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Analysis of Wedge Lock Washer using the Finite Element Method

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Abstract. Washers with a so-called wedge-locking effect are available for the engineering industry. The manufacturer assures, as confirmed by the Junker vibration test, that the tension in the thread increases when the screw is unscrewed. This is due to the appropriate geometry of the washers, which always work together in pairs. On the outside, the washers have serrations which, when tightening the screw, cut into the material of the clamped part, leaving a permanent plastic deformation. On the inside they have wedges, the angle of which is greater than the angle of the helix of the thread. The subject of this work is a study of creating a simulation model that takes into account the discussed effect of wedge lock of the washers. This model will be used in the future for simulation tests of washers with a different geometry than the one proposed by the manufacturer.

1 Introduction

In addition to standard, you can even say classic solutions securing the threaded connection against loosening, modern manufacturers offer modern solutions.We can distinguish, among others, special washers with the effect of a wedge lock, an example of which is shown in Figure 1.These washers, under the trade name NORD-LOCK, always work in pairs - a group of two washers. Each of them has serrations on one side and wedges on the other.In addition, the wedges are machined more precisely than the serrations themselves, so the coefficient of friction between the wedges is lower than the coefficient of friction between the serrations against the contact surface (surface of the clamped part or the surface of the bolt /nut head).The essence of these washers is that they lock together thanks to the effect of the so-called wedge locks.This was shown in Figure 2 and explained in the text above this figure.

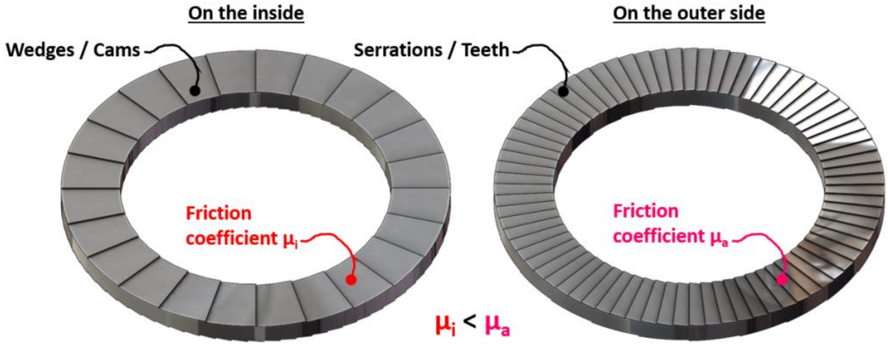

Fig. 1. Construction of washers with a wedge lock effect.

During tightening, the serrations cut into the head of the screw and into the surface of the clamped part.During untightening,the top washer's cams will override the cams of the bottom washer creating an increase in the force in the bolt because the cam angle α is greater than the thread pits of the bolt β.

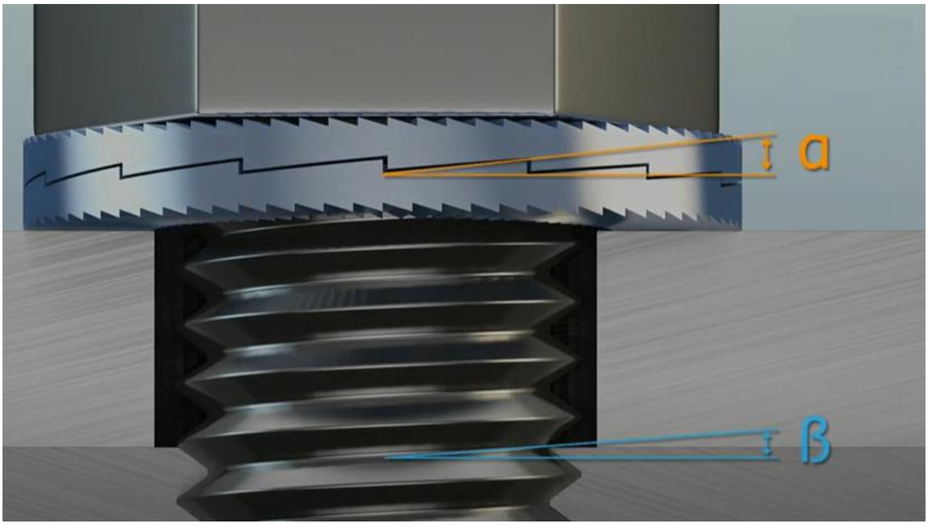

Fig. 2. The essence of the wedge block effect (explanation in the text above this figure) [1].

