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EXPERIMENTAL DETERMINATION OF THE EFFECT OF AXIAL FORCE ON A HEADLESS SCREW CONNECTION

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1. Introduction

Headless screws are commonly used fasteners in mechanical engineering, especially in applications where the screw must be flush with the surface it secures.

In real working conditions, this type of screw is often exposed to axial forces, which may result from tightening or from external loads. Therefore, it is important to understand how axial force affects a headless screw connection in order to ensure a reliable and strong joint. Monitoring the axial force, which may be either tensile or compressive, is a key factor in maintaining joint safety and preventing plastic deformation.

Recent studies have explored various non-destructive methods for determining axial force in screws. One such method is the ultrasonic technique based on the acoustoelastic effect, where the screw is divided into specific zones and the measurement error is typically below 10% [1]. By introducing corrections to the clamping length and using suitable sensors, this error can be reduced to below 3% [2]. In addition, advanced ultrasonic technologies allow for more accurate measurements by eliminating errors caused by poor sensor contact with the material [3]. On the other hand, experimental methods are used as a complement, as they are performed under actual load conditions and take into account factors such as friction and microslip [4,5].

The aim of this paper is to experimentally determine the axial force occurring in headless screws used to connect the outer and inner parts of a mechanical joint. The behavior of the screws under compressive load will be analyzed, and the results will contribute to a better understanding of the mechanical performance of headless screw connections.

Future research will focus on modifying screw parameters in order to examine whether the length and diameter of the screw affect its strength and behavior under load. In addition, the influence of repeated (cyclic) loading on headless screws will also be considered.

2. Connection achieved using headless screws

For the experimental investigation of axial force in the screws, it was necessary to create a prototype of the joint.

To connect the outer and inner parts of the joint, shown in Figure 1, headless screws were used. These screws conform to the DIN 913 standard, with a size of M5 and a length of 6 mm [6].

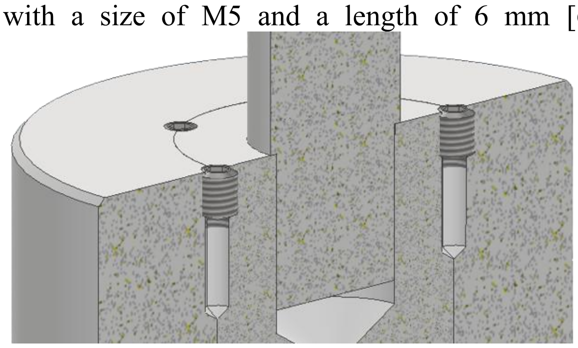


Fig. 1. Prototype of the joint connected with headless screws

Six holes for screws were made on each side of the joint to ensure repeatability of the experiment and to reduce possible random errors during testing or result analysis.

The tests were carried out on a SHIMADZU servohydraulic pulsator (testing machine) designed for precise testing of the mechanical properties of various materials.

This machine has the following specifications:

- Maximum force capacity: 100 kN,
- Operating frequency range: 0.01 Hz to 200 Hz,
- Force measurement accuracy: ±0.5% of full scale (FS),
- Stroke length: ±50 mm.

The test involved applying an axial compressive force with the pulsator on the inner part of the joint, which moves vertically downward, while the outer part of the joint was fixed. This setup generates axial force in the screws. Controlled axial loading was applied, and both the force and deformation of the screws were continuously measured.

To mount the prototype joint on the pulsator, it was necessary to design and manufacture additional auxiliary components: A plate fixed to the lower part of the pulsator, on which a hollow profile rests. The hollow profile is a separate component that rests partially on the plate and partially supports the outer part of the joint. The third and final component is a cylindrical part that fits into the upper jaw of the pulsator. During the experiment, this part applies pressure to the inner part of the joint. This is achieved by the gradual lowering of the upper part of the pulsator.

Figure 2 shows the main components of the joint and the auxiliary parts used for mounting the joint on the pulsator.

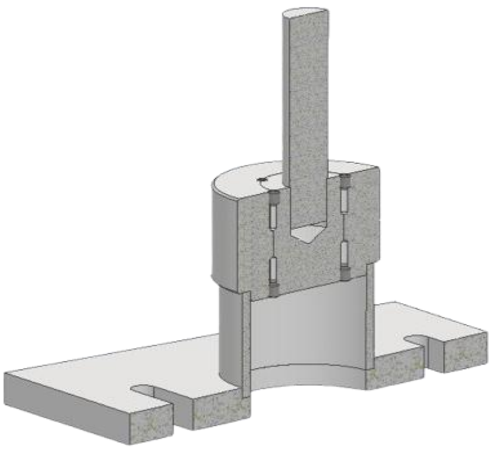


Fig. 2. Assembly of the joint and auxiliary components on the pulsator.

The plate is mounted on the lower part of the pulsator and is secured to it with two M15 screws to ensure a rigid connection between the joint structure and the pulsator.

This step is very important to prevent any movement of the joint during the experiment, as such movement would significantly affect the accuracy of the test results.

The joint is connected to the upper part of the pulsator through a component that fits into the jaw, where the jaw clamps firmly hold this part in place.

3. Axial force on a headless screw connection

In this study, the screws were tested under a static load of 60 kN.

Figure 3 shows the assembly of the joint prototype along with auxiliary components mounted on the pulsator before applying the axial compressive force.

Fig. 3. Assembly of the joint and auxiliary components on the pulsator.

To obtain accurate results, the experiment was repeated multiple times. In total, six test series were performed.

