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Analysis of stresses and deformations in the chassis of rough terrain forklifts

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Abstract. The outcome of studying the strength and the deformation characteristics of rough terrain forklifts, using a created 3D model applying FEM, is presented herein. The tested chassis design features are described. The external loads of the chassis structure have been estimated throughout two operation modes: handling the load at vertically elevated lifting mast and also featuring load lifted off the ground, using lifting mast in transport mode tilted backwards. Two alternating payloads have been applied for each of the selected modes: featuring reated load and standard size of the centre of gravity, and featuring reduced load at increased height of the centre of gravity. The resulting rates of stresses and deformations of the studied chassis of a rough terrain forklift have been calculated, presented and analysed with regard to the two main operating modes both of which entail two loading alternatives determined by the weight and the location of the payload.

Key Words. rough *terrain forklifts, chassis, stresses, deformations, estimated strength, FEM.*

1. Object and purpose of the study

The manufacture of rough terrain forklifts and the relevant dedicated work equipment has shown a continuous trend of increasing volume in recent years. The reason thereof is the constantly increasing need for mechanising loading and unloading operations and some other types of work on particular varieties of terrain and also an improvement in productivity in the construction business, forestry and agriculture, etc. The fierce competition between the manufacturers of this equipment makes the point of increasing its functionality, strength, and operational reliability increasingly topical [6, 11]. This is very much the case for the chassis design that constitutes a primary assembly of any rough terrain forklift [1, 3, 17, 19].

In view of the fact that the chassis incorporates high degree of metal, weighing from 17% to 20% of the forklift total weight, its optimal design could entail decrease not only in the production costs but also in the operating costs [1, 3, 6, 10, 13].

Given the complex shape of the design components and assemblies, which is characteristic of rough terrain forklift chassis, there is not always an exact analytical solution for estimating stresses and deformations.

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Numerical methods, whereof the finite element method (FEM) has become the most widespread, could successfully solve the problem irrespective of the shape and the way of loading and fixing the body [2, 9, 12, 15, 18]. It makes FEM a very appropriate method of studying the phenomenon of stress concentration that is noticeable in abrupt and complex changes to the shape of the component or the assembly, the chassis of rough terrain forklifts being such. The resulting maximum stresses should not exceed the ones that are unsafe for the material.

Regarding resilient and tough materials, the yield limit shall be considered a dangerous stress – R_{eH} ($R_{p0,2}$), and the tensile strength and the compression strength – R_m and $R_{\overline{m}}$ – shall be considered unsafe stresses in respect of fragile materials. The strength characteristics of materials are to be specified experimentally [6, 14]. Regarding the most often used machine-building materials, the reference books provide the values thereof [7].

The object of the study is a chassis of rough terrain forklifts featuring dual wheel drives; it is currently manufactured by the Balkancar Record JSC company [19].

The purpose of the study is to determine the stressed and deformed state of the structure of a rough terrain forklift chassis under two typical load conditions. When developing the model, the chassis has been subjected to the loads resulting from the forces of gravity of the main assemblies and units related thereto, such as engine, tanks, box, lifting mast, counterweight, etc.

The main purpose of the study is to identify the critical points in the chassis design based on the results of the strength and deformation analysis.

An FE model of the chassis and the stresses and the deformations thereto have been made using the SOLIDWORKS Simulation Xpress module within SOLIDWORKS 2019 [9].

2. Load conditions of the chassis of a rough terrain forklifts

The chassis, selected for the study, is used in the R2SR forklifts series, manufactured by Balkancar Record JSC, with wheel drive formula 4X2 and lifting capacities of 30, 40, and 50 kN. [19].

