THE INFLUENCE OF SELECTED SCREW-NUT PAIR ON THE VALUE OF AXIAL FORCES IN A SCREW CONNECTOR

Piotr Pawełko

Summary

This article presents the influence of selected screw nut pair on the value of axial forces present in a screw connector. The analysis concerned [1] the effect of subsequent cycles of tight fastening and loosening the nut on the value of axial force present in the screw connector and [2] the use or non-use of lubricating grease on thread surfaces and its effect on the value of axial force in the examined connector. Measurements were performed using one of the methods of fastening screw connectors to a fixed tightening torque. The study presents a measuring system used in the examination of axial forces in a screw connector, and the results of experimental research and conclusions based on the analysis of the results.

Keywords: screw connector, axial force, compressing screw connectors, experimental research

Analiza wpływu wybranych warunków współpracy pary śruba-nakrętka na wartość siły osiowej występującej w połączeniu śrubowym

Streszczenie

W artykule przedstawiono wpływ wybranych warunków współpracy pary śruba-nakrętka na wartość siły osiowej występującej w połączeniu śrubowym. Prowadzono analizę wpływu kolejnych cykli obciążenia i odciążenia nakrętki na wartość siły osiowej. W analizie uwzględniono wpływ użycia środków smarnych na powierzchniach gwintowych śruby i nakrętki na wartość siły osiowej. Pomiary prowadzono przy użyciu jednej z metod dokręcania złączy śrubowych oraz uzyskiwania momentu dokręcającego o ustalonej wartości. Opracowano układ pomiarowy do pomiaru wartości siły osiowej w połączeniu śrubowym.

Słowa kluczowe: połączenie śrubowe, siła osiowa, sprężanie połączeń śrubowych, badania doświadczalne

1. Introduction

Much attention has recently been paid to the design of computational models and computer simulations of virtual objects that would help to obtain the best possible correspondence to real objects. One of the most common

Address: Piotr PAWEŁKO, Ph.D. Eng., West Pomeranian University of Technology of Szczecin, Institute of Manufacturing Engineering, Al. Piastów 19, 70-310 Szczecin, e-mail: Piotr.Pawelko@zut.edu.pl

modelling methods is the finite-element method (FEM) [3-5], the accuracy of which depends, as in any modelling method, on the most exact description of the model, i.e. material properties, conditions and character of work, external and internal loads, etc. If parameters of such a computational model are carelessly assumed, it can result in incorrect decisions during design work with the model and also false presentation of the real object.

All of the aforementioned apply to the models of screw connectors which, in even the simplest ones, require a value of axial force in a connector. Although more precise models require the values of stiffness of connections, area of connection, etc., the determination of axial force is a basic and most crucial parameter in modelling screw connections. Its value is determined indirectly by referring to the tightening tightening torque value.

2. End-to-end screw connector

End-to-end screw connectors are divided into classes: D, E and F [6, 7]. Class D refers to unstressed connectors that can potentially be stressed. In these connectors only the ultimate limit state of the screw breaking is considered. Class E connectors are always stressed, and the ultimate limit state is determined by the screw breaking while the serviceability limit state is reflected by loss of contact. Class F connectors are also always stressed and used for dynamic stresses. The calculation of F connector limits allow only for the ultimate limit defined by the loss of contact [8-10].

These stressed and non stressed end-to-end connectors used with screws with a high strength grade are a modern connector used in the construction industry (Fig. 1). Their main component of stress is parallel to the axis of the screw.

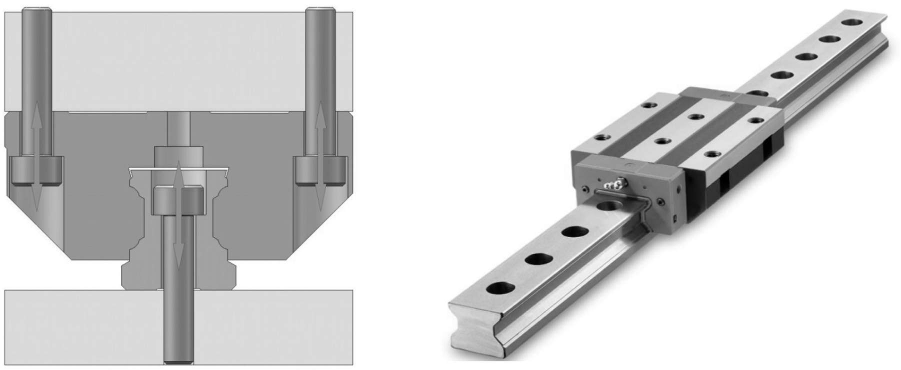

Fig. 1. The use of a screw connector in the guideway system manufactured by Mannesmann Rexroth, catalogue number 1651.25 – the assembly of rails onto the base

