Scientific Journal of Silesian University of Technology. Series Transport
Zeszyty Naukowe Politechniki Śląskiej. Seria Transport

Volume 114 **2022**

p-ISSN: 0209-3324

e-ISSN: 2450-1549

DOI: https://doi.org/10.20858/sjsutst.2022.114.4

Journal homepage: http://sjsutst.polsl.pl

Article citation information:
Jírová, R., Pešík, L. Analysis of screw connection in air conditioning systems. *Scientific Journal of Silesian University of Technology. Series Transport*. 2022, **114**, 43-54. ISSN: 0209-3324. DOI: https://doi.org/10.20858/sjsutst.2022.114.4.

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ANALYSIS OF SCREW CONNECTION IN AIR CONDITIONING SYSTEMS

Summary. Air conditioning systems in vehicles require long-term reliability during their entire service life. Especially, a good sealing function is needed for the prevention of coolant leaking. Unfortunately, in specific cases, after a particular time, screw connections of the air conditioning circuit lose their tightness, and the coolant starts to leak. Therefore, this paper focuses on the analysis and design optimisation of screw connections. We used the finite element method for describing the sealing, screw and disc spring behaviour. Then, we proposed a new design of the disc spring to obtain the proper force-deformation characteristics of the connection and ensure the tightness of the screw connection.

Keywords: air conditioning system, screw connection, sealing function

1. INTRODUCTION

Air conditioning systems in cars are realised as aluminium alloy high-pressure circuits conjunct through screw connections. Screw connections are based on fitting with eccentric screw against sealing from copper alloy. However, the pressure sealing of the circuit is unreliable after screw connection assembling under a standardised process, especially after

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a certain time or reassembling process. Performed checkups of connection have not detected possible failure during the assembling process. It should be noted that the literature indicates various diagnostic methods used in the technique [1, 2]. Therefore, this paper aims to analyse the screw connection to define its basic characteristics respecting its tightness and solution proposition.

2. DESIGN AND ANALYSIS OF SCREW CONNECTION

A design of a screw connection based on two bodies, a sealing, a holder of sealing and an M6 screw with a washer, is shown in Figure 1. Both bodies are produced from aluminium alloy, and one of them carries a steel pin for fixing the proper position. To bodies, high-pressure pipes are welded. The sealing is made from a copper alloy and is mounted through the holder to the body. This assembly is further connected through the screw with the washer in a shape of a disc spring.

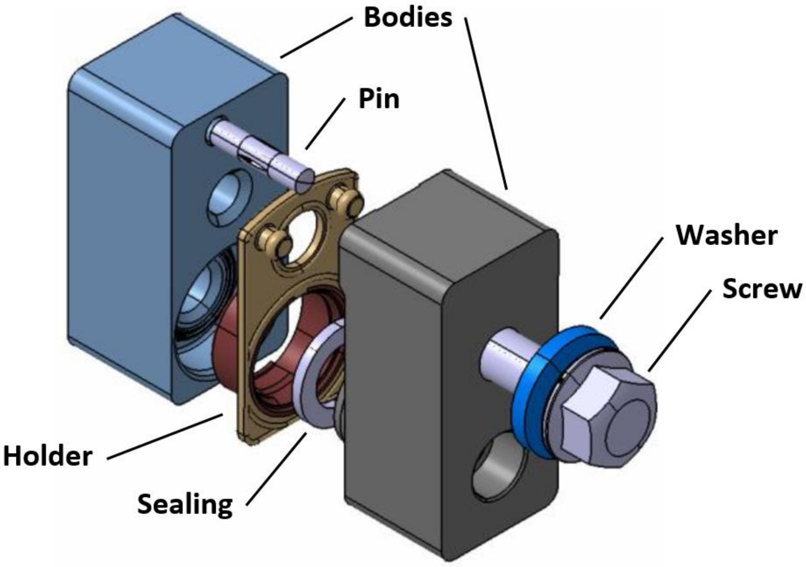

Fig. 1. The design of the screw connection

2.1. The force balance of the screw connection

Contact surfaces of bodies are shaped to make a single lever with an imaginary revolute joint at the longest distance of the surface. After mounting, a clamping force F_{Qs} made through the screw connection with the disc spring acts on both bodies. Where an index Q signs a screw preload. The clamping force loads the sealing by force F_{Qt}.

M6 screw with the disc spring is placed from the revolute joint at a shorter distance than the sealing. Thus, the clamping force F_{Qs} is transformed into the force of sealing F_{Qt}. After mounting, the balance of moment is:

$$F_{Qs} a_s = F_{Qt} a_t \tag{1}$$

where a_s is a distance of the screw axis and a_t a distance of sealing axis from the revolute joint.

A lever gear at the sealing position is:

$$i = \frac{F_{Qt}}{F_{Qs}} = \frac{a_s}{a_t} \tag{2}$$

By torque wrenching at $M_u \cong 12$ Nm the clamping force $F_{Qs} = 12$ kN occurs respecting the friction in a thread and contact surfaces between screw and washer [3].

When $a_s \cong 10$ mm and $a_t \cong 25$ mm, the lever gear is $i = 0{,}4$ and the force of sealing $F_{Qt} = iF_{Qs} = 4{,}8$ kN.

An operating force F of the connection is defined by the pressure p of a liquid and the inner diameter d of pipes in the location of the connection. The operating force increases the force in the screw from the preload force F_{Qs} to force F_s. Then, the force of sealing F_{Qt} decreases to force F_t. These force differences ΔF_s and ΔF_t depend on the stiffnesses of clamping parts k_s and clamped parts k_t in the connection location and the lever gear i:

$$\Delta F_s = \frac{F}{i} \frac{k_s}{k_s + \frac{k_t}{i^2}} \tag{3}$$

And

$$\Delta F_t = F \frac{k_t}{k_s i^2 + k_t} \tag{4}$$

The value of operating force F at the liquid pressure $p = 10$ MPa and the inner diameter of the pipe $d = 6$ mm is approximately $F = 283$ N.