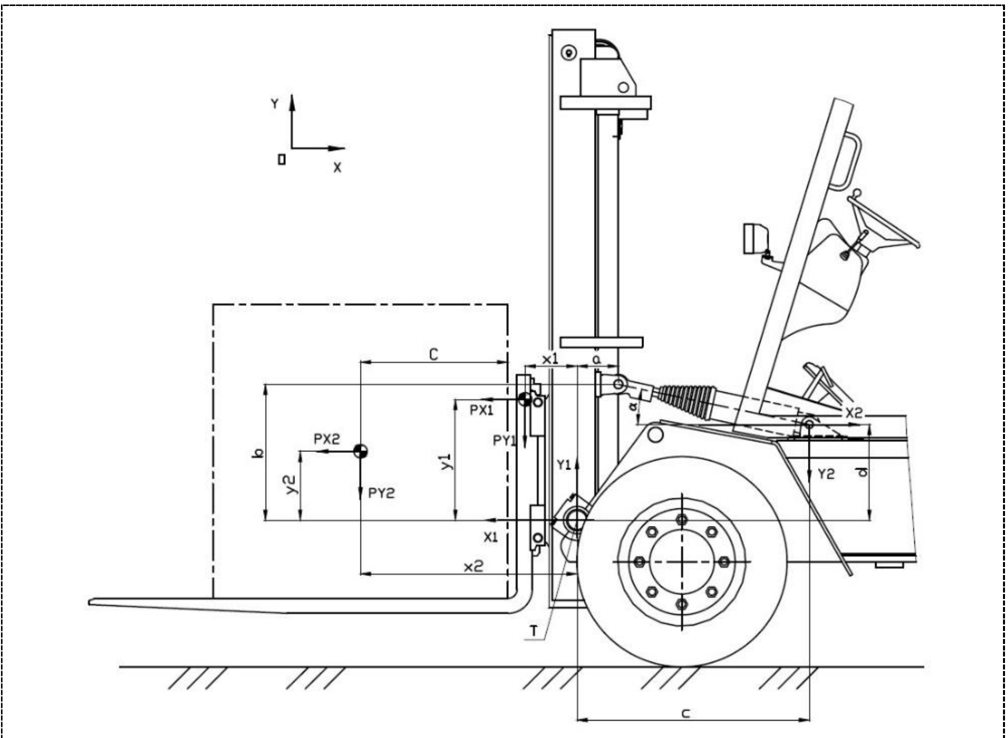

Figure 1. Mode one: Loading by taking the load at vertically elevated lifting mast

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The chassis has welded steel structure made of sheet material. The two side plates, left and right, constitute the main carrying elements of this chassis. They are flexed in the form of a Π-shaped section. Since they are linked to the wings and the transverse shield at the front, and to the plates whereto the weight is fixed, at the back, the result is a box-like enclosed form. The side plates thickness is 10 mm, and the mostly used material for these is steel ST355JR. Based on the experience acquired in the perennial company business, the calculations have been made in respect of the two most typical load conditions in the use of these machines [6].

2.1. ***Mode one*** *– taking the load at vertically elevated lifting mast*

2.2. ***Mode two*** *– load lifted 300 mm off the ground, the lifting mast being tilted backwards in transport position*

Calculations involving two positions of the centre of gravity of the load have been made, with regard to each of both load conditions, where C = 600 mm and C = 900 mm concerning the heaviest model representing the series, DV1798, which features lifting capacity of 50 kN [19].