In this paper, an analysis involved a class E end-to-end screw connector applied in the assembly of sliding modules in guideway systems – manufactured by Mannesmann Rexroth, type 1651-25 – used for example in the the assembly of guide rails in main body elements of technological machines [11].

3. Axial force in a screw connector

The initial screw tension established in order to achieve compression of the connection is based on norms and regulations and determined according to apparent elastic limit (0.7-0.8) R_e or tensile strength limit (0.65-0.7) R_m. In Poland, the value 0.8 R_e is commonly used but ISO recommends 0.7 R_m with the same tensile strength for different classes of screws.

Initial tension force is determined by the following formula:

$$F_O = 0,7\, R_m\, A_S \tag{1}$$

where: F_O – initial tensile force, N, R_m – yield tensile strenght of the screw, MPa, A_S – the area of the screw intersection, mm^2.

According to the theory, the initial tensile force for an M6x40 screw with a strength class 12.9 as used in this experiment, should be about 16 880 N.

Friction between the threads of the screw and nut during tightening causes shank torsion and a consequent decrease in the screw's yield and tensile strength. The effect of this torsion during initial tension on a metric thread may be presented as a decrease in tensile strength of about 15% [1, 2].

Another major factor in the estimation of the safety of compressed connectors is the scatter of initial compression force values. In tightening screws with a manual dynamometric spanner, the scatter of the force of compression ranges from –20% to +15% [1, 2], which is explained by the variability of k_d, a tightening torque coefficient. This coefficient depends on the friction between the surfaces of the screw and nut threads (and other surfaces) during tightening, and is also related to different angular velocities of the spanner's rotation in the moment of reaching a given tightening torque value.

In the examined screw connector, a method of controlled mounting tightening torque was used as one of the ways of tightening end-to-end screw connectors. According to this method, the value of mounting tightening torquedepends on: the coefficient of head friction (screw head) against the washer (the surface), friction of the nut thread against the screw thread, the screw diameter and the tensile force applied:

$$M_S = k_d\, d\, F_O \tag{2}$$

where: M_S – tightening torque, Nm, k_d – tightening torque coefficient, d – screw diameter, m, F_O – initial tensile force, N.

Screws in frictional connections should be tightened with a tightening torque equal to 1.1 M_S, to make up for the influence of tension relaxation. However, the tightening torque coefficient k_d is not unequivocally defined. Various sources present different values for this coefficient (Table 1).

Table 1. Values of the tightening torque coefficient k_d

No.	Values of the tightening torque coefficient k_d
I	- from 0.11 to 0.2, depending on the smoothness of surfaces, tolerance of threads, type of grease applied - 0.18 for graphite grease - 0.14 for MoS_2 grease [1]
II	- 0.18 for high strength friction grip screws with metric threads [2]
III	- 0.18 for screws and nuts without rustproof covers and with lightly greased contact surfaces [8]
IV	- 0.18 for screws and nuts without rustproof covers. threads and contact surfaces (nuts and washers) are lightly greased [12]

The analysis of the problem shows a quite imprecise determination of axial force present in the screw connector for connections obtaining compression through tightening (screw shank torsion) and not through extension, e.g. using hydraulic heads.

4. Experimental research

For the purpose of experimental research a measuring system was designed to determine the value of axial force in a selected screw connector consisting of a screw and a nut (Fig. 2). The system reflected the real characteristics of a system consisting of a guide rail.

Besides the mechanical construction that provided an appropriate (recommended by a manufacturer) casing for the Kistler force sensor, the measuring system also consisted of an operational amplifier, Kistler 5019 B131 [13] (Fig. 3a), creating a complete measuring workstation (Fig. 3b).

The main objective of the research was to determine the value of axial force present in the an M6x40 screw connector using a given mounting tightening torque. Initial measurements were made using new and previously unused pairs of screws and nuts without any grease.