Junker vibration tests show that this solution has the best anti-loosening properties compared to other classical methods.This is shown in the graph in Figure 3.It is clearly visible there that for the exemplary M8 threaded joint and the use of various methods of securing against loosening, the NORD-LOCK solution is unrivaled.The diagram is the dependence of the generated and maintained axial tension in the thread and the number of load cycles.

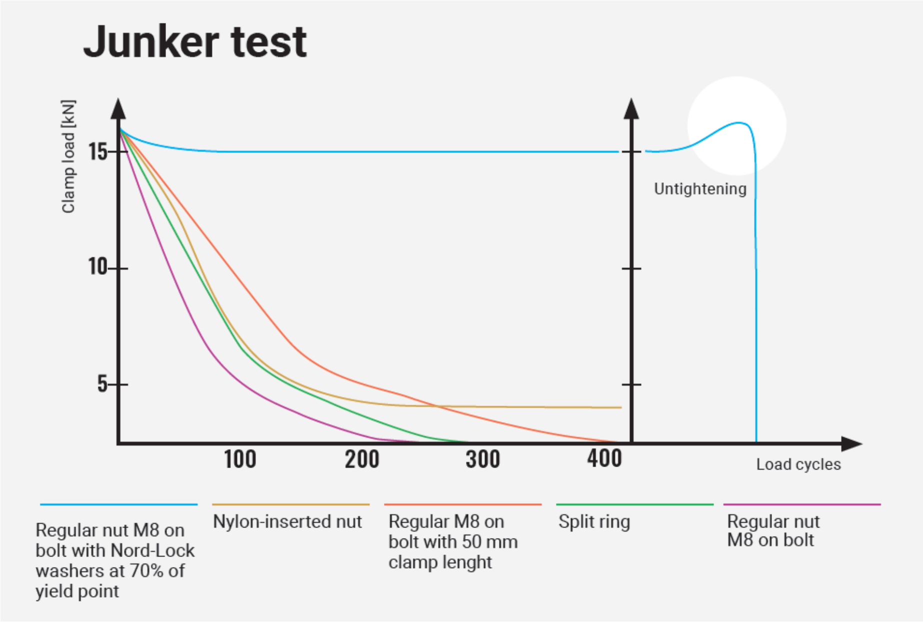

Fig. 3. Graph from the Junker vibration test [2].

These washers can be available in several different material variants. This is shown in Figure 4.The basic version is a steel washer in the EN 1.7182 standard.Hardness 465HV1, sizes available for threads from M3 to even M130.Another variant are stainless steel washers in the EN 1.4404 standard. Hardness 520HV0.05, dimensions for M3 up to M80 only.Designed for chlorine-free and acid-free environments. The third variant are washers made of 254 SMO® material in the EN 1.4547 standard. For Corrosive environment, chloride rich environments, pumps, heat exchangers, nuclear, food, medical, processing. The fourth option is Alloy C-276 the EN 2.4819 standard or equivalent. Only for M4 to M20. Application for Acidic environment, chemical industry, evaporators, offshore, downhole tooling. The last variant is Alloy 718 in EN 2.4668 standard or equivalent. Also only for M4 to M20. Hardness up to 620HV0.05. For high temperatures, gas turbines, turbo charges, incinerators.

Fig. 4. Various material variants [3].

