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## ASSESSMENT OF THE EFFECT OF TOPOLOGICAL OPTIMIZATION OF METAL PARTS

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## ОЦІНКА ЕФЕКТУ ТОПОЛОГІЧНОЇ ОПТИМІЗАЦІЇ МЕТАЛЕВИХ ДЕТАЛЕЙ

**Purpose.** The purpose of this article is to evaluate the efficiency of using the “Shape optimization” option in the Fusion 360 software product of the American company Autodesk for the details of the braking system of a mining electric locomotive.

**Methodology.** With the advent of modern computer programs, the content of the design engineer’s work has changed, the design process has been reduced to the development of a 3D model of a metal product, which can then be subject to stress-strain analysis and, based on the results of this analysis, low-stress areas of the product which can be removed are determined, that is, the weight of the metal used is reduced. Of particular importance is generative design, which is a new design technology. It is based on the use of software that can independently generate three-dimensional models that meet specified conditions without the involvement of a designer. Essentially, in the “human-machine” system, creative functions are passed to the computer, which deals well with them. The second most important technology is topological optimization (Shape optimization), which is applied to a model already developed by the designer in order to improve it.

**Findings.** The paper presents the results of the research on reducing the weight of the parts of the braking system of the mine electric locomotive due to the topological optimization of their structures in the Fusion 360 software product. The removal of unloaded areas of the product was performed using the special option “Shape optimization” of this program. The effect of weight reduction in products after topological optimization is estimated to be approximately 35-45%.

**Originality.** The use of topological optimization in the details of the braking system of the mining electric locomotive is a new approach to optimizing the structure and obtaining parts of reduced mass.

**Practical value.** The application of topological optimization at the design stage helps to find a construction design option with the most rational distribution of material and voids in a given area taking into account strength and stiffness, and, thus, significantly reduce its weight.

**Keywords:** *mechanical braking system, brake lever, rocker arm, Fusion 360, topological optimization, mass reduction.*

**Introduction.** Resource depletion means consuming resources faster than they can be replenished. Natural resources are usually divided into renewable and non-renewable ones. The use of any of these forms of resources beyond the rate of their replenishment is resource depletion [1]. The value of resources is a direct result of their availability in nature and the cost of extracting them: the more the resource is depleted, the more its value increases [2].

The consumption of most metals continues to grow due to increasing population, welfare, and technical development. Common sense is calling for more efficient use of resources and preservation of metals in the economy.

Important ways of saving metal are structural ones (reducing the metal content of structures). They can include the following factors:

a) application of high-strength and corrosion resistant metals, as well as new metals with advanced physical and mechanical properties, which ensure weight reduction while increasing the durability, reliability and performance of products during operation;

b) development of the optimal design of the product from the point of view of strength and rigidity at the lowest weight.

**The main part.** With the advent of powerful computer programs (Inventor, Fusion 360, Solid Works, Ansys, etc.), the design engineer's work content has changed dramatically. The design process is reduced to the development of a 3D model of a metal work, which can then be subject to stress-strain analysis.

According to the results of this analysis, low-load areas of the product are determined, which can be removed, that is, the weight of the required metal can be reduced.

Removal of unloaded parts of the product can be done using the special option "Shape optimization", which has appeared in most of the above programs.

The content of this option involves topology optimization of the product. Topology optimization is an approach to structural design optimization that seeks the best distribution of material in a given area for specified loads and boundary conditions. Applying topology optimization during the design phase helps to find a design option with the most rational distribution of material and voids in volume, thereby significantly reducing its weight.

It should be noted that the geometry of the product after topology optimization can be quite complex and difficult to implement using conventional manufacturing methods. The emergence of additive technologies solves this problem.

The purpose of this article is to evaluate the effectiveness of using the "Shape optimization" option at the modern stage of development of the machine-building industry [3].

For this purpose, two parts of the mechanical brake system of the AM8 mining battery locomotive produced by the Druzhkivka Machine-Building Plant were selected (Fig. 1).



Fig. 1. AM8 electric locomotive

The main type of service braking on this electric locomotive is dynamic braking. The mechanical brake with a manual drive (Fig. 2) is used as a parking and emergency brake [4].

