The use of CAD when designing forest machines

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Abstract. Wheeled forest skidders - pack pickers are widely used by logging enterprises. However, such vehicles have insufficient maneuverability. Therefore, development of tracked pack pickers is an urgent task of forest machine building. When designing such machines, it is required to ensure high reliability and durability of the structure for operating in hot and cold climates, poorly maintained roads or their absence. It is also necessary to fulfill the condition of sufficient strength and minimum weight of technological equipment and the machine as a whole. The use of computer-aided design (CAD) systems makes it possible to realize these conflicting requirements. In the process of research in Altair Inspire CAD system, a constructive element of the technological equipment of the tracked skidder is developed. The use of the finite element method makes it possible to ensure the strength of the structure. As a result of topological optimization of Altair Inspire, the design weight of the projected element is reduced by 45% compared to the weight of the prototype machine. Reducing the mass of the structure does not have a negative effect on the strength indicators. The required standard safety factors, operating stresses and deformations of the structure are provided.

1. Introduction
According to the report [1], the demand for forest products will continue to grow at the global level. In high-income countries, the share of wood fuel will increase as wood is an environmentally friendly and renewable source of energy, while some of the wood fuel will be produced from low quality wood. In low-income countries, this share will remain unchanged or decline. Area data - Russia has significant reserves of forest resources (over 814 million hectares or 20% of the world’s forest area). [1] Theoretically justified logging volumes exceed 500 million m³ per year, although in fact about 215 million m³ is harvested. [2]

Insufficient volumes of logging and the lack of additional income from a unit of forest exploited area have a negative impact on the state of the logging industry of the country as a whole and individual economic entities associated with logging and processing of timber. In general, the deplorable state of forest machine-building enterprises leads to a shortage of inexpensive and efficient forestry equipment on the market. Large logging enterprises can afford to purchase and operate expensive logging complexes of foreign production. Small and medium-sized businesses, in fact, do not have such an opportunity and continue to operate outdated forestry equipment with a service life of 15 years or more. At the same time, the forest machine-building enterprises of the USSR had a fairly successful experience in the design and manufacture of forest equipment. When implementing new modern approaches to the design and production of forest machines, targeted competition with foreign products...
in certain niches of affordable and inexpensive forest equipment is possible. Design technologies, decision-making in the development of such machines should be based on modern scientific achievements. Including computer-aided design (CAD) systems.

Long-term studies of samples of wheeled tractors - pack pickers (skidders) showed their insufficient maneuverability due to design flaws, especially because of overestimated specific pressure of the wheels on the ground and unsuccessful weighting along the axles. In the cargo direction, the rear axle was excessively overloaded, and the tractor lost its maneuverability. Three-axle wheel skidders have significant dimensions and are not maneuverable enough. However, most foreign-made wheeled skidders have a wheeled chassis. In the face of climate change, early spring and fall, traditional tracked vehicles will have higher cross-country ability and economic efficiency.

Creation and development of serial production of various kinds of specialized equipment, technological samples and modular machines must be carried out taking into account the possibility of creating modular structures, consisting of separate technological modules that are joined together. In particular, there is a real need to design a pack-picker - a skidder on a tracked basis. At the same time, it is necessary to provide a set of measures to reduce the weight of the vehicle and increase maneuverability when picking a pack. In particular, to reduce the weight of the vehicle, it is necessary to abandon the winch. Also, a rotary mechanism of the pack gripper is required, which allows to produce a set of packs located at an angle to the direction of the tractor movement. The main design objects will be the technological equipment of the skidding machine, which (for the skidder) will include an arch, an arrow, and a pack gripper.

Structural and strength calculations in the design of technological equipment are priority for assessing the efficiency of the forest machine as a whole. [3,4] The technological and operational qualities of the designed machine will largely depend on the mass of technological equipment. These conditions determine applicability and compliance of the technique with silvicultural requirements, the allowable value of pressure on the ground, the degree of preservation of economically valuable undergrowth.

The projected machine (Figure 1) consists of the basic tracked chassis 1 of the revised ML-107 machine, skidding equipment consisting of an arch 4, a boom 5, a turning mechanism 6, a pack gripper 7, hydraulic cylinders, a boom drive and an arch 8, 9. The skidding equipment is connected to the frame of the base tractor via subframe 2. The machine also consists of a hydraulic system for driving the working bodies, rear axle guard 3.

![Figure 1. Projected tracked skidder.](image-url)
Objective: Carry out strength calculations and optimization of the tracked skidder boom based on CAD Altair Inspire SolidThinking, to reduce the product weight while maintaining strength indicators. The traditional grapho-analytical methods of optimization, without the use of computer-based engineering systems, are rather labor-consuming [6]. Altair Inspire SolidThinking, Inc is based on the finite element method and mathematical modeling methods. [7-10]

2. Materials and research methods
Altair Inspire is a topology optimization technology developed by SolidThinking, Inc. of the Altair Group. [11,12] The technology makes it possible to develop structures based on the given force factors, the part fixing parameters, the conditions for the action of loads. The main capabilities of Altair Inspire enable to optimize the structure for maximum rigidity and minimization of weight.