The force in the screw is $F_{smax} = F_{Qs} + \Delta F_{smax} = 12{,}7$kN, where ΔF_{smax} equals:

$$\Delta F_{smax} = \frac{F}{i} \tag{5}$$

The force in the screw oscillates between the values of 12 kN and 12,7 kN. The loading might be considered as static or quasi-static, and thus, does not cause a fatigue failure.

2.2. The stress and deformation analysis of sealing

A stress and deformation analysis of the sealing is based on the finite element method (FEM). FEM analysis compares three types of sealings A, B and C with different stiffness that is a dominant parameter of stiffness k_t. For all sealing types, the analysis result is deformation and contact pressure at the contact surface of sealing with the body (Figures 2-7). The sealing A belongs to the current state of the screw connection.

Results of deformations and pressures at contact surfaces of sealing show influence of sealing stiffness, resp. stiffness k_t. We may notice a significant effect of stiffness on the contact pressure distribution. This state is crucial for the sealing function of the screw connection assembly. Uneven distribution of contact pressure at A sealing is caused by great sealing stiffness that disables reaching parallelism of both contact surfaces with bodies (Figure 8).

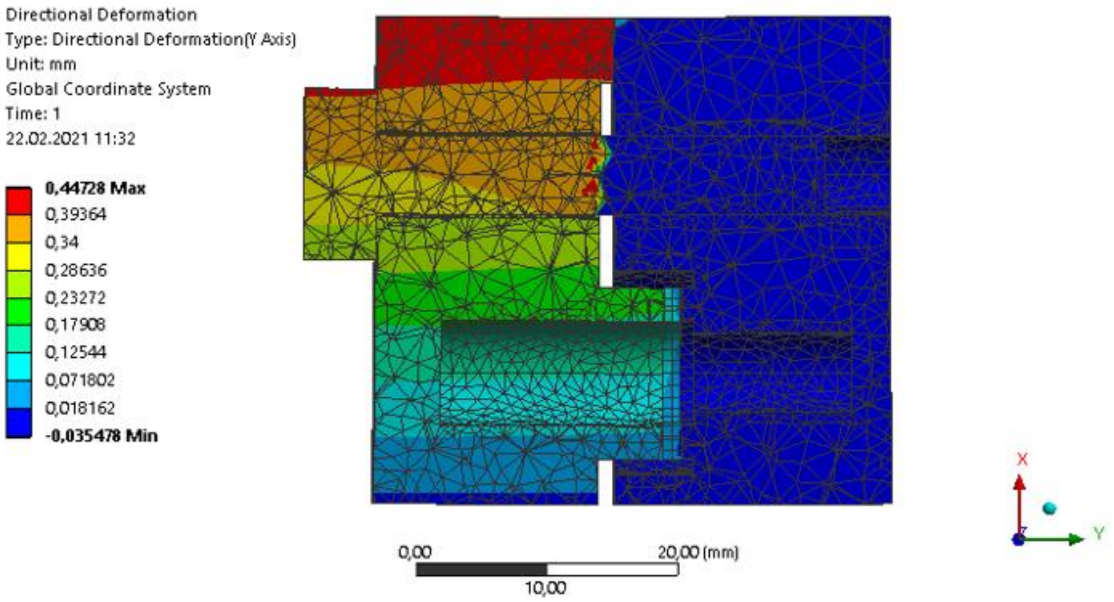

Fig. 2. Deformation in the Y-axis direction – Sealing A

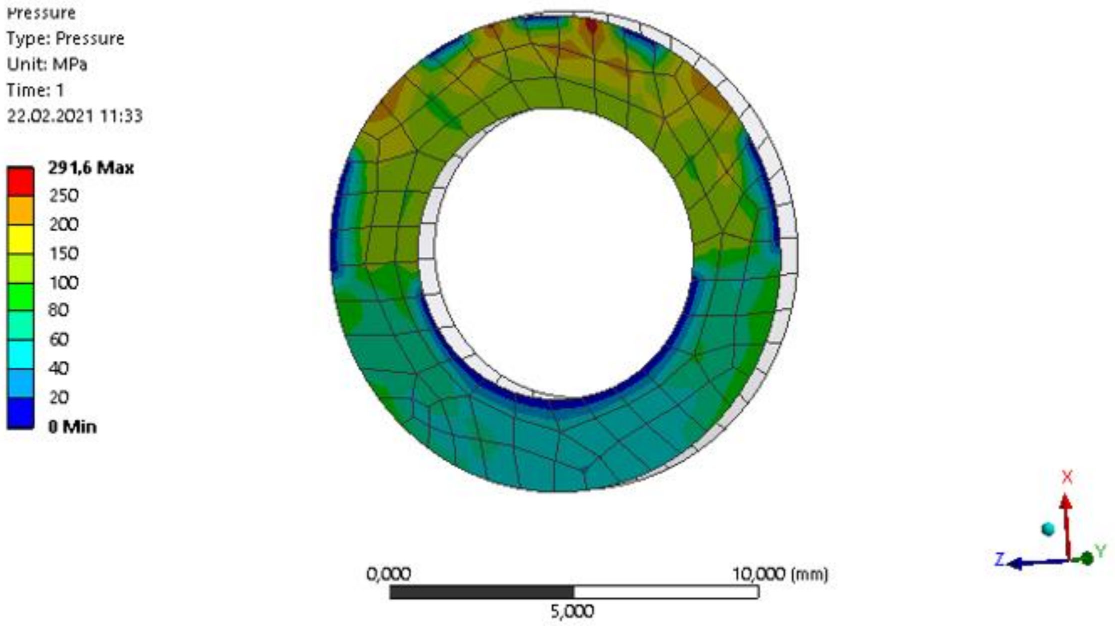

Fig. 3. Contact pressure – Sealing A

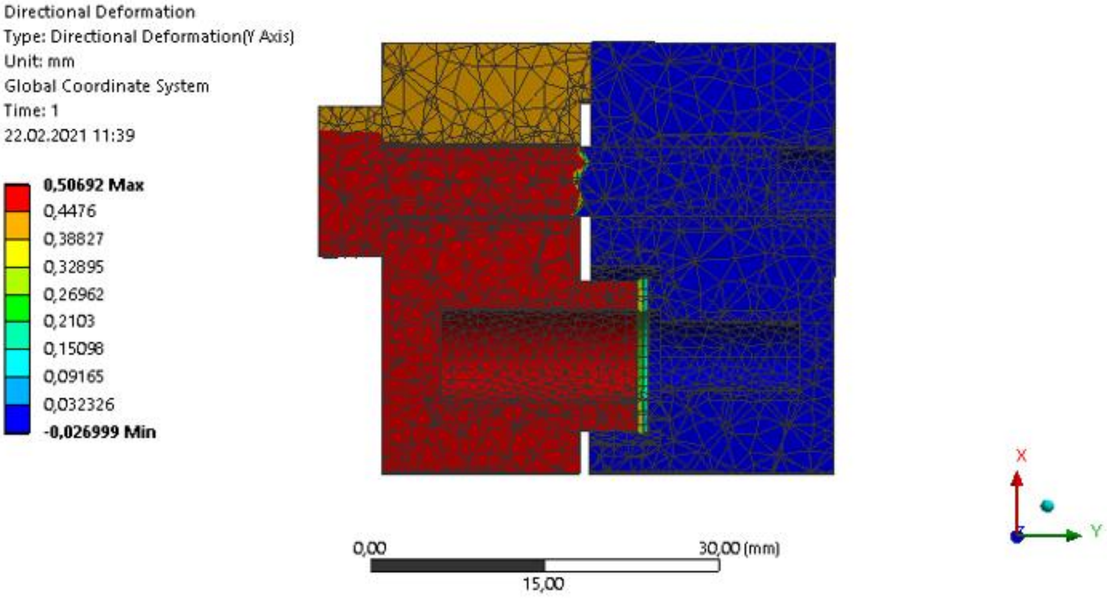