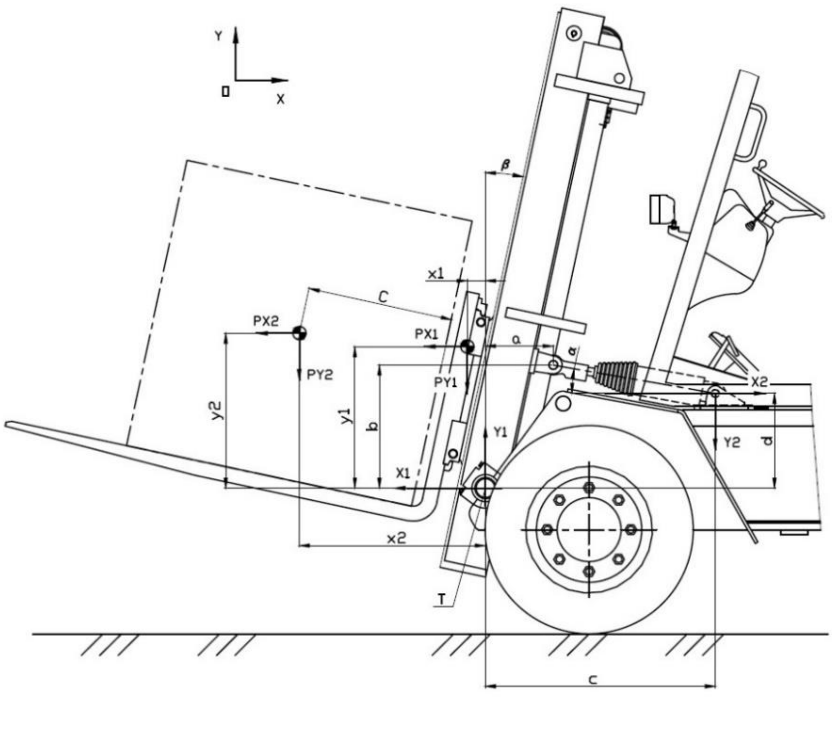

Figure 2. Mode two: Load lifted 300 mm off the ground, the lifting mast being tilted backwards in transport position

It is known from the theory and the design of forklifts [1, 3, 6] that when moving the centre of gravity forward, in respect of the longitudinal axis of the forklift, the reated load should be reduced in order to preserve the machine stability against overturning while handling any load [4, 5, 8].

Therefore, the second purpose of the study has been set – to identify and analyse the stressed state of the chassis structure and its deformed state at various positions of the centre of gravity and using various rates of the payload, which ensure the longitudinal stability of the terrain forklift against overturning [4, 5].

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3. Stresses and deformations in the chassis of a rough terrain forklift featuring dual wheel drive

3.1. Stresses and deformations of the chassis under the first load conditions featuring a standard centre of gravity at C = 600 mm and a rated load of Q = 50 kN.

The results of testing the strength under the first load conditions, featuring a standard centre of gravity of the load at C = 600 mm and a rated load of Q = 50 kN, are shown in Figure 3 and Figure 4.