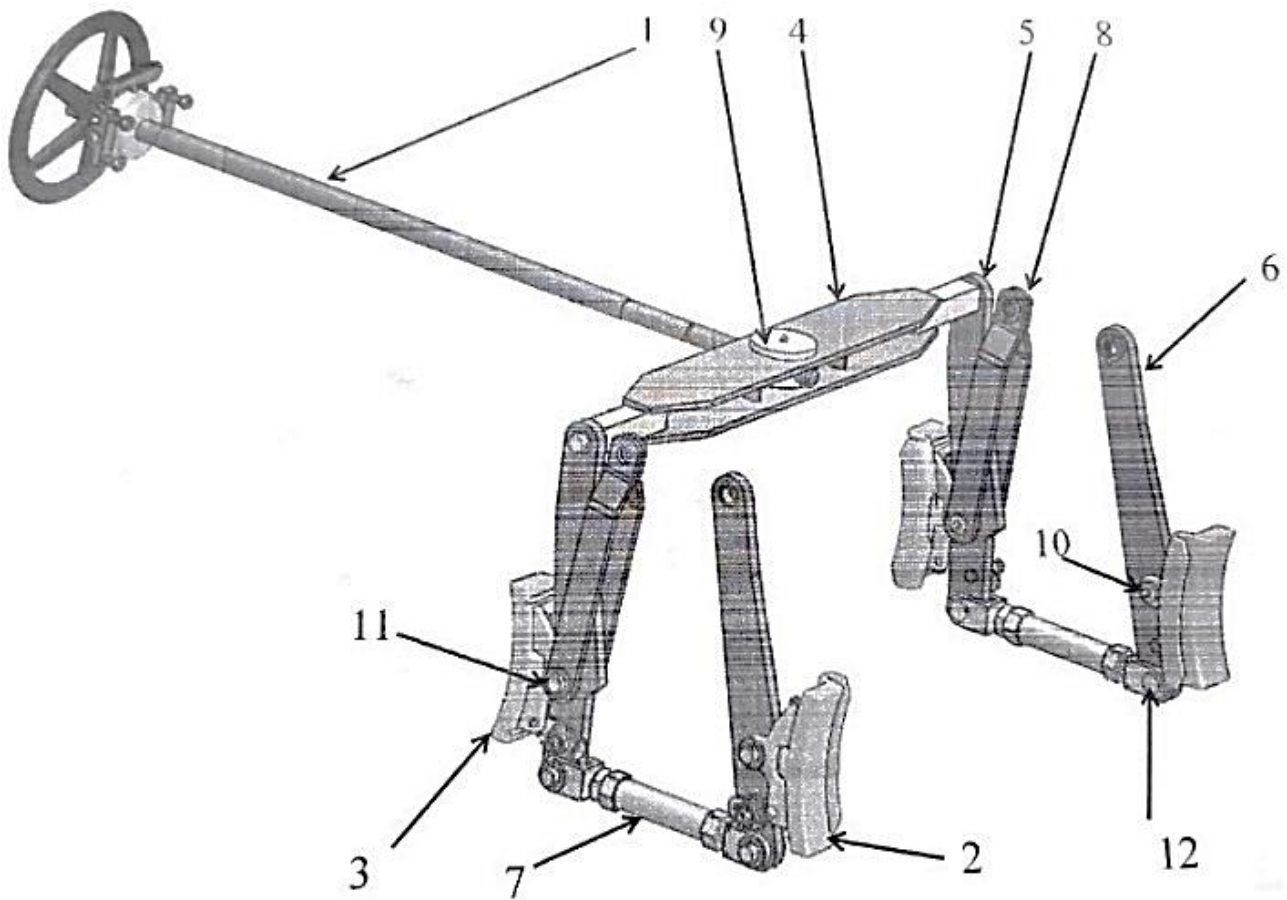


Fig. 2. Mechanical brake of the AM8 electric locomotive.