The purpose is to create a simulation model that takes into account the effect of wedge lock of the washers. The most recognizable manufacturer of these washers presents a graph which clearly shows that the tension in the thread increases when loosening the screw. Figure 5 shows a graph based on the manufacturer's data.

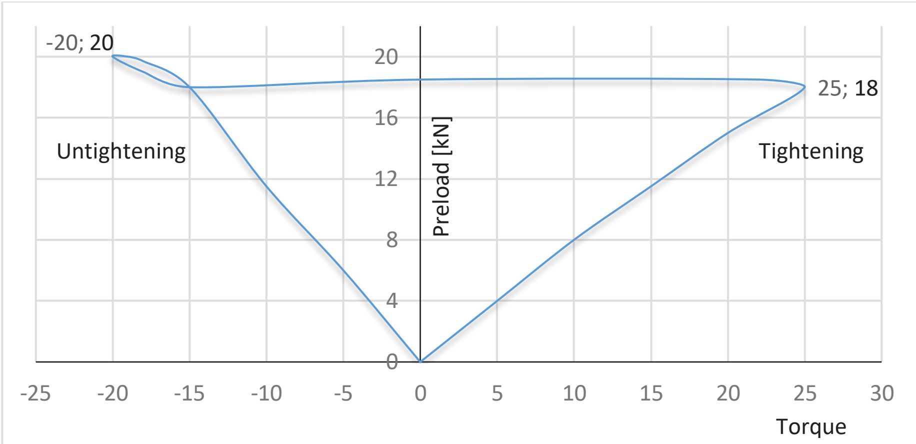

Fig. 5. Torque-Preload graph for galvanized screw M8 – 8.8 using the wedge washers. Thread friction coefficient $\mu_{th} = 0.10$; Washer friction coefficient $\mu_b = 0.16$; Lubrication withmachine oil; The resulting preload in relation to yield point Gf = 75%; Tightening torque M_T = 25 Nm; Preload F = 18 kN [4]

2 Geometry of the analyzed model

A model was prepared for the analysis, consisting of a hexagonal bolt, a clamped part inthe form of a plate with a threaded hole and a pair of wedges washers. The geometry of the washers is in most consistent with the data from the quality control protocol from Nord-Lock Group. Figure 6 shows the exact dimensions of analyzed model.

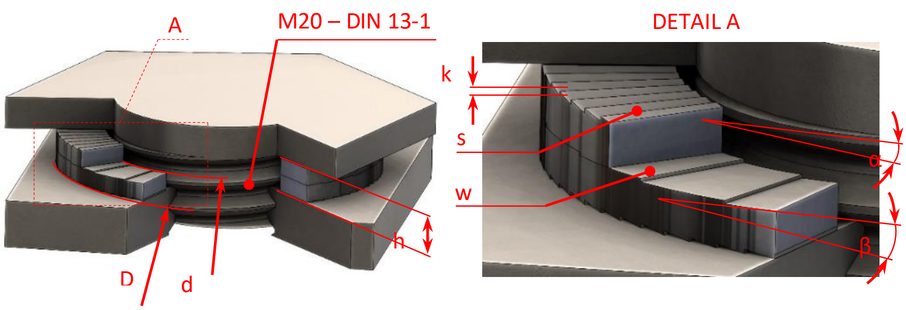

Fig. 6. Exact dimensions of the analyzed model – view using partial sections. Number of wedges w = 20; Number of serrations s = 80; Height of a pair of washers h = 3.4 mm; Serrations height k = 0.163 mm; Inner diameter d = 20.4 mm; Outer diameter D = 30.7 mm; Wedge angle β = 3.19°; Thread diameter M20 mm; Thread pitch P = 2.5 mm; Helix angle of the thread α = 2.28°

3 Material properties

According to the manufacturer's recommendations, the clamped part must be made of a material softer than the washers themselves. The washers are made of EN 1.7182 boron steel, hardened to over 465 HV1. The strength class of the bolt is 8.8. Based on this data, two material properties were specified. This is shown in table 1.