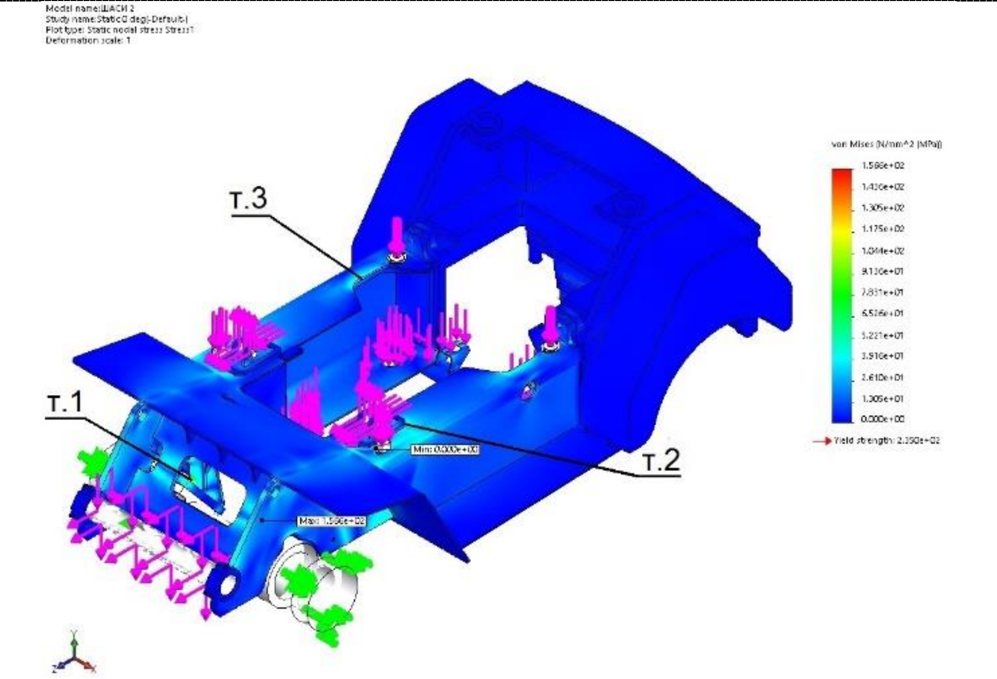

Figure 3. Stresses in the chassis under the first load conditions featuring a standard centre of gravity at C = 600 mm and a rated load of Q = 50 kN

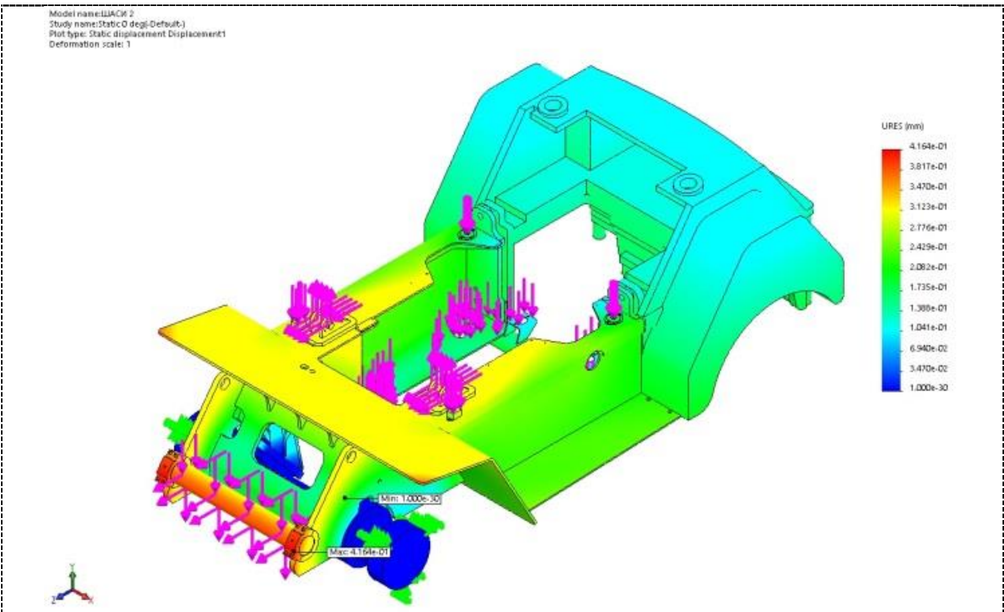

Figure 4. Deformations of the chassis under the first load conditions featuring a standard centre of gravity at C = 600 mm and a rated load of Q = 50 kN

3.2. Stresses and deformations of the chassis under the second load conditions featuring a standard centre of gravity at C = 600 mm and a rated load of Q = 50 kN.

The results of testing the strength under the second load conditions, featuring a standard centre of gravity of the load at C = 600 mm and a rated load of Q = 50 kN, are shown in Figure 5 and Figure 6.