Fig. 4. Deformation in the Y-axis direction – Sealing B

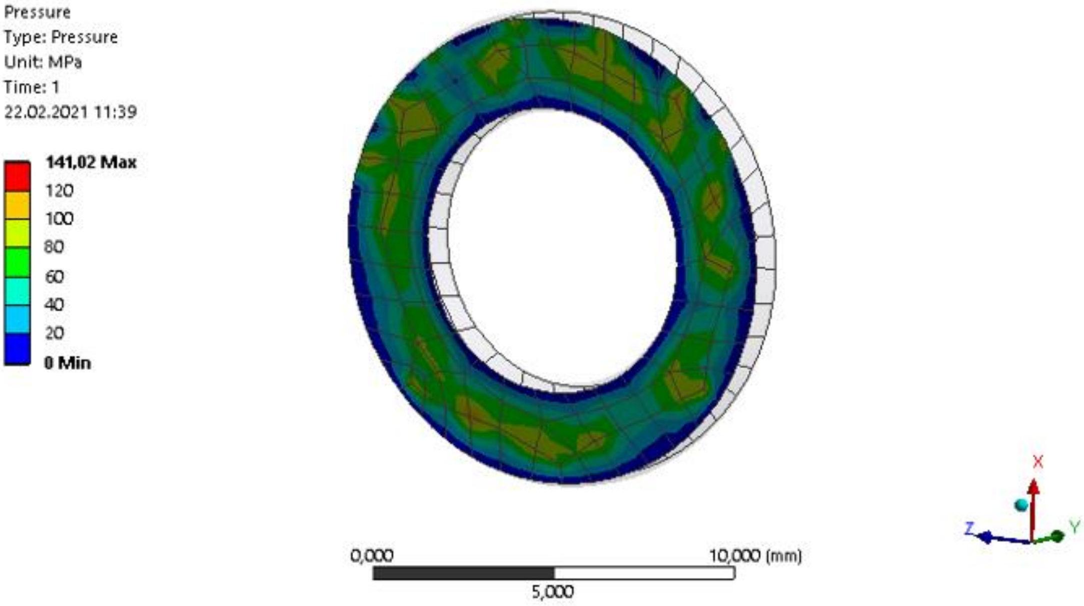

Fig. 5. Contact pressure – Sealing B

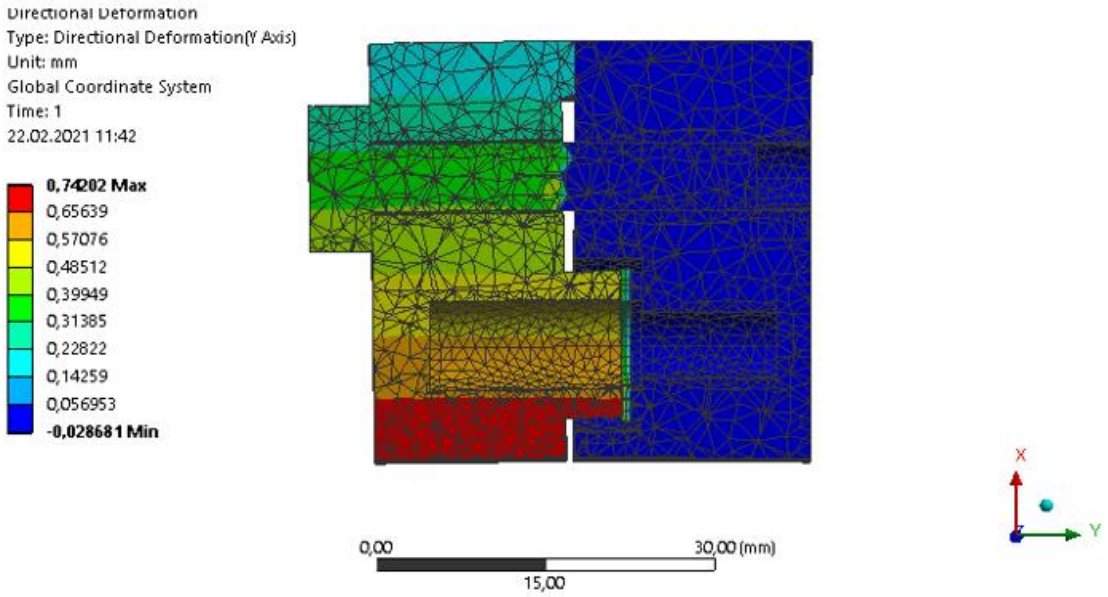

Fig. 6. Deformation in the Y-axis direction – Sealing C

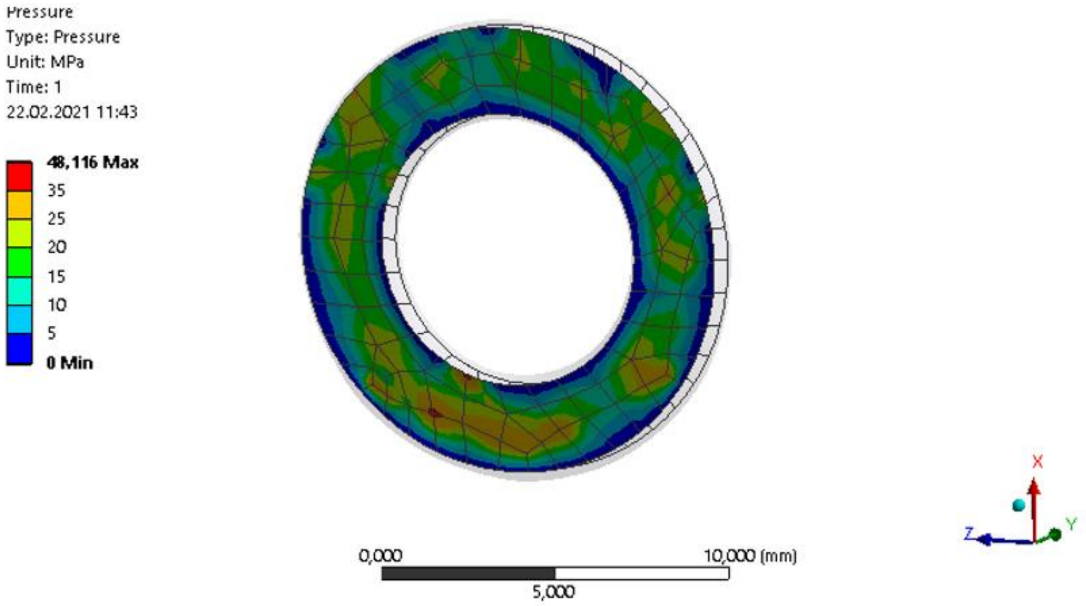

Fig. 7. Contact pressure – Sealing C

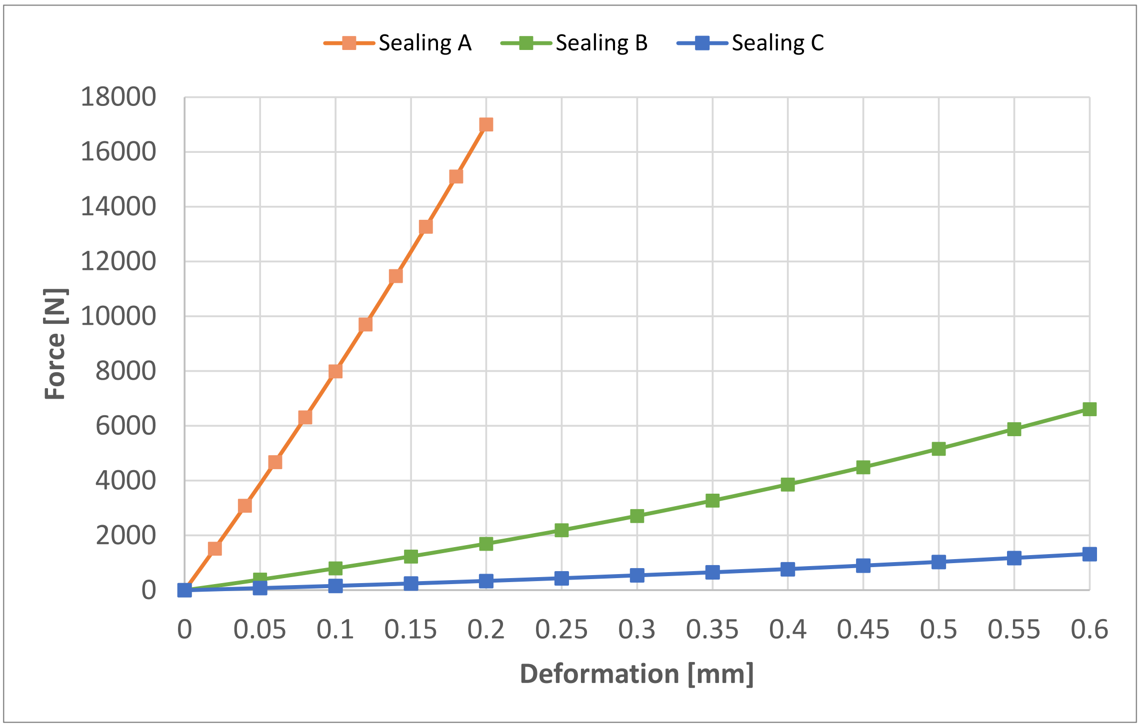

Fig. 8. Comparison of load characteristics – Sealing A, B and C

2.3. The deformation analysis of disc spring

An influence of the disc spring on stiffness k_s is essential. Simulations show deformations of screw connection with disc spring A and B. While disc spring A represents the current state of screw connection (Figure 9), disc spring B demonstrates an optimised state with degressive load characteristics (Figure 10).