The secondary aim of this experimental research was to record axial forces in an M6x40 screw connector caused by mounting tightening torque under different frictional conditions of the screw-nut pair (without grease, copper grease, graphite grease).

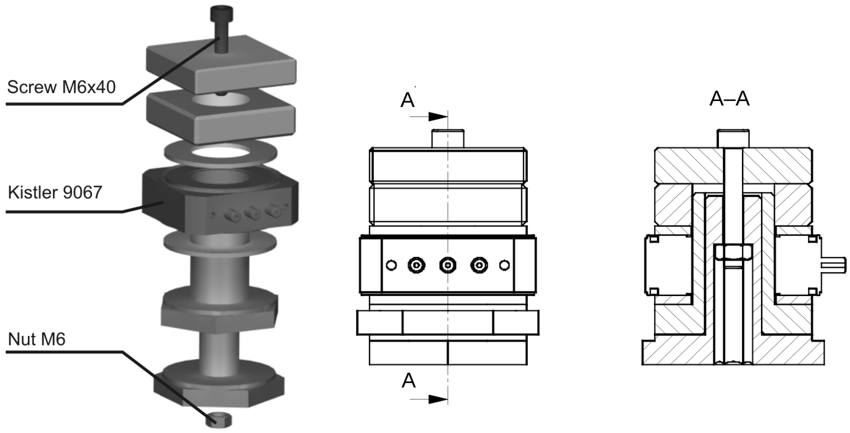

Fig. 2. Measuring system for the determination of axial force in a screw-nut connection

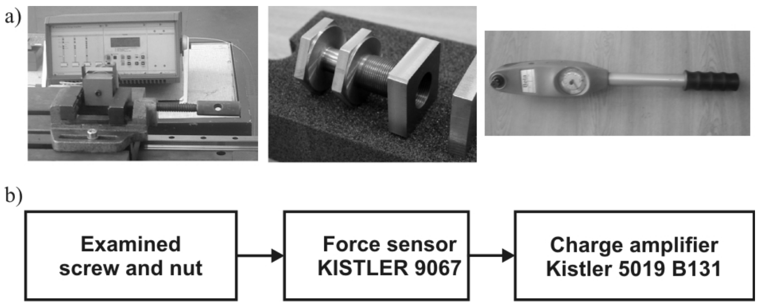

Fig. 3. Measuring workstation: a) general view, b) block diagram

Subsequent measurements were to show the influence of grease on the value of the measured force. Also in this case each measurement was performed on new screw-nut pairs. Two kinds of grease were used: copper grease and graphite grease.

A final series of measurements were to determine the influence of thread wear on the value of axial force. The examination involved tightening the connector and loosening it until obtaining a fixed value of measured force.

5. The analysis of results

The statistical analysis of obtained data showed that the values of axial force can be treated as a variable with a normal distribution at a level of significance α = 0.05. The Lilliefors and Shapiro-Wilk tests were applied, and it was ascertained that that the variable (values of axial force) for each group of measurements has a normal distribution. The mean value and standard deviation of the random variable (values of measured force) were estimated for 95% confidence level (Table 2). Comparisons were made for axial force values in new screw connectors working in different conditions:

a) **without** grease on thread surfaces,
b) using **copper grease** on thread surfaces,
c) using **graphite grease** on thread surfaces.

Table 2. Statistical data for the screw – nut pair

Values	Without grease	Copper grease	Graphite grease
Mean	12 664,20	12 116,13	13 885,48
Confidence interval –95%	12 235,88	11 598,88	13 421,70
Confidence interval +95%	13 093,15	12 633,38	14 349,27
Minimum	9 500,00	9 300,00	11 000,00
Maximum	15 100,00	14 400,00	16 600,00
Standard deviation	1 168,56	1 410,17	1 264,40

Based on the data obtained from the statistical analysis, the table below presents the values of the scatter of measurements with the theoretical scatter of –20% +15% of tightening screws with a manual dynamometric spanner (Table 3).