To brake the electric locomotive, the driver, using a wheel, rotates the screw 1 in the nut 9 installed in the lever 4. The lever acts on the brake levers 5, which press the cast iron brake pads 3 against the wheel rims. The resulting frictional force is realized as a braking force between the wheels and rails. The brake levers are suspended on the levers 8. The clearances between the brake pads and wheel rims are adjusted by the brake clamps 7. The hinge connection of the brake system parts is provided by the pins 10, 11, 12 [5].

Two objects with different designs were selected for topological optimization. The first object is the brake lever 6 (Fig. 2), used as a separate steel part. The second object is the lever 4 (Fig. 2), used as an assembly unit, whose weight was reduced to a reasonable minimum by the designer's idea.

Thus, 3D models of these two objects were developed (Fig. 3, 4).

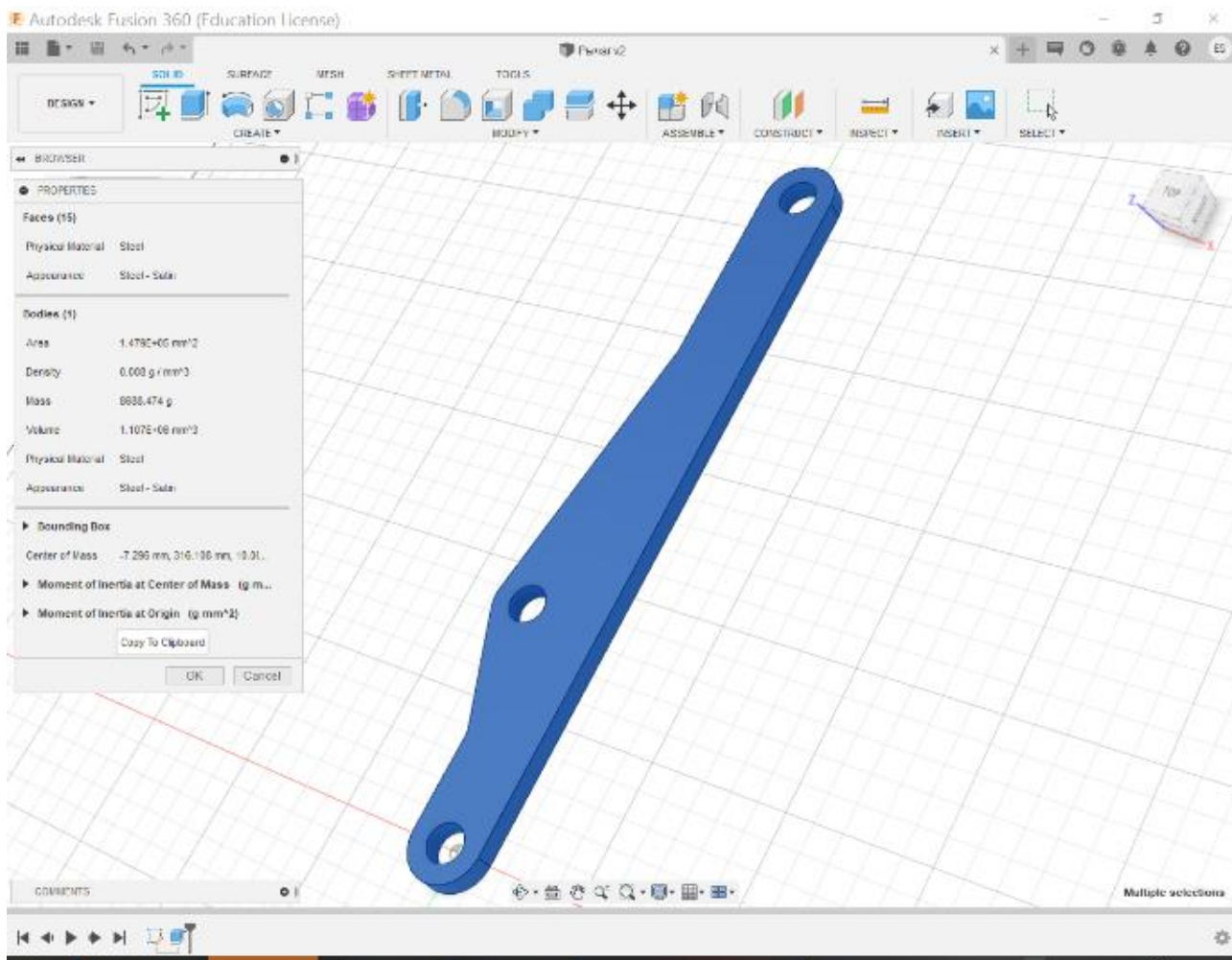


Fig. 3. 3D model of the brake lever

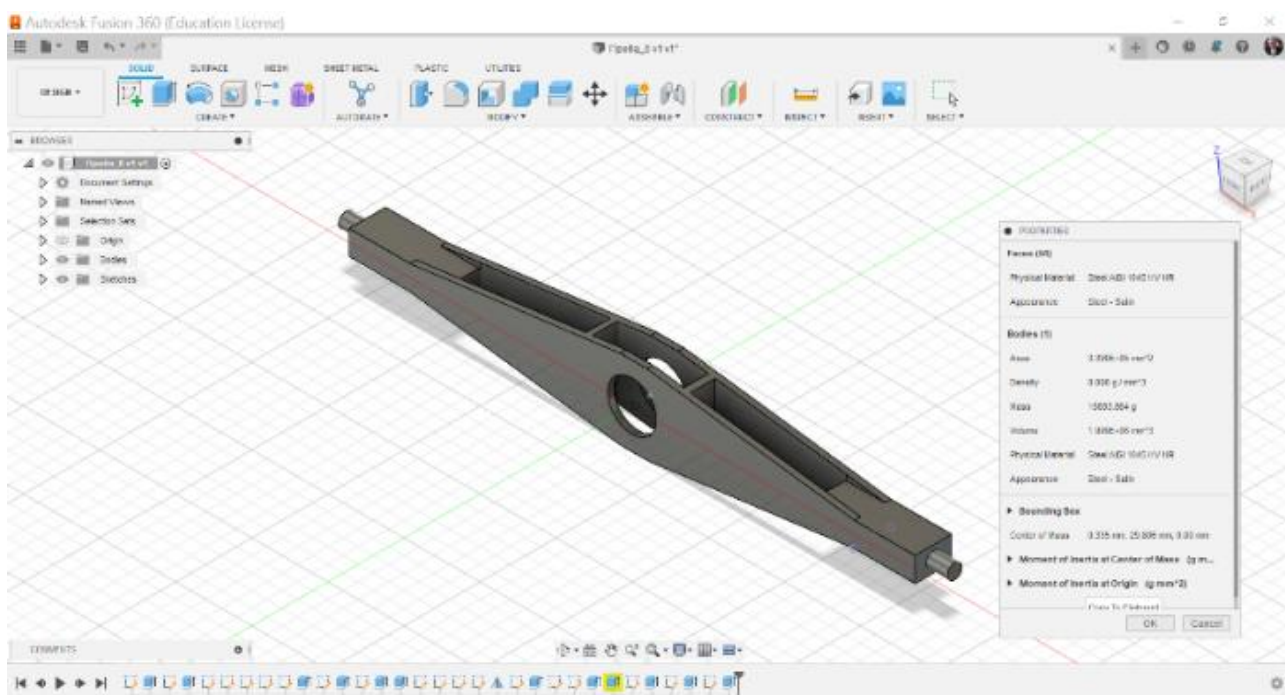


Fig. 4. 3D rocker arm model

To determine the loads on the brake lever and the rocker arm, the following data were taken into account:

- the coupling weight of the electric locomotive, 8 tons;
- the vertical load on one wheel,  $G \approx 20\,000\text{ H}$ ;
- the calculated coefficient of wheel-rail adhesion (rails are dry and clean) – 0.24;
- the coefficient of friction between the cast iron brake pad and the steel wheel rim – 0.35.

As a result of the calculation, the loads on the brake lever and the rocker arm were obtained according to Fig. 5 and 6.