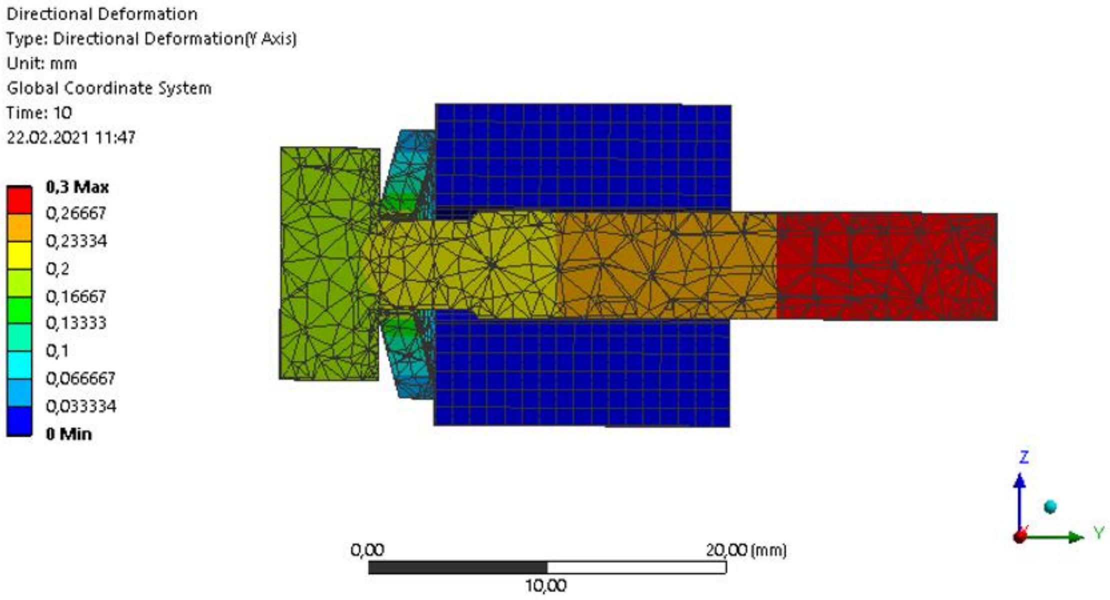

Fig. 9. Deformation in the Y-axis direction – Disc spring A

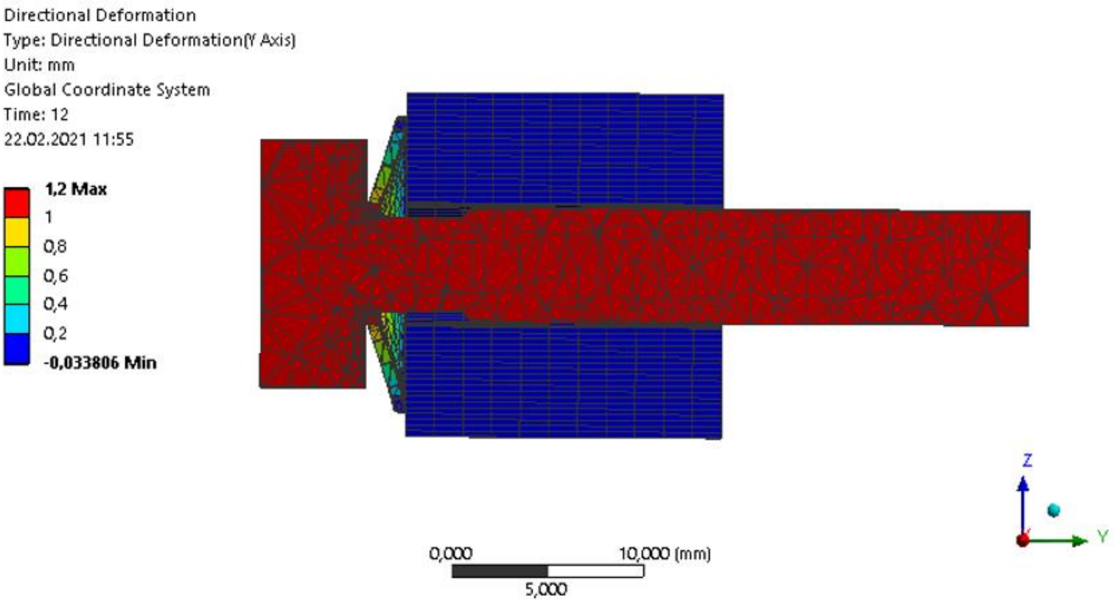

Fig. 10. Deformation in the Y-axis direction – Disc spring B

Results show significant differences between characteristics of disc spring A and B (Figure 11). The first case of A disc spring relates to the current state, and B disc spring is the optimised variant with degressive characteristics. The disc spring B provides minimal stiffness in the relatively wide band of deformations that lead to minimal stiffness k_s of clamping parts.