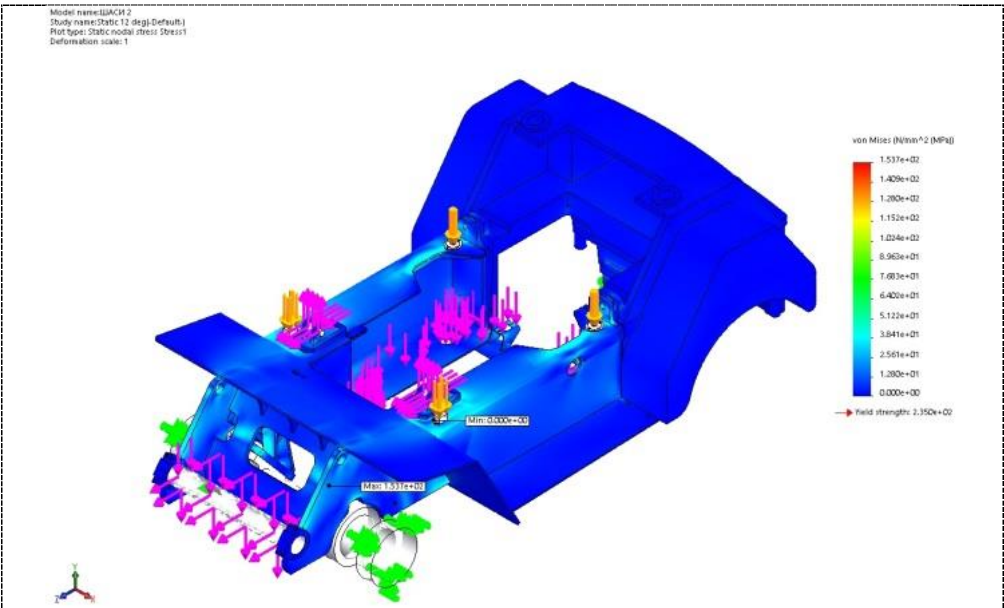

Figure 5. Stresses in the chassis under the second load conditions featuring a standard centre of gravity at C = 600 mm and a rated load of Q = 50 kN

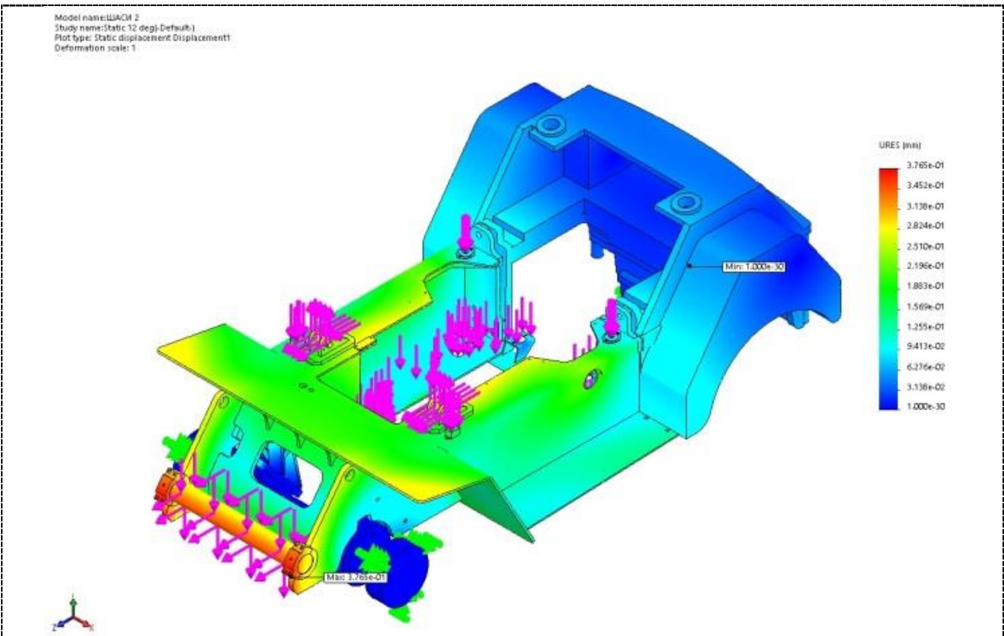

Figure 6. Deformations in the chassis under the second load conditions featuring a standard centre of gravity at C = 600 mm and a rated load of Q = 50 kN

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3.3. Stresses and deformations in the chassis under the first load conditions featuring an increased centre of gravity of the load at C = 900 mm and reduced load of Q = 35 kN

The results of testing the strength under the first load conditions and featuring increased centre of gravity at C = 900 mm and reduced load of Q = 35 kN, are shown in Figure 7 and Figure 8.