Table 3. Comparison of the experimental and theoretical scatter of measurements [1]

<table>
<tr><th rowspan="2">Values</th><th colspan="2">Without grease</th><th colspan="2">Copper grease</th><th colspan="2">Graphite grease</th></tr>
<tr><th>Force, N</th><th>Scatter, %</th><th>Force, N</th><th>Scatter, %</th><th>Force, N</th><th>Scatter, %</th></tr>
<tr><td>Mean measurement value</td><td>12 664,20</td><td rowspan="3">±18,45</td><td>12 116,13</td><td rowspan="3">±23,28</td><td>13 885,48</td><td rowspan="3">±18,21</td></tr>
<tr><td>+2 σ</td><td>15 001,50</td><td>9 295,80</td><td>11 356,68</td></tr>
<tr><td>-2 σ</td><td>10 327,00</td><td>14 936,46</td><td>16 414,29</td></tr>
<tr><td rowspan="2">Theoretical scatter</td><td>10 131,36</td><td>–20</td><td>9 692,904</td><td>–20</td><td>11 108,38</td><td>–20</td></tr>
<tr><td>14 563,83</td><td>+15</td><td>13 933,55</td><td>+15</td><td>15 968,30</td><td>+15</td></tr>
</table>

The results of the experimental research against the theoretical value of axial force in a screw connector are presented on three graphs for a new screw – nut pairs:

a) **without** grease (Fig. 4),
b) with **copper grease** (Fig. 5),
c) with **graphite grease** (Fig. 6).

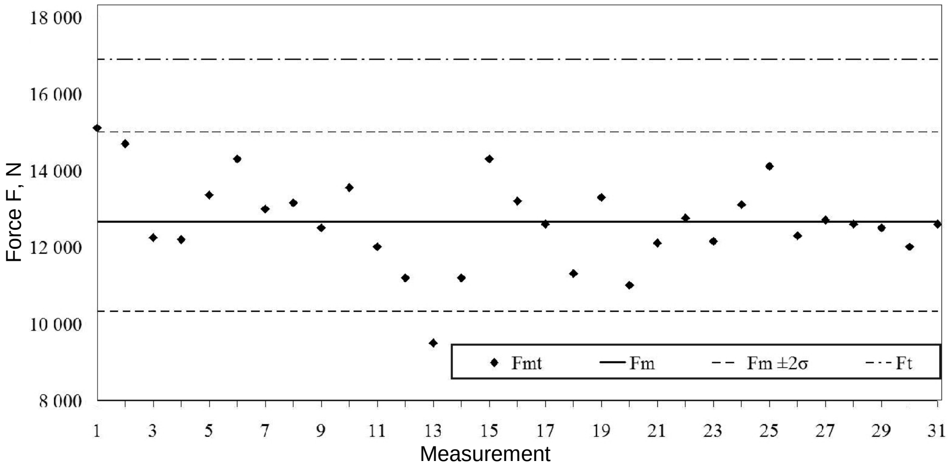

Fig. 4. Results of measurements for a new screw-nut pair without grease (Fmt – force measurement value, Fm – force mean measurement value, Ft – force theoretical value)

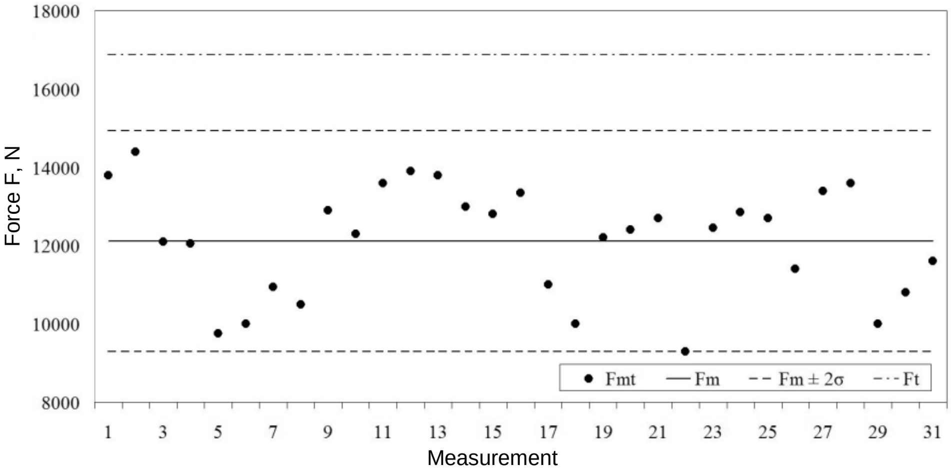

Fig. 5. Results of measurements for a new screw-nut pair with copper grease (Fmt – force measurement value, Fm – force mean measurement value, Ft – force theoretical value)

Nevertheless, none of the measurement points, at a scatter ±2 σ, attains this limit. It is possible to obtain such a result through increasing the tightening tightening torque. However, it is contradictory to the recommendations of the manufacturer (Bosch Rexroth) who defined the value of the mounting tightening torqueto be 16 Nm for a M6 screw in the strength class 12.9.