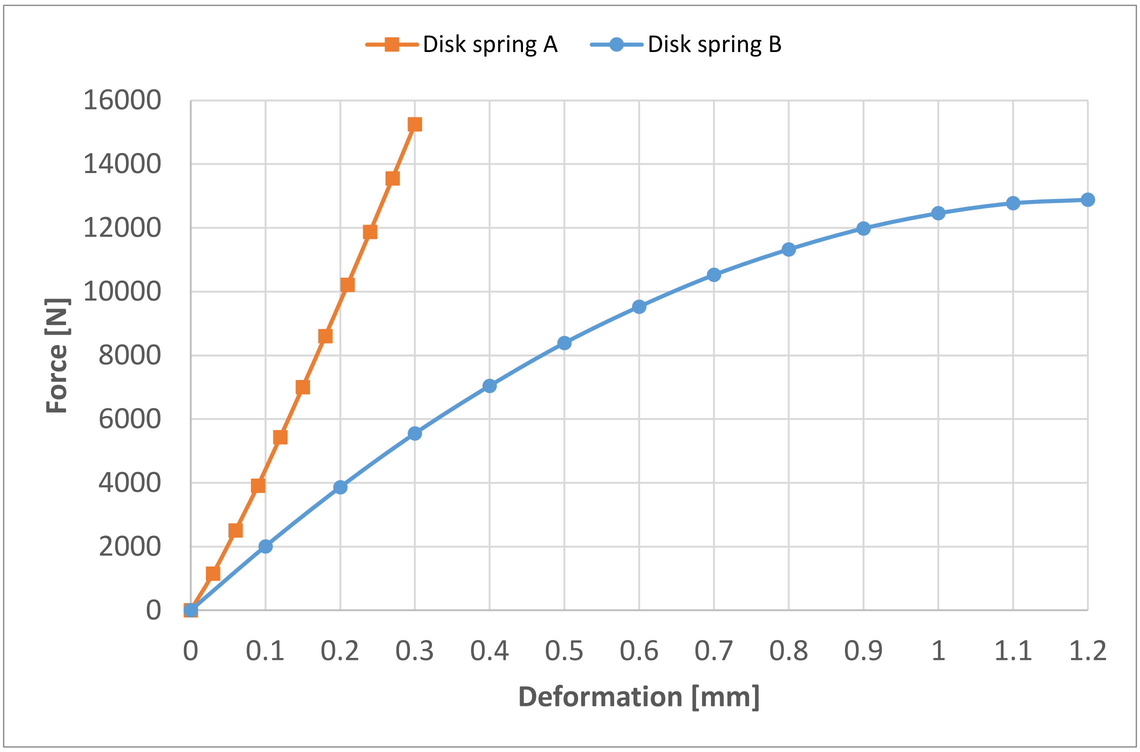

Fig. 11. Comparison of load characteristics – Disc spring A and B

3. ENSURING OF SEALING FUNCTION

The sealing function of the screw connection is ensured by sufficient and evenly distributed contact pressure to the sealing. This state relates to the value of the sealing force F_t and the design of the screw connection for reaching parallelism of contact surfaces under clamping force F_s.

Described conditions are met by optimal stiffness k_t associated primarily with the sealing one. The state after mounting should be preserved during the entire service life. The sealing deformation exceeds an elastic one, and plastic deformation with a creep effect appears. Therefore, the contact pressure is decreased and unevenly distributed. This process leads to the embedding effect of screw connections. If the stiffness k_s of clamping parts is high, then the clamping F_s and sealing F_t force decreases rapidly. Thus, the screw connection becomes unreliable. This process may be represented by a diagram of the force-deformation characteristics that depicts the state after mounting as well as the embedding effect [4, 5] (Figure 12).

Characteristics of clamping parts (screw and disc spring) and clamped parts (both bodies and sealing) correspond to the simulation of the current state. An intersection of the screw and sealing characteristics belongs to the value of preload F_{Qs}, approx. 12 kN. An overall deformation (elongation of clamping parts and compression of clamped parts) is approximately 0,3 mm.