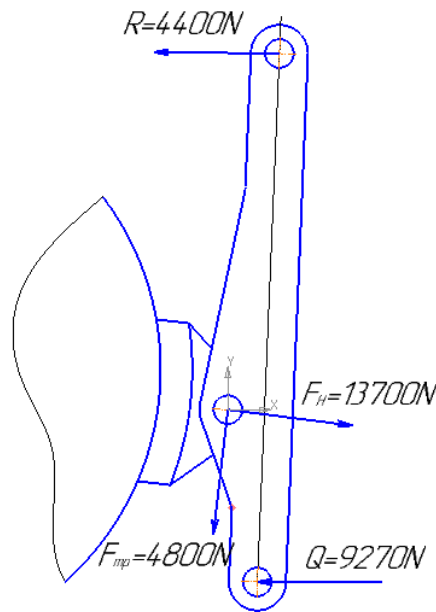


Fig. 5. Values of forces acting on the brake lever

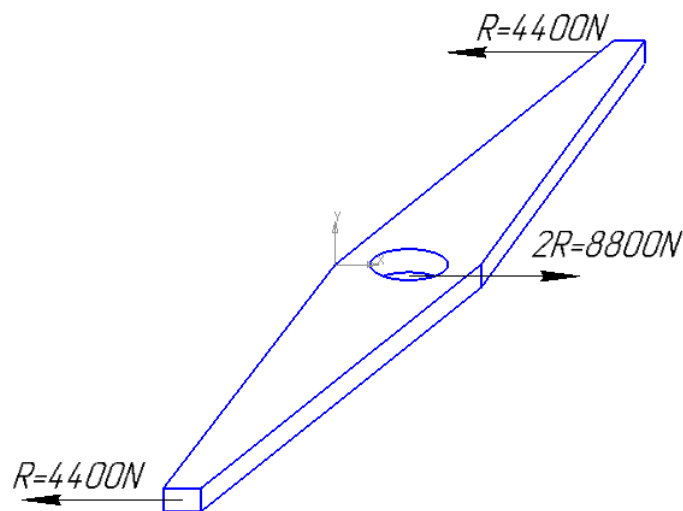


Fig. 6. Values of forces acting on the rocker arm

The development of lightweight models of the brake lever and rocker arm of the electric locomotive was carried out using the Fusion 360 program, through the “Shape optimization” option [6]. Optimization of geometric dimensions is one of the most common optimization methods. This approach involves changing the CAD design dimensions directly to minimize the weight.

The results of the topology optimization of the brake lever and rocker arm constructions are shown in Fig. 7 and 8.

