tightened in place, which is generally required to be installed according to half of the torque of the inner nut.

Table 2. Tightening torque of transmission tower bolts.

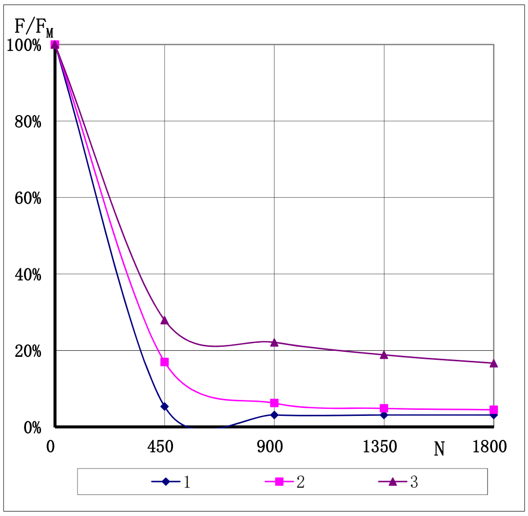
| Bolt Load Type | Bolt Size | Bolt Strength Class | Tightening Torque (N.m) |
|---|---|---|---|
| Shear (connection of tower components) | M16 | / | 80 |
| | M20 | / | 100 |
| | M24 | / | 250 |
| Tensile (steel pipe flange) | M16 | 6.8 | 80 |
| | M20 | 6.8 | 160 |
| | M24 | 6.8 | 280 |
| | M24 | 8.8 | 380 |

### 3.3 Anti-loosening performance test

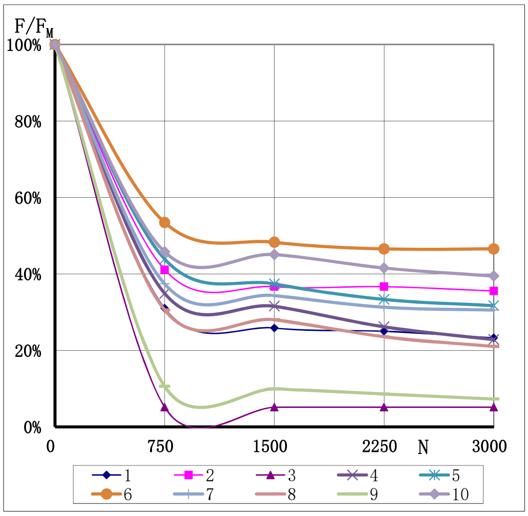
In order to test the anti-loosening performance of different anti-loosening methods, three commonly used bolts of 6.8M16, 6.8M20 and 8.8M24 on the transmission tower are selected, and the transverse vibration test is carried out according to the national standard [8]. The test conditions are as follows: the test frequency is 10Hz, and the no-load amplitude is ±1.6mm, ±1.9mm and ±2.0mm respectively. After installing the nut according to the torque required by the specification, record the initial clamp force of the bolt, and record the residual clamp force of the bolt during the test. Draw the change trend of the ratio of "residual clamp force (F) / initial clamp force ($F_M$)" of each group of test pieces. Figure 3(a)~(d) shows the trend diagram of M20 bolt. Table 3 lists the average value and standard deviation of the ratio of each group of test pieces. It can be seen from Figure 3 that the pre tightening force of bolts decreases rapidly after the vibration starts, and tends to be stable in the later stage. After a certain number of vibrations (N), the residual clamp force of bolts with different locking methods is small, and the locking performance is poor. The ratio of residual clamp force of double nut bolt is 20% - 30%, and the anti-loosening performance is relatively good.