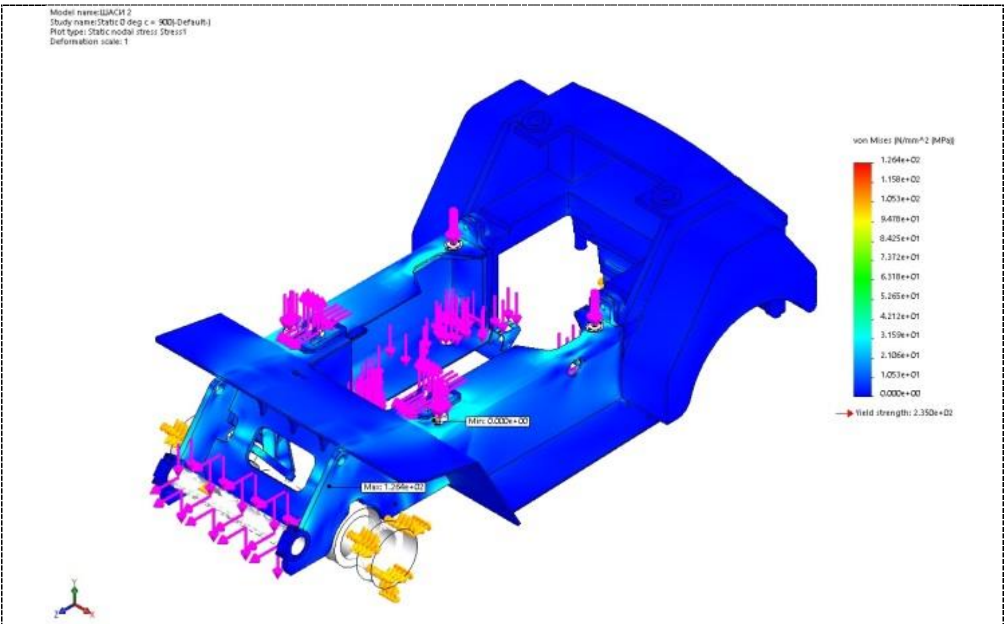

Figure 7. Stresses in the chassis under the first load conditions featuring an increased centre of gravity at C = 900 mm and reduced load of Q = 35 kN

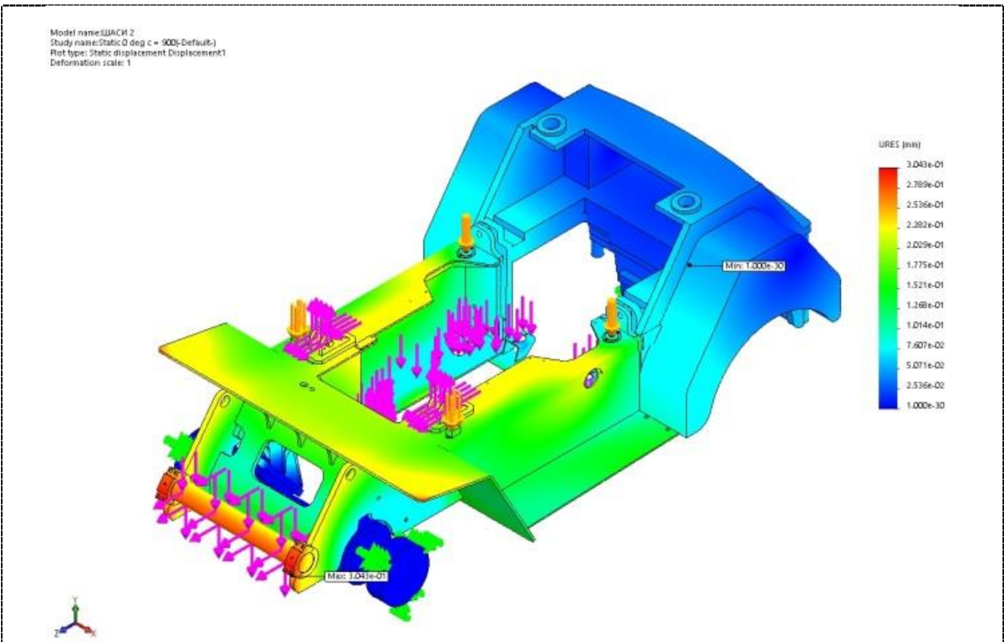

Figure 8. Deformations of the chassis under the first load conditions featuring an increased centre of gravity at C = 900 mm and reduced load of Q = 35 kN