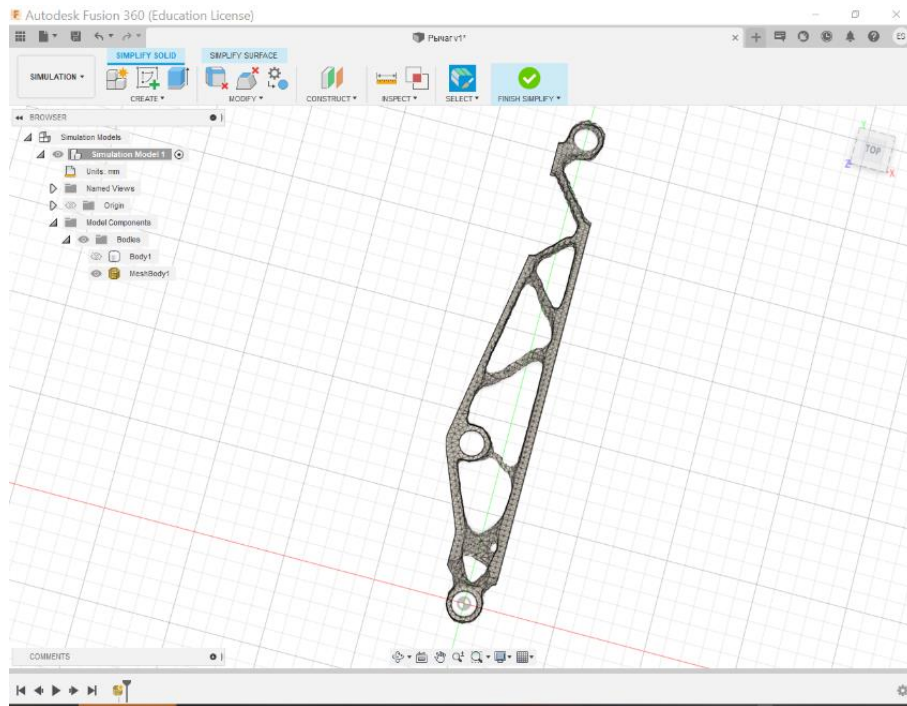


Fig. 7. The result of the topological optimization of the construction of the locomotive brake lever

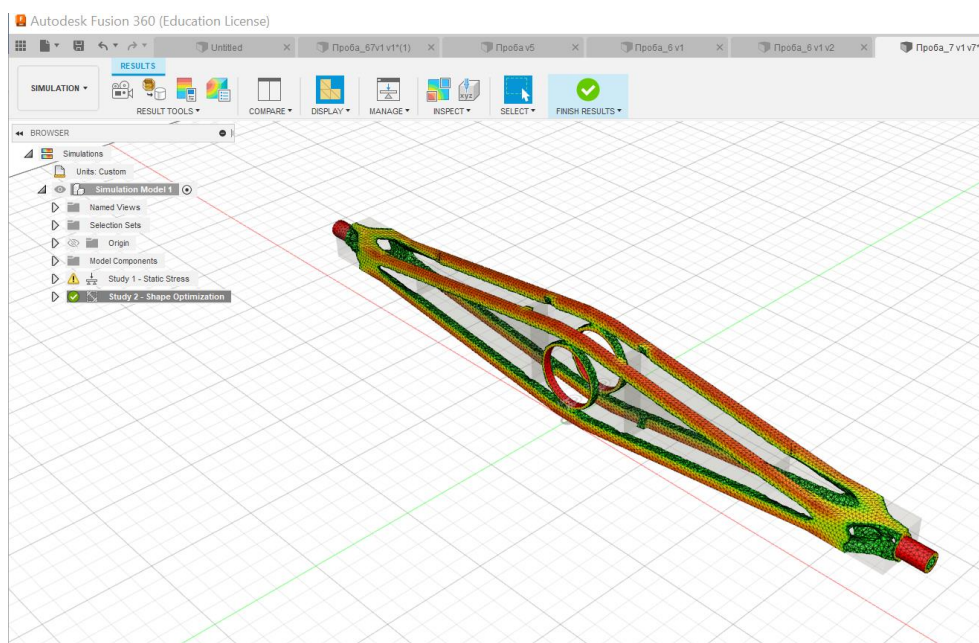


Fig. 8. The result of the topological optimization of the rocker arm construction

Figures 9 and 10 show what the products look like after processing the optimization results.