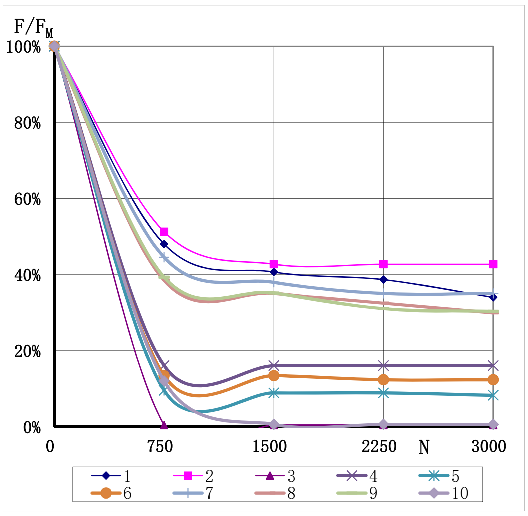
(a)Spring washer(M20)



(b)Tightening nut(M20)



(c) Double nuts(M20)



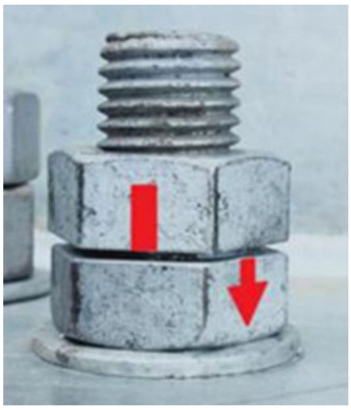

(d) Unequal thickness double nuts(M20)

Figure 3. Trend diagram of residual clamp force ratio of bolts

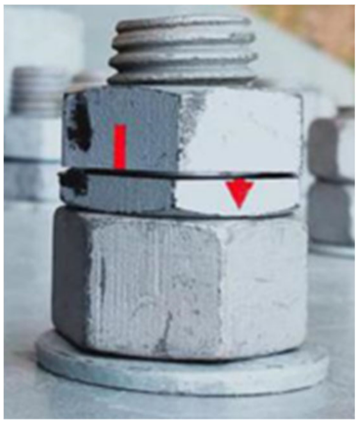
## 4. Integrated self-locking double nut

### 4.1 Basic structure

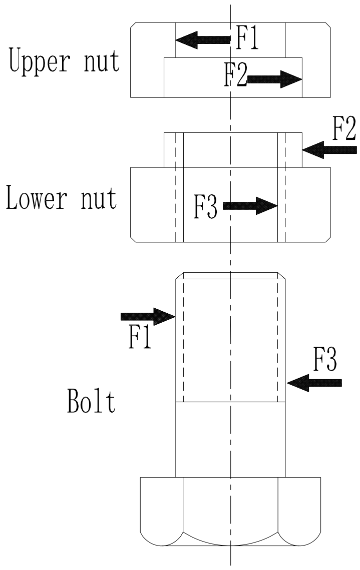
In response to the long-standing pain point problem of loose bolts in transmission lines, the project team developed an "integrated self-locking double nut", which applied the eccentric self-locking principle of the nut and the screw. Figure 4(a) is a standard height nut, suitable for new lines, Figure 4(b) is a thin nut, suitable for an in-transit line, and Figure 4(c) is a schematic diagram of the principle of the anti-loosening structure.



(a)Standard height style



(b)Thin height style




(c)Structure

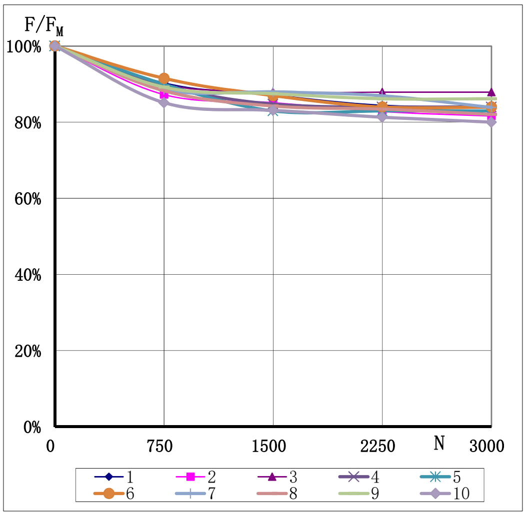
Figure 4. Integrated self-locking double nut.

In the initial state of the integrated self-locking double nut, the upper and lower nut threaded holes are concentric; when the upper nut is locked, the upper nut rotates at a certain angle (60~90 degrees) relative to the lower nut, and causes the inner hole of the upper nut thread to be eccentric with respect to the lower nut thread. The upper nut and the lower nut will generate an interactive transverse force F2, thereby generating a transverse pressure F3 on the lower nut, and then a radial friction force F3 will be generated between the lower nut and the thread of the connecting bolt, and the friction force is the locking force that prevents the nut from loosening.