Table 1. Material properties created in the program.

Part Name	M20 8.8 Bolt	Clamping part	Wedge washers
Mass Density	7850 kg/m^3		
Young's Modulus	210 GPa		
Poisson's Ratio	0.3		
Yield Stress	640 MPa		1000 MPa
Tensile strength limit	800 MPa		1250 MPa
Maximum plastic strain	13.5%	13.5%	8%
Hardening	Isotropic		

4 Assembly and Steps

Independent part instances were created from imported parts. To calculation steps were prepared, the parameters of which are presented in table 2.

Table 2. Step parameters.

Step Name	Initial	Tightening	Untightening
Procedure	(Initial)	Dynamic, Explicit	
Nlgeom	N/A	ON	
Time period	N/A	1.0	2.0
Mass Scaling	N/A	0.0001	

5 Constrains

To give proper boundary conditions two constraints were first created. The first constraint is the coupling of the references point with the bolt head. The second constraint is the coupling the references point with the bottom of the clamped part. This is shown on Figure 7.

a) b)

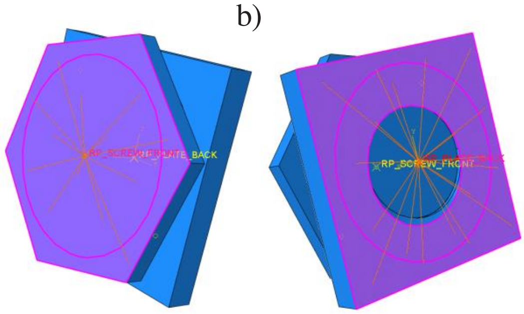

Fig. 7. Constraints: a) coupling references point with bolt head, b) coupling references point with bottom of plate.

6 Boundary conditions

Table 3 below lists the boundary conditions used in the simulation.

Table 3. Step parameters.

Step Name	Tightening	Untightening
Encastre (All degrees of freedom are taken away)	The clamped part was fixed	
Displacement	-0.1 mm	0.2 mm
Rotation	$-\frac{2}{25}\pi$ rad (≈0.251327)	$\frac{4}{25}\pi$ rad (≈0.502655)
Amplitude	Tabular, from 0 to 1	

7 Mesh

Figures 8, 9 and 10 show the details of the mesh created on the part instances.

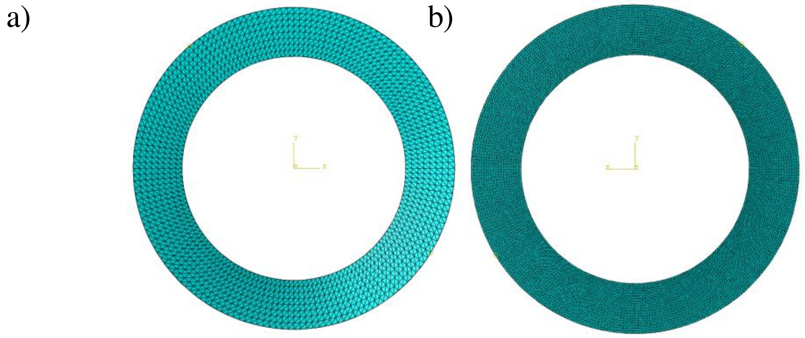

Fig. 8. Mesh created on the washer part instance: a) side of serrations, b) side of wedges/cams. Shape of elements: regular tetrahedron. Elements size approximately: 0.6 mm on serration, 0.3 mm on wedges.