Literature on the subject gives a formula for the value of the mounting tightening torque (formula 2). However, this formula is imprecise due to the

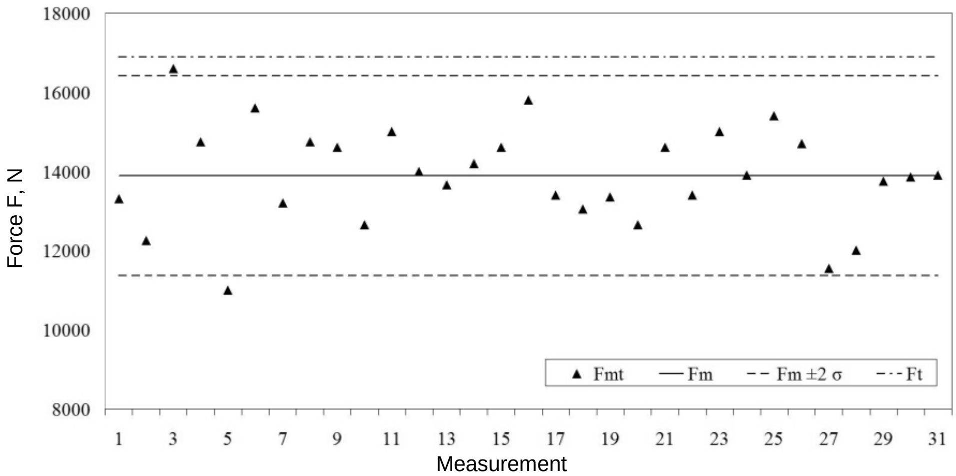

Fig. 6. Results of measurements for a new screw-nut pair with graphite grease (Fmt – force measurement value, Fm – force mean measurement value, Ft – force theoretical value)

tightening torque coefficient k_d included. The coefficient's values range from 0.11 to 0.20, and consequently the theoretical mounting tightening torquefor the M6 screw ranges from 11.142 Nm for a coefficient for 0.11, to 20.26 Nm for k_d equal 0.20. Based on the obtained experimental results we can determine the value of coefficients k_d through the following change to formula 2:

Table 4. The determined values of coefficient k_d

Condition of connection	k_d
New pair of screw and nut with out grease	0,21
New pair of screw and nut with copper grease	0,22
New pair of screw and nut with graphite grease	0,19

Table 4 confirms that the value of coefficient kd depends on the friction between screw and nut thread surfaces and consequently on the applied grease. The problem concerns only the coefficient's value. Literature on the subject, as presented in Table 1, is not unanimous in this regard. Also coefficients obtained thanks to the experimental research are not in compliance with theory. In this situation, it seems reasonable to treat the formula 2 only as an approximation. The value of the mounting tightening torque should instead be fixed according to the recommendations of the screw manufacturer.

A subsequent step of the analysis was the determination of a relationship between the value of axial force in the screw connector and the extent of its wear at an established tightening tightening torque. 15 screw-nut pairs were subjected to compressing at a fixed mounting tightening torqueand then subjected to loosening (Fig. 7). The action was performed 30 times during which, changes in the axial force and wear were recorded.

