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.
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 \( R_{\pi} \) – 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](image-url)
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 where 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].

![Diagram](image)

**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].
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 \( C = 600 \text{ mm} \) and a rated load of \( Q = 50 \text{ kN} \).

The results of testing the strength under the first load conditions, featuring a standard centre of gravity of the load at \( C = 600 \text{ mm} \) and a rated load of \( Q = 50 \text{ kN} \), 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 \( C = 600 \text{ mm} \) and a rated load of \( Q = 50 \text{ kN} \)

**Figure 4.** Deformations of the chassis under the first load conditions featuring a standard centre of gravity at \( C = 600 \text{ mm} \) and a rated load of \( Q = 50 \text{ kN} \)
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
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
3.4. Stresses and deformations of the chassis under the second load conditions featuring an increased centre of gravity at \( C = 900 \text{ mm} \) and reduced load of \( Q = 35 \text{ kN} \)

The results of testing the strength under the second load conditions and an increased centre of gravity at \( C = 900 \text{ mm} \) and reduced load of \( Q = 35 \text{ kN} \), are shown in Figure 9 and Figure 10.
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 $\sigma_{\text{max}} = 156 \text{ MPa}$ 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 forklift 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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References

[1] Georgiev G 1980 Design, construction and calculation of forklifts Technika Sofia Bulgaria
[2] Genov J and Kralov I 2019 A linear quadratic regulator synthesis for a semi-active vehicle suspension Part 1-Modeling of the dynamical system AIP Conf. Proc. 2172 110006 1-8
[3] Evtimov I 2014 Electric and motor forklift trucks University of Ruse, Ruse, Bulgaria

[4] Iliev I and Nikolov V 2007 System for automatic stability of forklift trucks Patent BG 62225 B1 November 15 2007

[5] Iliev I and Nikolov V 2007 System for control of the operations of forklift trucks Patent BG 62226 B1 November 15 2007

[6] Kostov K 1982 Electric and motor forklifts. Methodology for strength testing and strength assessment IEM Sofia Bulgaria

[7] Nikolov N and Tsonev V 2013 Strength of materials Handbook Avangard Prima Sofia Bulgaria

[8] Nikolov V 2013 Mechanical-mathematical modeling of the tilting process of lifting masts of forklift trucks with load Journal of the Technical University at Plovdiv “Fundamental Sciences and Applications” Plovdiv Bulgaria 19(2) 347-350

[9] Rusimov V, Borisov I, Dimitrov N and Angelov P 2019 SOLIDWORKS - Modeling and Drawings Technologika Sofia Bulgaria

[10] Sofronov Y, Stoyanova Y, Kopralev N and Todorov G 2019 Kinematic study of the articulated trucks operating layout of turn for articulated vehicles TechSys 2019 16-18 May Plovdiv Bulgaria IOP Conf. Se.: Mat. Sc. and Eng. 618 012044

[11] Stoilov K and Karadimitrov I 1989 Attachment equipment for forklifts Technika Sofia Bulgaria

[12] Stoychev G, Chankov E, Dimova B 2010 Stress analysis of a fork-lift truck lifting installation BulTrans-2010 24-26 September Sozopol Bulgaria Proc. 205-208

[13] Todorov G and Kamberov K 2017 Virtual prototyping of drop test using explicit analysis AIP Conf. Proc.1910 020012

[14] Tsonev V Kuzmanov N Borisov B and Penkov K 2019 System for materials testing at static loading TechSys 2019 16-18 May Plovdiv Bulgaria IOP Conf. Se.: Mat. Sc. and Eng. 618 012048

[15] Tsonev V Stoychev G Chankov E 2017 Stress analysis of a link for slat chain conveyor BulTrans-2017 11-13 September Sozopol Bulgaria Journal MATEC Web of Conferences 133

[16] Valkov G and Nikolov V 2018 Classification of terrain forklifts 7th Int. Sc. Conf. TECHSYS 2018 Plovdiv Bulgaria Proc. 253-257, ISSN online: 2535-0048

[17] Valkov G and Nikolov V 2019 Analysis of the power drives of terrain forklifts. Proc. of 12th Int. Sc. Conf. “Environment. Technology. Resources” June 20-22 2019 Rezekne Academy of Technologies Rezekne Latvia III 241-248

[18] Yordanov P and Petkov G 2018 Comparative Study of the Bending and Torsional Stresses in Opened Cross Section Thin-Walled Beam. Sc. Jour. Mechanics of Machines 121(3) 49-53 ISSN 0861-9727

[19] https://balkancar-record.com/en-US/Products/Forklifts, [Accessed March 9, 2020]