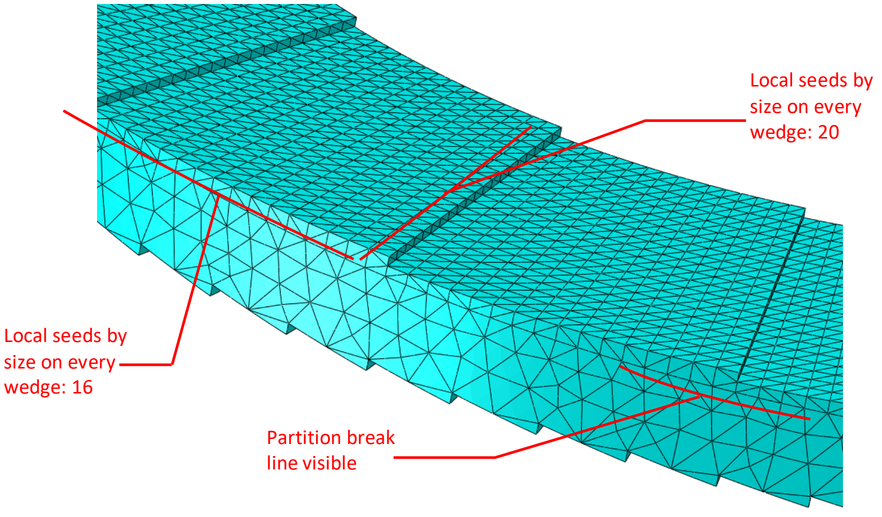

Fig. 9. Details related to meshing on an washer part instance.

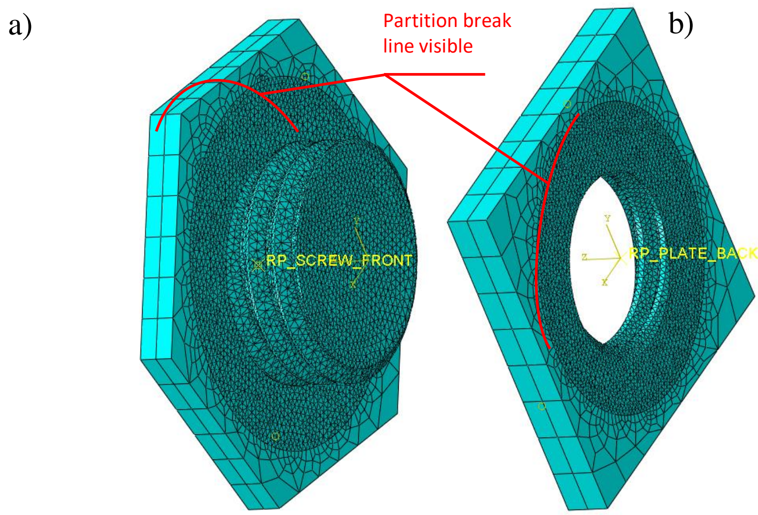

Fig. 10. Details related to meshing on an bolt (a) and plate (b) part instance. Elements size approximately: 0.6 mm on thread.

8 Interactions and interaction properties

Table 4 below shows the details of the contact properties used in the model. Figure 11 shows the contact on the wedges.

Table 4. Interactions and interaction properties

Property Name	IntProp_Wedge	Int_Prop_General
Friction formulation	Tangential behavior	
	Penalty; Friction Coeff. 0.05	Penalty; Friction Coeff. 0.2
Pressure-Overclosure	Normal behavior	
	“Hard” Contact	“Hard” Contact
Used	Surface-to-surface contact (Explicit) on wedges	General contact (Explicit)

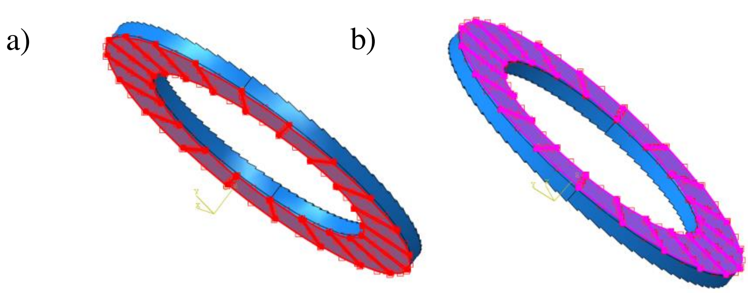

Fig. 11. Contact properties used on the wedges in pair of washers: a) Master surface on wedges of first washer, b) Slave surfaces on wedges of second washer. Mechanical constraint formulation: Kinematic contact method. Type: Surface-to-surface contact (Explicit)

9 Results

Figures 12, 13 and 14 show the simulation results using the finite element method.