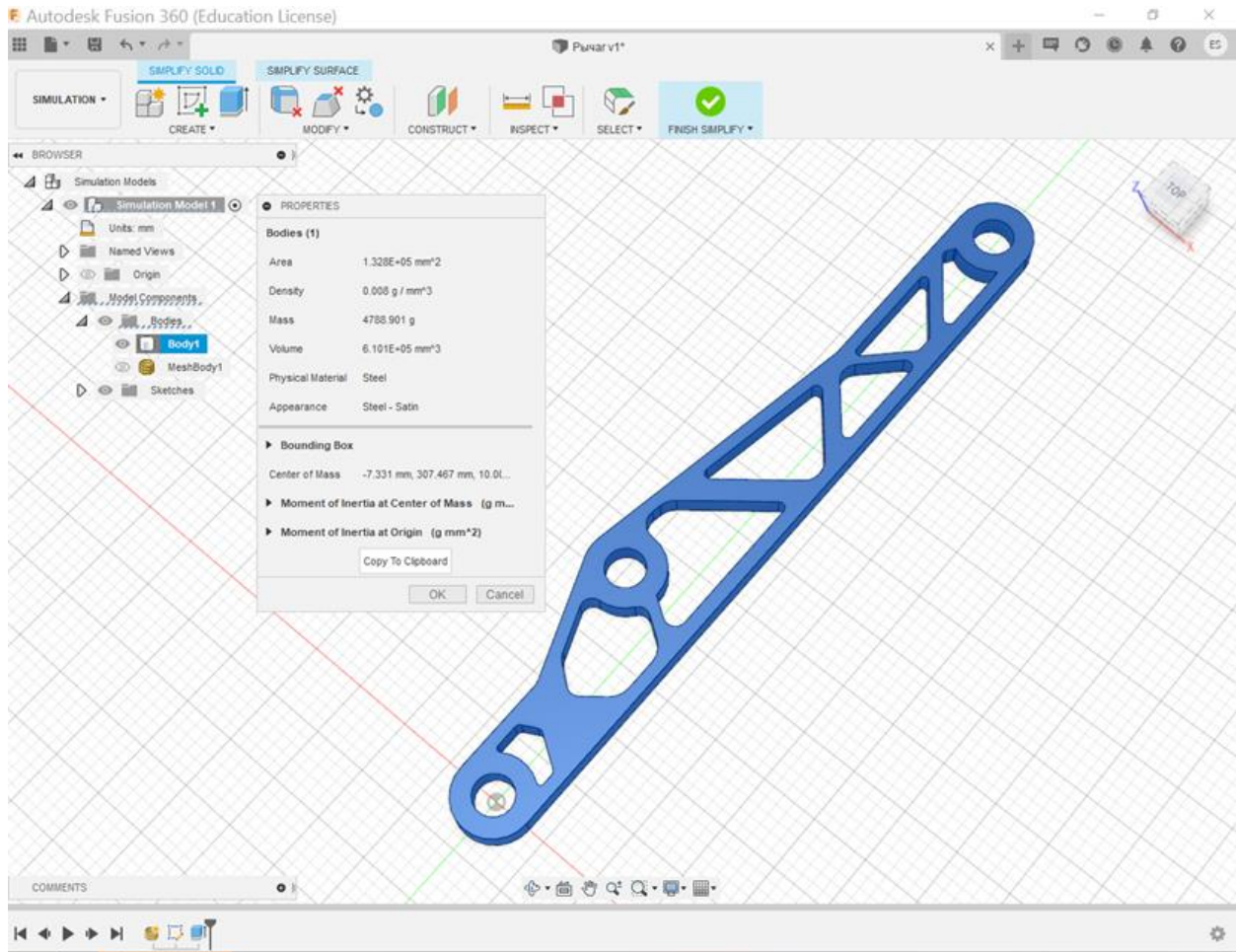


Fig. 9. Brake lever after processing the results of topological optimization

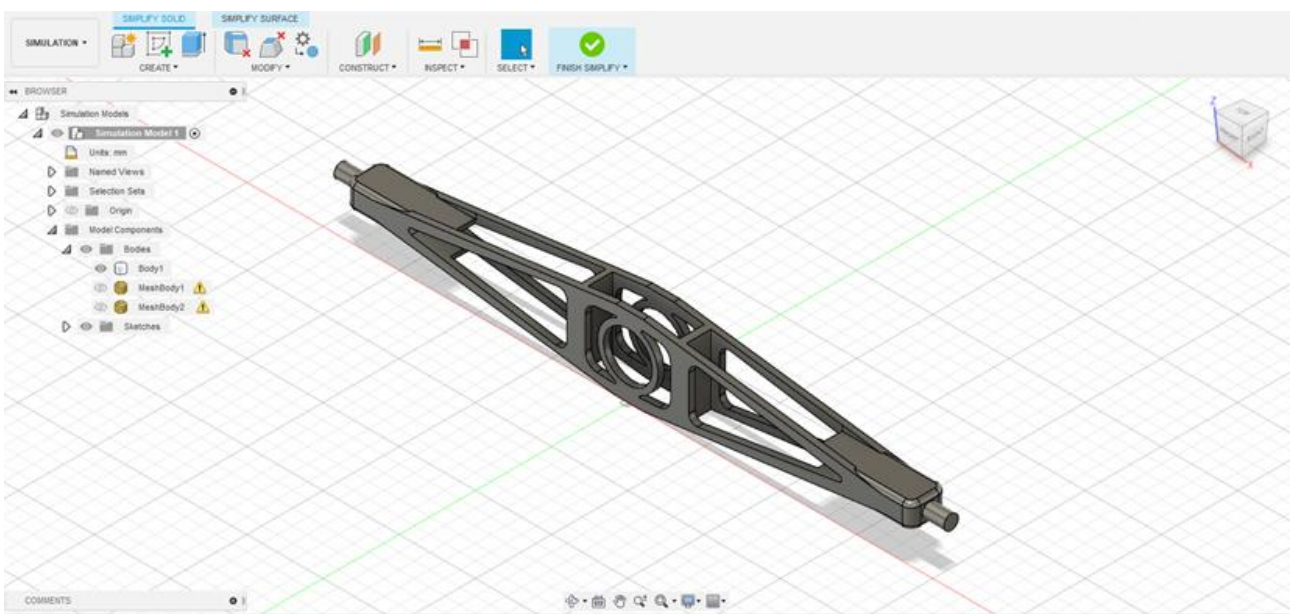


Fig.10. The rocker arm of the locomotive brake system after processing the results of topological optimization

The weight of the products before the topological optimization was as follows:

- the brake lever – 8.7 kg;
- the rocker arm – 15.7 kg.

The weight of the products after optimization is:

- the brake lever – 4.8 kg;
- the rocker arm – 10.3 kg.

Therefore, the application of topology optimization in the components of the brake system of the mining electric locomotive optimizes their structures, and as a result, we have obtained parts with reduced weight.

**Conclusions.** The paper presents the results of a study on reducing the weight of braking system components of a mining electric locomotive through the use of topological optimization of their designs in the software product Fusion 360 developed by the American company Autodesk.

It has been shown that this tool is highly effective and recommended for mandatory use in the process of developing new designs.

The obtained effect of weight reduction of the products after topological optimization can be estimated to be approximately 35-45%.

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#### АНОТАЦІЯ

**Мета.** Метою даної статті є оцінка ефективності застосування опції «Shape optimization» у програмному продукті Fusion 360 американської компанії Autodesk для деталей гальмівної системи рудникового електровозу.

**Методика.