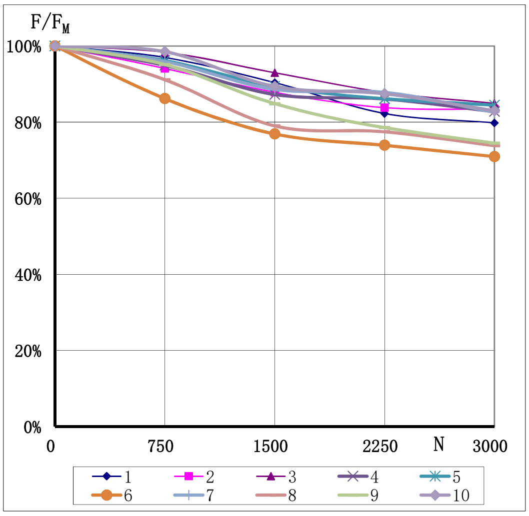
Since the lateral pressure F3 generated by the locking force is completely generated by the eccentric structure of the upper and lower double nuts, it is not affected by the installation torque. Even if the clamp force of the nut completely disappears, the lateral pressure F3 will not be weakened. Therefore, the locking force generated by the mechanical eccentric structure of the upper and lower double nuts can ensure the stability and durability of the anti-loosening performance.

### 4.2 Anti-loosening performance test

In order to evaluate the anti-loosening performance of the integrated self-locking double nut, an accelerated lateral vibration test was carried out and compared with the current anti-loosening methods of transmission lines. Figure 5 shows the change trend of the ratio of residual clamp force to initial clamp force.




(a) 6.8M20




(b) 8.8M24

Figure 5. Trend diagram of residual clamp force ratio of integrated self-locking double nut.

The lateral vibration test shows that, compared with the double nut with the best anti-loosening performance of the current transmission line [9], the "residual clamp force ratio", which reflects the anti-loosening performance index, has increased from an average of 20～30% to about 80%, which is increased by more than 2 times, and the "standard deviation" reflecting the variability of bolt anti-loosening performance is reduced from an average of more than 10% to about 5%, indicating that the anti-loosening performance is more stable.

Table 3. Comparative test of anti-loosening performance of transmission line bolts.

| No. | Bolt Type | Bolt Size | F/F$_M$ | Standard Deviation | Number of Vibrations |
|---|---|---|---|---|---|
| 1 | Spring washer | 6.8M16 | 16.7% | 19.5% | 1800 |
| | | 6.8M20 | 5.9% | 3.2% | |
| 2 | Tightening nut | 6.8M20 | 24.2% | 20.4% | 3000 |
| | | 8.8M24 | 8.1% | 6.1% | |
| 3 | Double nuts | 6.8M20 | 26.3% | 12.5% | |
| | | 8.8M24 | 30.4% | 11.8% | |
| 4 | Thin nut | 6.8M20 | 21.0% | 14.5% | |
| | | 8.8M24 | 12.3% | 11.4% | |
| 5 | Integrated self-locking double nut | 6.8M16 | 77.4% | 7.4% | |
| | | 6.8M20 | 83.7% | 2.1% | |
| | | 8.8M24 | 80.0% | 4.8% | |

## 5. Conclusion

The transmission lines are subjected to wind load for a long time, and the bolts are prone to frequent vibrations, resulting in loosening or falling off, which greatly weakens the bearing capacity of the members and reduces the overall bearing performance of the tower. Bolts should take corresponding anti-loosening methods.
Among the bolt anti-loosening methods commonly used in transmission lines at present, the anti-loosening effect of double nuts is relatively good, but the installation quality has a great influence on its anti-loosening performance, and the anti-loosening durability against long-term or strong vibration loads is still insufficient. The integrated self-locking double nut has excellent locking performance and convenient installation. It is recommended to be popularized and applied in transmission lines with high requirements for bolt locking in galloping, windy regions and no-man land.

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