The first three series involved testing two screws, size M5 and length 6 mm, positioned opposite each other. The distance between them was equal to the diameter defining the spacing of the screw holes, which in this case was 80 mm.

Gradual movement of the upper part of the pulsator applies force to the inner part of the joint via a component that fits into the jaw of the upper part of the pulsator.

The force increased steadily from 0 up to approximately 11 kN. The moment when the force reached its maximum value was considered the point of failure.

From that point, the force dropped significantly, indicating the end of the test series. The results recorded by the pulsator's software were then saved in Microsoft Excel for further analysis.

In addition to force measurement, the software was set to continuously monitor the displacement of joint components during the application of force.

After the test, the joint was removed from the pulsator and prepared for the next series by installing new screws between the outer and inner parts of the joint. The entire assembly was then remounted on the machine. This procedure was repeated three times.

Figure 4 shows the joint assembly after the first test series. The inner part of the joint is visibly displaced from its initial position, and damage to the screws can be seen.

Fig. 4. Assembly of the joint and auxiliary components on the pulsator after the first test series.

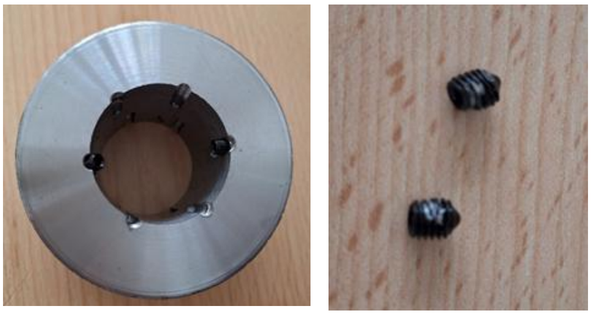
The fourth, fifth, and sixth test series were performed by rotating the joint 180°.

This was made possible by the sufficient length of the hollow profile supporting the outer part of the joint. The purpose of rotating the joint was to ensure repeatability and achieve more accurate results.

During the testing, three different failure scenarios were observed, where either one or a combination of them could occur:

1. Damage to the thread on the inner side of the joint,
2. Damage to the thread on the outer side of the joint,
3. Damage to the thread on the contact surface between the joint parts, i.e., damage to the screw thread.

Figure 5 shows (a) the outer part of the joint and (b) the screws after the fourth test series. The images display the damage that occurred to the joint components during the experiment.



(a) (b)

Fig. 5. (a) Outer part of the joint and **(b)** screws after the fourth test series.

The last, sixth test series was performed with a single headless screw of the same dimensions as in the previous tests, instead of two screws.

4. Results

During the tests, the screws were subjected to a static compressive force that continuously increased from 0 kN up to the maximum force, which varied slightly between each test series.

The force values were measured continuously throughout the experiment. These values were recorded by the pulsator's software. At the end of each test series, the results were transferred to Microsoft Excel for further processing.

In addition to force, deformation values were also recorded. The deformation increased proportionally with the force until the maximum force was reached. From that point until the end of the series, the deformation began to decrease sharply.

Figure 7 shows a diagram of the results, illustrating the relationship between force and deformation for all six-test series.

The diagram displays the Z-axis representing the change in force, while the Y-axis represents the change in deformation dependent on the force.

Results from all series are combined into one diagram and are distinguished by different colors.

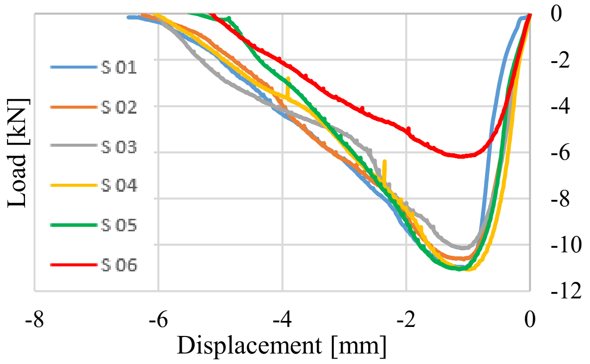


Fig. 7. Diagram of force versus deformation for six test series of headless screws.

As seen from the diagram, the compressive force sharply increases until it reaches the maximum value, which is similar for five repeated test series. This indicates that the experiment was performed correctly, with a low percentage of random errors. The cause of the small differences in values is difficult to determine. Random errors in the experiment may arise from instrumental variations, including temperature fluctuations, voltage variations, or mechanical vibrations.

The first five test series examined the effect of compressive force on two headless screws, size M5 and length 6 mm, with a maximum force of approximately 11 kN.

Further evidence of the experiment's validity and relevance of the results is shown by the sixth test series. This series tested the behavior of a single screw of the same dimensions under compressive load, where the maximum force was almost half compared to the tests with two screws. The maximum force value in this case was around 6 kN.

5. Conclusion

The experimental investigation of the effect of axial force on a headless screw connection, performed using a servohydraulic pulsator, enabled the analysis of the joint behavior under static compressive load. This study determined how headless screws behave under load and the maximum forces they can withstand. The results showed that two screws of size M5 and length 6 mm can withstand a force of approximately 11 kN, while a single screw of the same dimensions can withstand a force of about 6 kN.

Three types of possible damage were observed: on the internal threaded part of the joint, on the external part, and on the screw itself, indicating the complexity of the screw connection behavior under load.

The obtained results contribute to a better understanding of the mechanical behavior of such connections, provide a foundation for future research, and can serve as a basis for the design or optimization of connections using headless screws.

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