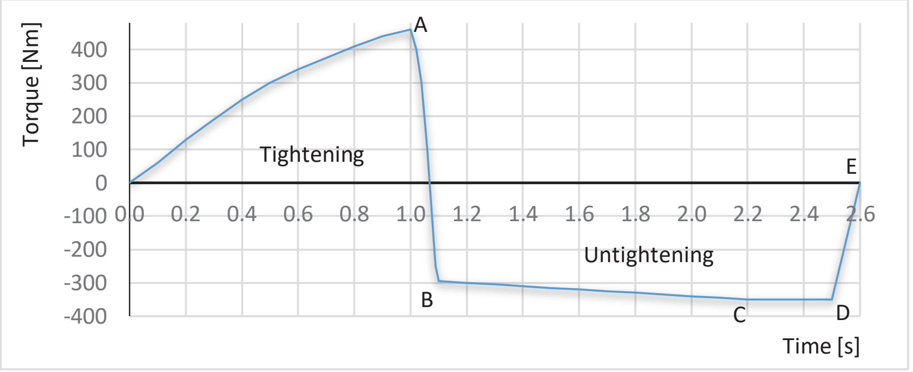

Fig. 12. Torque-Time graph using the FEM after data processing. A – The point where tightening ends and the torque changes its direction. B – The point where untightening begins. C - Point that is described in details below the graphs. D - The point at which the wedges slide together and the bolt is unscrewed from the clamping part, so that both the thread frictional moment and the wedge frictional moment are no longer generated.

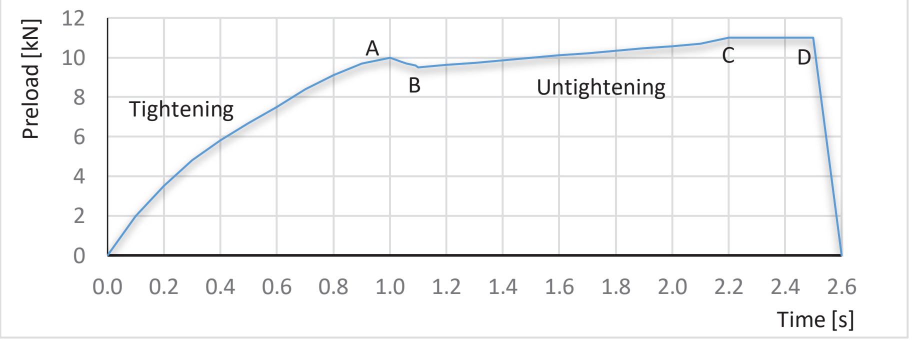

Fig. 13. Preload-Time graph using the FEM after data processing. A – The point where tightening ends. B – The point where untightening begins. C - Point that is described in details below the graphs. D - The point at which the wedges slide together and the bolt is unscrewed from the hole.

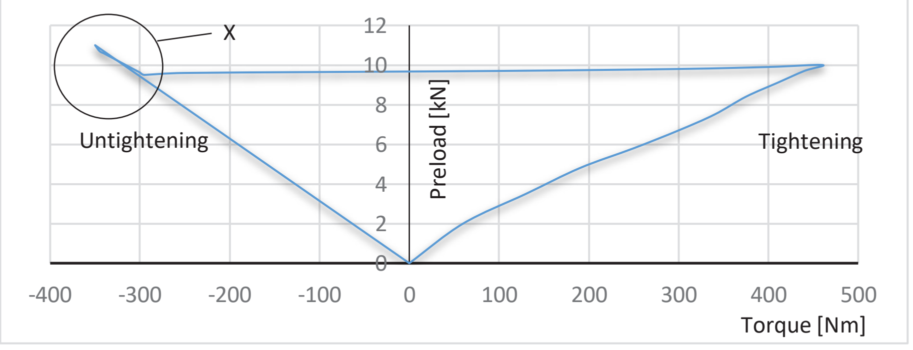

Fig. 14. Torque-Preload graph using the FEM. Area X is described in detail below the graphs.