** З появою сучасних комп'ютерних програм змінився зміст роботи інженера-конструктора, процес конструювання зводиться до розробки 3D-моделі металевих виробів,



яку потім можна піддати аналізу напружено-деформованого стану та за результатами цього аналізу визначити малонавантажені ділянки виробу, які можна видалити, тобто зменшити масу використовуваного металу. Особливе значення має генеративний дизайн – нова технологія проектування. Заснована вона на застосуванні програмного забезпечення, здатного самостійно, без участі конструктора, генерувати тривимірні моделі, що відповідають заданим умовам. Практично у системі «людина – машина» комп'ютеру передаються творчі функції, і він із нею добре справляється. Другим по значенню є топологічна оптимізація (Shape optimization), якій піддають вже розроблену дизайнером модель для її вдосконалення.

**Результати.** В роботі викладено результати дослідження зменшення маси деталей гальмівної системи рудникового електровозу за рахунок топологічної оптимізації їх конструкцій у програмному продукті Fusion 360. Видалення ненавантажених ділянок виробу здійснено за допомогою спеціальної опції «Shape optimization» цієї програми. Ефект зменшення маси виробів після топологічної оптимізації оцінюється приблизно у 35-45 %.

**Наукова новизна.** Використання топологічної оптимізації у деталях гальмівної системи рудникового електровозу – це новий підхід до оптимізації конструкції та задля отримання деталей зменшеної маси.

**Практична значимість.** Застосування топологічної оптимізації на етапі проектування допомагає знайти варіант дизайну конструкції з найбільш раціональним розподілом матеріалу та порожнеч в заданій області, з урахуванням міцності та жорсткості, і таким чином помітно знизити його масу.

**Ключові слова:** механічна гальмівна система, важіль гальмівний, коромисло, Fusion 360, топологічна оптимізація, зменшення маси.