Changing the spatial structure of the rocker arm of the tipping mechanism in a garbage truck

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Abstract. Building a model of spatial structure of the rocker arm and its design optimization are related to the problem of excess weight of the rocker arm in the garbage tipping system. The simulation was aimed at producing a structure where stresses are minimized. The body of the rocker arm model was determined using the Equivalent Static Load Method (ESL). Based on the simulation, the design of the rocker arm was developed. The weight of the improved rocker arm was reduced by 10.8 kg while maintaining the level of stress produced by loads.

1. Introduction
The container tipping system is an important part of the garbage truck design (Figure 1). Its main function is to pick up the waste container and rotate it so that the waste is dumped into the hopper of the truck. The system consists of support frame 1, folding hydraulic cylinder 2, rocker arm 3, pull rod 4 and support stand 5, as shown in Figure 2. When the piston extends, the folding hydraulic cylinder sets the waste container with support stand in motion rotating it counterclockwise and tips the container over into the hopper.

The initial position is achieved by retracting the piston of the folding hydraulic cylinder. In this case, it is difficult to determine the operating conditions of the rocker arm, which is affected by the system of forces, since it is a part of a four-link mechanism. The currently used rocker arm is bulky and heavy, which reduces the overall load capacity of the garbage truck.

The increasing volume of waste collection led to the idea of optimizing the design of the rocker arm and the spatial arrangement of its elements. In the study [1], optimization was carried out using the finite element method in the ANSYS software environment. Another research [2] presents a static analysis of the forces applied to the rocker arm under maximum load conditions. The finite element method is also used to analyze the strength of the rocker arm in the study [3]. Papers [4,5] analyze dynamic loads in container tipping systems. Paper [6] is focused on validating the design changes to small waste collection truck made in the stress analysis environment.

The aforementioned works focus on the analysis of one operating position of the rocker arm simulated as an elastic body, which is quite different from the actual process of tipping a container.

For solving the above issue and data preprocessing, the Hyperworks environment was used. The complex stress state of the rocker arm in real-life conditions and the optimal load were addressed using the Motionsolve module, and the optimization of the spatial structure was carried out using Optistruct.

The article discusses a fully loaded rocker arm, and the analysis of the design optimization is carried out using a dynamic model, where the rocker arm is considered as an elastic body with a hinged pull rod, which is more consistent with the real-life operation.
2. The theory of elastic body and topological optimization

A complex mechanical system, consisting of several objects connected by hinges, is called multi-link. It can be described as a rigid system of elastic bodies joined by rigid links. In such case, the deformation of the bodies should be addressed in the simulation.

A flexible body is associated not only with the general motion of the system, but also has its own elastic deformation. It can be described as a set of nodes of a finite element model, with the deformation as a linear superposition of the shape in this model. The nodes in the local coordinate system will perform translational and rotational motion relative to a slight displacement of the model coordinate system.

In this article, the rocker arm is considered as an elastic body and other components of the tipping system as rigid bodies.

The main idea of optimization is to transform the structure to reach optimum distribution of material. Optimization methods chosen are variable thickness method, homogenization method and relative density method.

The mathematical optimization model with the variable thickness method is simple, but the optimized object can only be applied to two-dimensional space.

The homogenization method is a physical description method and is widely used. The basic idea is to introduce the microstructure shown in Figure 3 into the topological model. The area of the microstructure is defined in the expression $\Omega_\varepsilon = \int (1 - ab)d\Omega$, the density function of the element is $\rho = (1 - ab)\rho_s$, where $0 \leq a \leq 1$, $0 \leq b \leq 1$. $\Omega$ is the computational domain, $\Omega_\varepsilon$- object domain, $\rho_s$ - material density, a and b - design parameters.
The relative density method is a common topological optimization method, and its main idea is to introduce not an elementary microstructure, but a hypothetical material, the relative density of which varies from 0 to 1.