Point C, which is visible both in the graph in Figure 8 and in the graph in Figure 9, is a point in time before the wedges slide off each other. The graphs show that from this point C neither tension in the bolt nor the loosening torque increases. This requires further, more detailed tests to check that the wedges are not deformed from point C. One should also check what kind of deformation it is: elastic or permanent plastic. If plastic, then how much is the displacement. This is important in the context of the manufacturer's claims that the washers are reusable. It is not necessary for this analysis. In order to investigate the type of wedge deformation, in a further stage of the research, it is necessary to delve into a more detailed determination of the material properties of the hardening steel, which the washers are made of.

As for the area X marked in the graph in Figure 10, there is a small annotation: the graph in Figure 1 shows a sort of "loop", which could not be achieved so precisely in the simulation. Of course, this is also not necessary for the creation of a valid, acceptable simulation model. However, this is also the purpose of subsequent tests, which can probably be achieved taking into account the above-described material problem related to point C.

Figure 15 shows the degree of deformation on the plate in the current simulation. The plastic deformation comes from the serrations cutting into the material of clamped part. Figure 16 shows also the deformation, but on the bolt head.

a) b)

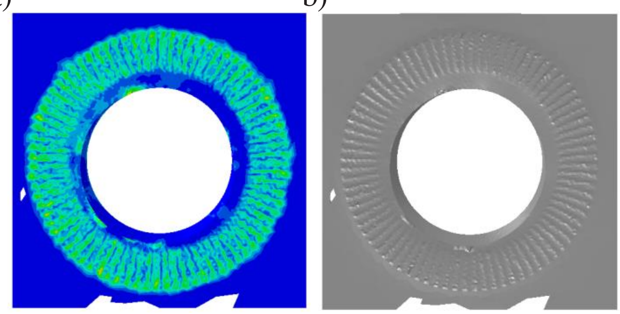

Fig. 15. Plastic deformation on the plate. Excessive deformations/distortions were removed in the visualization of the results: a) Contour plot on deformed shape, b) Deformed shape with deformation scale factor equal 25.

a) b)

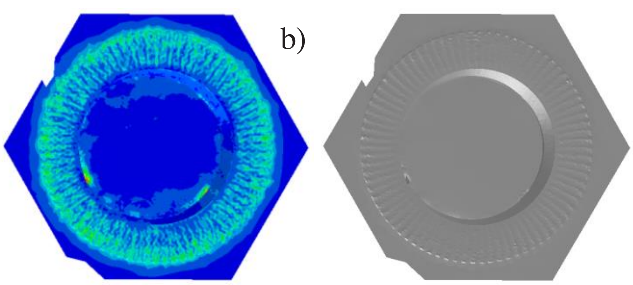

Fig. 16. Plastic deformation on the bolt head. Excessive deformations/distortions were removed in the visualization of the results: a) Contour plot on deformed shape, b) Deformed shape with deformation scale factor equal 25.

10 Summary

The paper presents the most important points of the algorithm for creating a correct, relatively acceptable simulation model of washers with a wedge lock effect. As a result, the correct graphs of dependencies were achieved: torque-time, preload-time and torque-preload. It was possible to obtain the effect of plastic deformation from cutting serrations. The simulation also showed that there is still a large area related to the topic of wedge washers that should be further investigated. However, this simulation model produces an approximate value for the maximum tension in the bolt that can be obtained from the wedge lock effect.

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