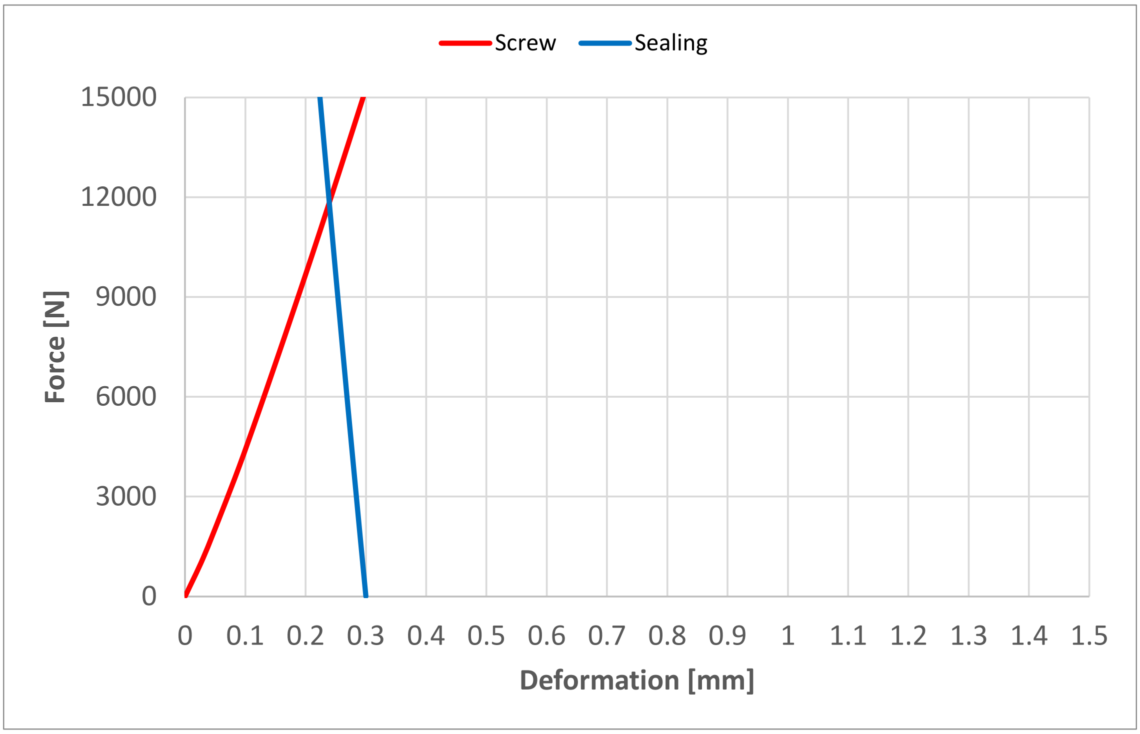

Fig. 12. Diagram of screw connection – the current state after mounting

In service, components of screw connection embedded around 0,1 mm. The overall deformation decreases to the value of 0,2 mm (Figure 13).The preload F_{Qs} decreases to the value approx. 7,5 kN, which means reducing clamping force to 60% of the initial value (12 kN). This embedding process might lead to insufficient tightness of the screw connection.

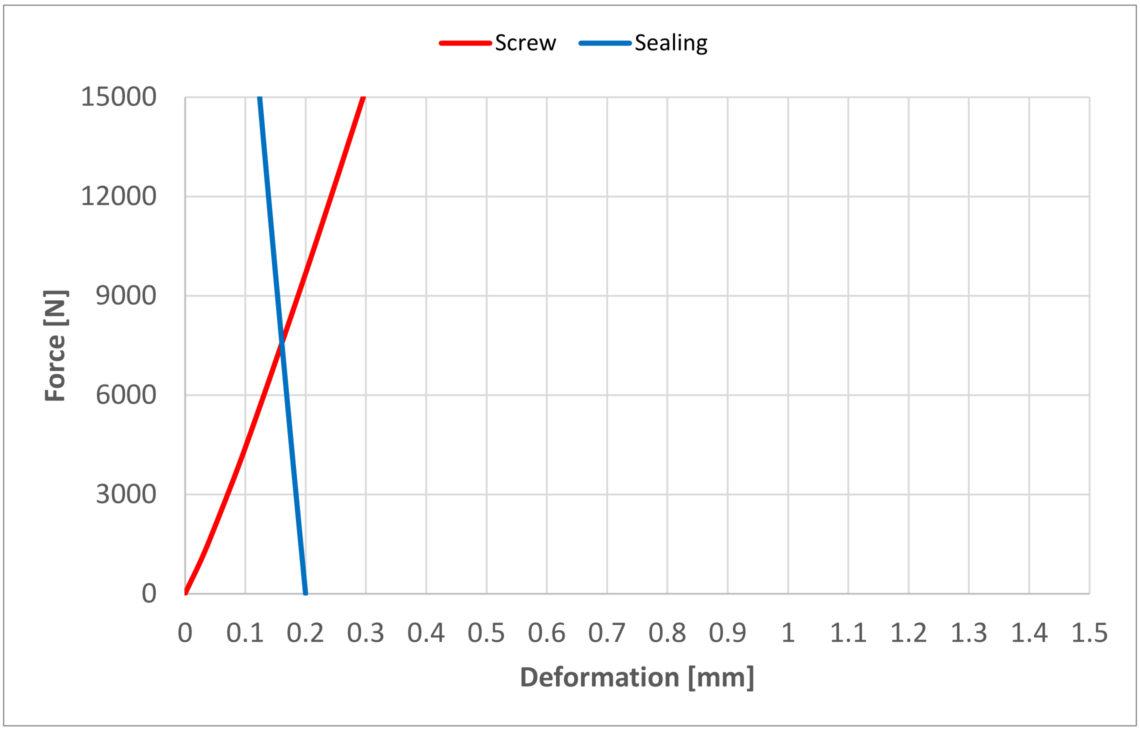

Fig. 13. Diagram of screw connection – the current state after embedding

From the upper diagrams, we may conclude that the stiffness of clamping parts is essential for sufficient sealing function. This means that the disc spring is a significant part for reaching the degressive force-deformation characteristics.

The force-deformation diagram shows the characteristics of clamping parts (screw and disc spring) and clamped parts (both bodies and sealing) respecting the optimised state of the disc spring B with the degressive characteristics (Figure 14). The intersection of the screw and sealing characteristics belong to the value of preload F_{Qs}, approx. 12 kN. The overall deformation (elongation of clamping parts and compression of clamped parts) is approximately 1,27 mm. The deformation is more significant than in the previous case. We note that the disc spring fulfils its function.

In service, components of screw connection are embedded around 0,1 mm (Figure 15). The overall deformation decreases to the value of 1,17 mm. The preload F_{Qs} decreases negligibly, which means preserving clamping force at 100% of the initial value (12 kN). The screw connection is ensured for sufficient tightness.

4. CONCLUSIONS

This paper focused on proper sealing function analysis of the screw connection used in the air conditioning system. We proposed the optimised design of this connection mainly based on decreasing the stiffness of clamping parts through the disc spring.

We may sum up a few conclusions:

1. The essential effect to the sealing function is related to the disc spring with the degressive force-deformation characteristics.

2. The relevant factor of the sealing function is the elastic and plastic deformation of the sealing.
3. The increment of wrecking moment above the value of 12 Nm does not contribute to the reliability of the screw connection.