The material model can be described by a system of equations:
\[
\rho(x) = x_e \rho_0 \quad (1)
\]
\[
E(x) = x_e^0 E_0 \quad (2)
\]
where: \( \rho_0 \) and \( \rho \) – initial and final density of the topological structure; \( E_0 \) and \( E \) – initial and final elasticity of the topological structure of homogeneous objects, respectively; \( x_e \) – the relative density of the hypothetical material.

The relative density of the hypothetical material is used as a design variable, so optimization translates into optimal material distribution in the rocker arm design. The algorithm of the topological optimization process is shown in Figure 4.

**Figure 3. Elementary microstructure**

**Figure 4. Algorithm of Typical Topological Optimization Process**
3. Building of the master model of the rocker arm and the model of topological optimization

In the original design the rocker arm is welded from steel plates, properties shown in Table 1.

| Properties of steel plates |
|---------------------------|
| Elastic modulus (MPa)     | Poisson’s ratio | Density (t mm⁻³) | Tensile strength (MPa) | Permissible stress (MPa) |
| 210,000                   | 0.28            | 7.9e-09          | 235                     | 156                      |

Following the analysis and calculation, the maximum stress of the rocker arm has been determined at 90.3 MPa, which is much less than the permissible value, as shown in Figure 5. The weight of the rocker arm reached 24.5 kg, which is relatively heavy.

![Figure 5. Stress level of the original structure](image1)

The main space of original rocker is filled, and the three pivot points are set as non-project areas. (fig. 6.)

![Figure 6. Topological model of the rocker arm (non-project areas shown in blue color)](image2)

The objective function and the constraints must be defined prior to the topology optimization. The objective function is the minimum number of design areas and elements, while the constraint is imposed at the permissible stress level of 156 MPa.
4. Results of topological optimization of the rocker arm

The optimization calculations were performed in three iterations, the results for second and third iterations shown in Figure 7, 8.

![Figure 7. The second iteration of topological optimization](image1)

![Figure 8. The third iteration of topological optimization](image2)

After considering design and operational factors, the structure and design of the rocker arm took on the following form (Fig. 9).

![Figure 9. Optimized rocker arm](image3)
The level of stresses in the optimized rocker has been imitated (Fig. 10).

Figure 10. Stress level in the optimized rocker arm design

Optimization of the design of the rocker arm of the tipping system in a garbage truck and modelling the spatial arrangement of the material allowed to maintain maximum stress levels below the permissible level. Its value for the optimized design is about 132 MPa.

Optimization of material distribution allowed to reduce the weight of the rocker arm to 13.7 kg, which is 44% less than the weight of the original design. Thus, the main optimization goal, which was weight reduction of the existing rocker arm, has been achieved.

References
[1] Balovnev V I and Danilov R G 2019 Development of garbage trucks in Russia Construction and road machines 11 3–11
[2] Kargapol'tseva N P 2019 Removal and disposal of MSW: garbage trucks for solving urgent problems Municipal solid waste 11(161) 24–25
[3] Mironov S E and Safyannikov N M 2008 Construction of technologically invariant topology sketches based on the description of the topology in specific design codes Izvestia SPBGETU LETI 2 19–25
[4] Kiryan V I, Dvoretsky V I and Malgin M G 2012 Calculation of local stresses in the zones of welded joints of large spatial structures Automatic welding 4 (708) 3–7
[5] Suknev S V 2001 Taking into account the scale effect in strength calculations of structural elements with stress concentrators Factory laboratory. Diagnostics of materials 67 57–6
[6] Vitus M Tabie, Yesuenyegbe A K Fiagbe 2014 Weight optimization of A lift-Tipping mechanism for small solid waste collection truck International journal of scientific & technology research 3(11) 8–12
[7] Andruchov N M, Kulik K M, Pysnina D Yu 2020 Garbage trucks with replaceable containers Education. Transport. Innovations. Construction (Electronic Materials vol 3) ed Fedosov B B (Omk: SibADI) chapter 1 pp 4–8