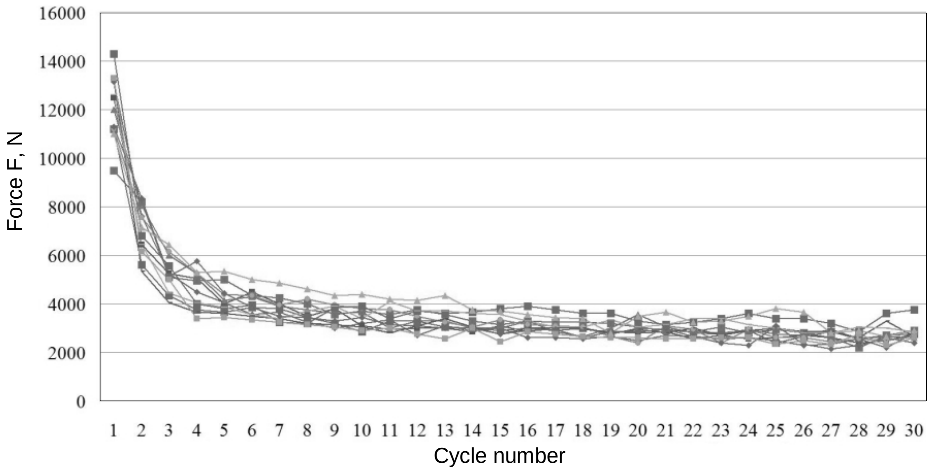

Fig. 7. The comparison of results observed during multiple use of a screw connector for 15 screw-nut pairs

The analysis of measurements for the gradually wearing connector was limited to the determination of a dependence that describes the value of axial force in relation to the number of a given use of a connector. For this purpose a non-linear estimation was used. An estimated regression equation was obtained to determine the dependence: force vs. the number of subsequent uses in the following formula (formula 3, Tab. 5):

$$Force = A*(1-C*\exp(-B*\ Cycle\ number\ )) \quad (3)$$

Table 5. Estimation results

Parameter			**Correlation coefficient R**
A	C	B	0,93225
3180,72	-5,4397	0,679314	

Results of measurements unequivocally show that a strong dependence exists between the number of times a screw connector has been used and the obtained value of axial force in the connector. The stabilization of axial force occurs after about the 10th use of the connector, with a simultaneous fourfold decrease in the force value (Fig. 8).

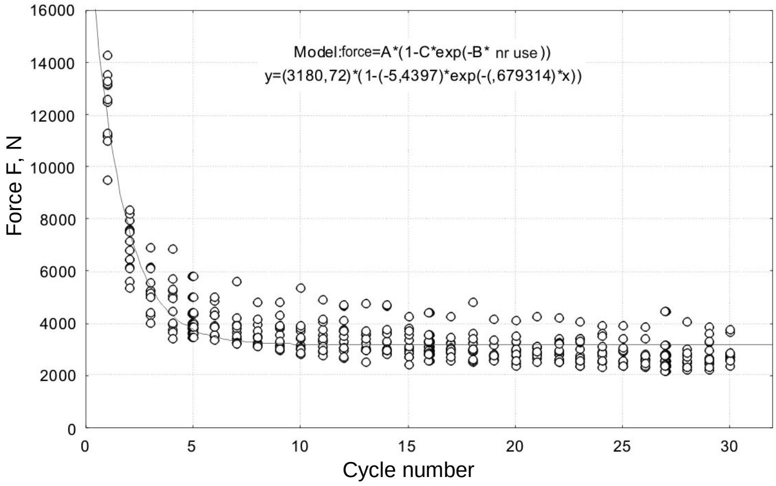

Fig. 8. Graph of regression dependence

6. Conclusions

Before the experimental research, it was assumed based on literature that axial force should be considerably greater for a frictional pair with grease than for the same connector without grease. Table 3 and Figure 6 show clearly that the use of graphite grease causes an increase in the value of axial force in the connector in comparison to the connector in which no grease was used. A paradox was observed for copper grease – the average value of axial force was smaller than the average for the connector without grease (12116.13 N < 12664.2 N). The value of axial force decreased rather than increased. The obtained result questions the purpose of using copper grease for compressed connectors.

Is it then necessary to use any greasing substances for compressing connectors? This study show that the answer is positive – one ought only to pay attention to the greasing properties of the used grease, such as is in the case of the graphite grease. Suitable “greasing” of threads will enable the proper compression of the connector to be obtained, using a smaller mounting tightening torque than for the “dry” connector.

A quite significant conclusion related to the analysis of the repeated use results is having to pay attention to the multiple use of individual screw-nut connectors. Recommendations of the manufacturer refer only to the values of mounting tightening torque (in relation to compression of the joint or safety of the screw?), and do not provide information on the conditions of the connection between the screw and nut. This study shows that for each subsequent use of a screw connector, the value of axial force is decidedly smaller than the theoretical axial force for the same tightening torque.

During maintenance of machines, it is recommended to use new and previously unused screw connectors that would provide the expected axial force. Multiple use with the maintained mounted tightening torque that is recommended by the manufacturer will not guarantee a suitable compression of the connector and consequently the stiffness of the connection may change considerably.

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