Topological optimization by designing structural elements of logging machine manipulators

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Abstract. The structures of manipulators of modern logging machines are subject to a wide variety of requirements related to the implementation of the functions of these machines, as well as the technology of manufacturing, operation and disposal of structures. The leading requirements are to ensure high strength and operational reliability under a wide range of loads, high and low temperatures. In this case, it is necessary to obtain the minimum metal consumption of the design product. Structural optimization, in particular, topological optimization, should be used when designing manipulators for logging machines. The use of topological optimization makes it possible by calculation to carry out the redistribution of material in the calculation area of the design product, taking into account the required conditions. The use of Altair Inspire 2018.3 software tools makes it possible to reduce the weight of the designed structural element of the hydraulic manipulator of the forestry machine by 39%. At the same time, acceptable indicators of tensile strength, deformation, and standard safety factors are provided.

More than 80 billion m$^3$ of timber is concentrated in the Russian Federation. This is the second largest timber stock after Brazil, whose wood resources are estimated at 126.2 billion m$^3$ [1]. The annual volume of timber procurement in Russia is more than 200 million m3. Russia is one of the ten world leading countries in the field of logging volumes [2]. To develop such significant areas of forest plantations and volumes of timber, a wide range of forestry equipment is used. Everywhere, such logging equipment is equipped with hydraulic telescopic manipulators, allowing to ensure the mechanization of complex spatial-oriented technological tasks [3].

The most widespread in logging and forestry production are loading and unloading manipulators, to which, along with technological requirements (maximum and minimum reach of the working body, load moment, turning moment in the horizontal plane, maximum height of load lifting), are subject to requirements for limiting the manipulator by weight. This is due to the fact that the weight of the manipulator affects the choice of the base of the loading and transport machine (forwarder or short log truck), on which, to a large extent, the compliance of the forest harvesting or forestry machine with forestry requirements depends, including set value of specific pressure on the ground and preservation of undergrowth. [4] The purpose of this research is to optimize the design of the elements of the telescopic manipulator of the logging machine based on the use of topological optimization tools of the Altair Inspire engineering package.

When designing and substantiating specific solutions in the design of forest hydraulic manipulators, the developer relies on the experience and decisions of specific structural schools, intuition, as well as...
on the technical and software tools for computer-aided design and modeling. The studies conducted earlier carried out work on the substantiation of the sizes of the elements of the hydraulic manipulator of the logging machine - the harvester. [5] The study was conducted in “Solidworks Simulation”, which is a set of tools using the finite element method for linear, non-linear static and dynamic analyzes. In the study of fatigue, models were investigated based on the operating conditions of the equipment in forest conditions, as well as monthly temperatures during the year for the city of Kodinsk (Krasnoyarsk Territory). A design load of 15 kN was applied to the structures. The harvester manipulator produces about 200 work cycles per day. The total number of cycles corresponds to two years of operation of the harvester manipulator. Rational shapes and sizes of manipulator elements were established.

Structurally, the hydraulic telescopic manipulator is a few box-section elements made of rolled steel. The subject of optimization was the final element of the manipulator with a cross section of 166×368 mm, made of picture 1S 235 J2 G3 rolled steel (an analogue of steel VSt3SP) with a thickness of 8 mm. The goal of optimization is to reduce weight while maintaining the strength properties of the structure. The principle is based on the finite element method and mathematical methods of modeling [6-8]. To do this, a model of the telescopic element of the hydraulic manipulator was made in the Compass 3D software package and converted to the igs format for transfer to the Altair Inspire 2018.3 package. [9,10] The length of the optimized part of the manipulator was taken equal to 2 m, based on the condition of fixing the standard non-optimized part 3 m long. In the Altair Inspire 2018.3 package in the Apply Pressures module, the base points of the optimized body were fixed and the loads were applied: vertical 15 kN and additional lateral force of 7.5 kN (calculated version of lateral loading when moving timber with a partial touch of the ground). The estimated mass of the object of optimization was 135.84 kg. The calculation results are shown in figure 3.

![Figure 1. Dimensions of structural elements of the telescopic manipulator.](image1)

![Figure 2. 3D model of the telescopic element of the manipulator.](image2)
Figure 3. Results of strength calculations of the manipulator element (a - acting stresses, b - safety factor, c - value of deformations).

Based on the data obtained, it can be seen that the basic design has an unreasonably high safety factor, which leads to an increase in its metal consumption and a decrease in the efficiency of the designed machine. The Altair Inspire Run Optimization tool with the target mass minimization feature was used.

Figure 4. Results of Altair Inspire run optimization.

Altair Inspire topological optimization technology allows to obtain the product shape that exactly corresponds to the specified loads and restrictions. However, due to the specifics of the optimization algorithms, it may be necessary to increase the amount of material in the part manually to make the optimized assembly more technologically advanced. To do this, the Topology slider may be used.

Topological optimization results in an area with an optimal distribution of material density. The researcher independently sets the parameter on the basis of which the final product form is generated, while selecting those areas in which the specified parameter takes smaller values.

There are some problems with adapting the resulting topological model to the actual technological capabilities of manufacturing the product [11]. That is, the implementation of classical (non-additive) manufacturing technology imposes certain restrictions on the possibility of optimizing the shape and size of the design product.
Since the design of the element of the hydraulic manipulator provides for the welding of a box-shaped product from sheet metal, cuts were provided in accordance with the lines of force of the optimized body in figure 4. In the Compass 3D package, the design solution was adjusted, the result is shown in figure 5.

![Figure 5. Model after adjustment in the Compass 3D package.](image)

To check the correctness of design decisions in the Altair Inspire 2018.3 package, the Apply Pressures module re-secured the base points of the element body after optimization and applied loads: vertical 15 kN and additional lateral force of 7.5 kN. The estimated mass of the optimization object was 82.562 kg. The calculation results are shown in figure 6.

![Figure 6. Results of strength calculations of the optimized element (a - operating stresses, b - safety factor, c - the value of deformations).](image)

Classical design methods allow you to get design solutions that have certain reserves in terms of the possibility of using modern optimization tools. In particular, the finite element method allows to optimize the design of elements of hydraulic manipulators of logging machines.

When using the Altair Inspire 2018.3 software package, it was possible to reduce the weight of the project product from 135.84 to 82.562 kg, or by 39%. With this reduction in weight, the permissible values of the tensile strength, deformation, and standard reserve coefficients are provided. At the same time, the complexity of manufacturing the product increases somewhat, but the use of modern lines (for example, laser or hydro-cutting of metals) fully ensures the possibility and feasibility of manufacturing the part.

Reducing the metal content of the manipulators of logging machines (harvester, forwarder or logger) allows you to work in the field of increasing travel loads or reducing the environmental impact by reducing the specific pressure on the ground. All this increases the efficiency and realizes the
competitive advantages of the upgraded equipment.

References
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