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3.4. Stresses and deformations of the chassis under *the second load conditions featuring an increased centre of gravity at C = 900 mm and reduced load of Q = 35 kN*

The results of testing the strength under the second load conditions and an increased centre of gravity at C = 900 mm and reduced load of Q = 35 kN, are shown in Figure 9 and Figure 10.

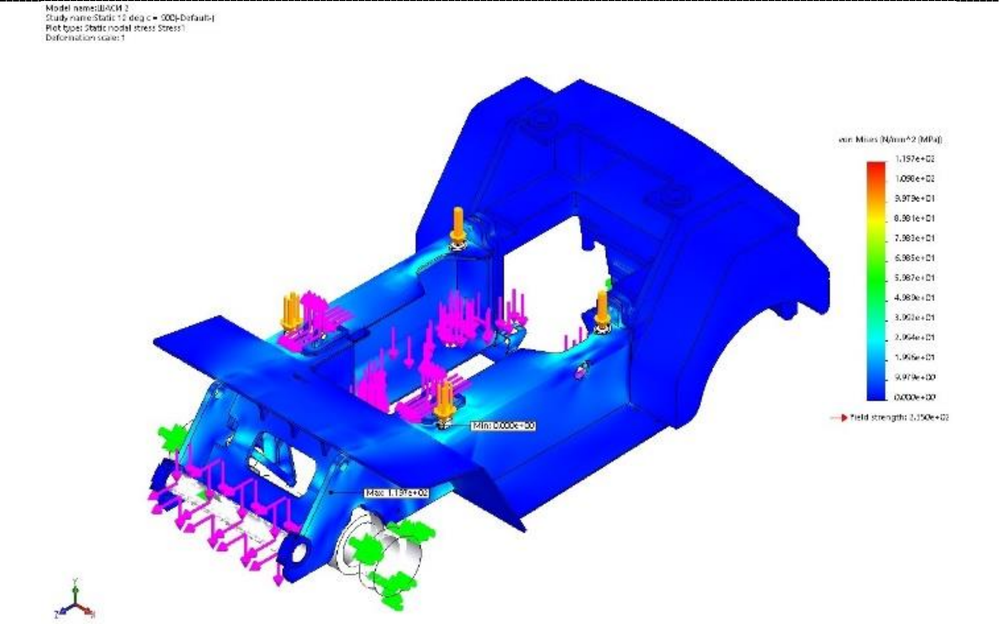

Figure 9. Stresses in the chassis under the second load conditions featuring an increased centre of gravity at C = 900 mm and reduced load of Q = 35 kN