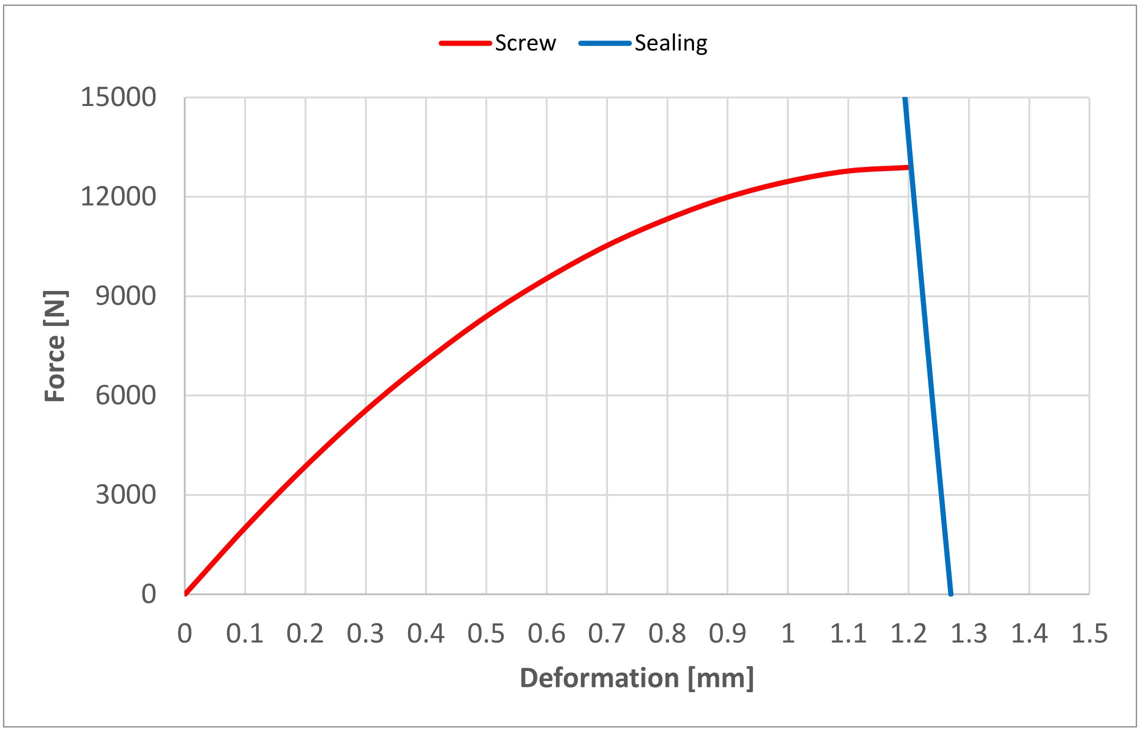

Fig. 14. Diagram of screw connection – the optimised state after mounting

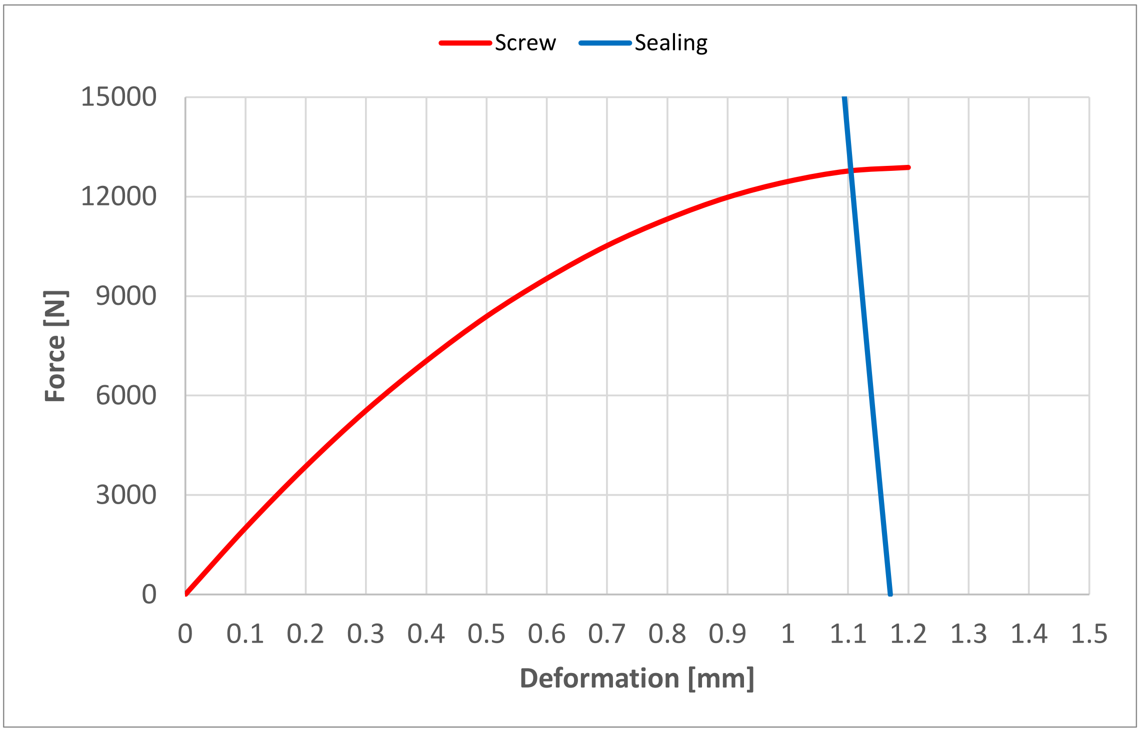

Fig. 15. Diagram of screw connection – the optimised state after embedding

Acknowledgement

This work was supported by the Student Grant Competition at the Technical University of Liberec under project No. SGS-2019-5036.

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Received 05.10.2021; accepted in revised form 08.12.2021