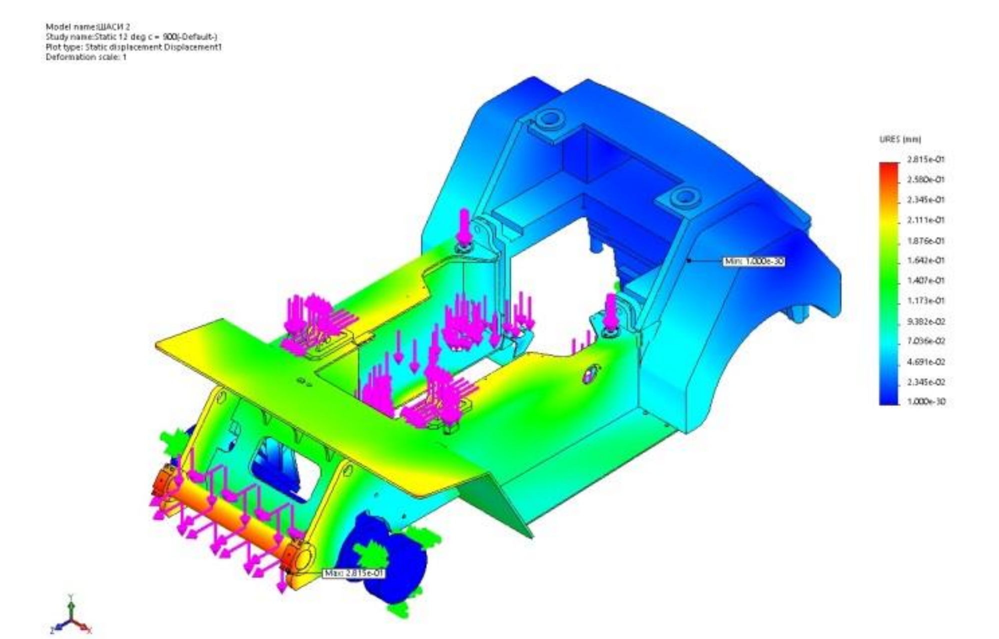

Figure 10. Deformations of the chassis under the second load conditions featuring an increased centre of gravity at C = 900 mm and reduced load of Q = 35 kN

3.5. Results analysis

Based on the obtained results, the following conclusions could be drawn:

1) The critical points in the structure, where the highest stresses under both load conditions have been identified, could be reduced to three, shown on Figure 3: Point 1 – underwing plate used for fixing the drive axle; Point 2 – front upper section of the carrying side plate within the bracket of the tilting cylinder; Point 3 – the rear section of the carrying side plate within the counterweight carrying plate. The estimated maximal static stresses are $\sigma_{Max} = 156$ MPa within the underwing plate (p. 1) in the first instance of loading – taking the load. This value has been confirmed by the conducted strain measuring tests of a chassis of this class of machines at the testing laboratory of Balkancar Record JSC. Pursuant to [3], the dynamism coefficient of chassis and lifting mast of rough terrain forklifts, featuring pneumatic tyres, is $C_d = 1.9$. The maximum stress value multiplied by the dynamism coefficient results in the highest stress value – 296 MPa. Considering the fact that the yield limit regarding the ST 355 JR steel, whereof the chassis components have been made, is 355 MPa, it may be assumed that this section of the construction is optimal.

2) There is a negligible difference in the values of the maximal static stresses regarding both load conditions. When the load is being lifted, the values are 3-6 MPa higher than the ones regarding tilted lifting mast, which shows that operating the forklit in both load conditions does not considerably affect the stresses; it is stability that matters more.

3) Regarding the calculations entailing an increased centre of gravity and reduced load at both load conditions, the registered stresses have been 25% lower compared to the ones entailing reated load and a standard centre of gravity. It practically means that with regard to a forklift optimally designed for rated loads and a standard centre of gravity, compliance with the loads chart specified by the manufacturer shall ensure not only the required stability but also the strength and the reliability of the forklift chassis structure.

4) The achieved results regarding the structure stresses in the other two critical points, 2 and 3, show that there is sufficient reserve for additional lightening the chassis structure by further reduction of the thickness of the carrying side plate, from 10 mm to 8 mm, in respect of forklifts of this series that feature smaller lifting capacity, i.e. 30 kN and 40 kN.

4. Conclusion

The resulting values of the stresses and the deformations in the chassis of rough terrain forklifts have been calculated, presented and analysed using the created 3D model applying the FEM under two main operation modes, each of which has undergone two alternative types of loading determined by the weight and the location of the payload.

A real assessment of the strength and the deformations of the chassis of rough terrain forklifts has been made by analysing the obtained numerical results, and changes to the chassis structure have been proposed, which determines the practicality and the applicability of this study.

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