The program has a built-in editor for making 3D models, and also supports standard stp formats. Fixation of boundary conditions and loading conditions is carried out with reference to the geometry of a specific 3D model.

3. Experimental part
At the initial stage, the boom structure was calculated for strength using traditional analytical methods. The boom of the skidder’s technological equipment is structurally a welded box-section element consisting of two sidewalls, an upper and a lower shell. To attach the gripper to the sidewalls, two lugs with coaxial holes with a diameter of 60 mm are welded. To attach the boom to the arch of technological equipment, two pads with a hole for the boom attachment pin, 60 mm in diameter, are welded to the boom sides. The basic dimensions of the boom were taken according to the analytical theoretical calculation. Then, using the standard CAD tools of Compass 3D package, a 3D model of the boom was made and converted into stp format for loading into CAD package Altair Inspire 2018.3. (Figure 2)

![Boom model made in Compass 3D.](image)

Altair Inspire 2018.3 included the exploration module and performed basic attachment and boom loading. The estimated resistance force to pulling the pack $T = 29509$ N; the total gravity on the suspension hinge, $Q = 50094$ N. A condition was accepted according to which a load of 80 kN was applied to the lug for fastening the rotary gripper, in the form of four vectors of symmetric load of 20 kN for each hole of 4 bolts of the rotary mechanism. Moreover, along the loading axes, the force of 20 kN is distributed according to the ratio of 25% along the X-axis, and 75% along the Z-axis. Next, the Analyze module is launched, the calculation results are shown in Figure 3.
Figure 3. Results of calculating the module for the safety factor, deformation and acting stresses.

The estimated boom weight was 200 kg. The calculation results show that the minimum safety factor is 0.3, the maximum deformation under load is 6.6 mm, the maximum stress is 797 MPa, which significantly exceeds the permissible values (350 MPa). Consequently, the design of the boom is not strong enough and design measures need to be taken to strengthen its design. An interesting point here is that the boom design of ML-30 machine, which served as a prototype for the design, has a mass of 385 kg, i.e. the designers clearly planned high safety factors when designing it.

The task of boom reinforcement is made easier by the fact that Altair Inspire software enables you to see the boundaries of propagation and the magnitude of the acting loads along the boom surface, which makes it possible to select components of reinforcement in the form of pads. In places of maximum effective load, the reinforcing pads were provided. Then, again, in the CAD package Compass 3D, a model of the reinforced boom was made (Figure 4).
The estimated weight of the reinforced boom came up to 231 kg. Further calculations by Altair Inspire showed that the minimum safety factor was 0.9, the maximum deformation under load decreased from 6.6 to 3.9 mm, the maximum stress decreased from 797 MPa to 135 MPa, which did not exceed the permissible values (350 Mpa). Consequently, the modernized boom design meets the conditions of strength and deformation. However, in the process of strengthening the structure, the boom mass increased from 200 to 231 kg. The boom design needs to be optimized. The optimization goal is to reduce weight while maintaining the strength properties of the structure.

The Altair Inspire Run Optimization tool with the target mass minimization function was used (Figure 5). The Altair Inspire topology optimization technology enables the solution to obtain a product shape that exactly matches the given loads and constraints. Topological optimization produces a 3D solid with optimized material density placement. There are certain problems of adapting the resulting topological model to the real technological capabilities of manufacturing a product. [13] This is due to the fact that the most widely used metal processing technology (subtractive) involves mechanical action associated with the removal of material from the workpiece body. Modern CAD optimizers enable you to get models based on (additive) manufacturing, that is, production by ‘adding’ materials, i.e. in the implementation of the classical (non-additive) manufacturing technology imposes certain restrictions on the possibility of optimizing the shape and size of the design product. [13] Namely, the classic production of a box-shaped structure from welded elements will reduce its cost.

Since the optimized boom design provides for the welding of a sheet metal structure, cutouts were provided in accordance with the force lines of the optimized body in Figure 5. The design solution correction is shown in Figure 6. The calculated mass of the reinforced boom after its optimization is 212 kg.
To check correctness of design solutions in Altair Inspire 2018.3 package in Apply Pressures module, a new fixation of the base points of the element body after optimization was carried out and the corresponding loads were applied, equal to the loads for the body before optimization. The results of calculations of the optimized model are shown in Figure 7.

Figure 7. Results of calculating the modulus for the safety factor, deformation and acting stresses of the optimized design
The design boom structure meets the conditions of strength and deformation. In addition, during the optimization process, it was possible to reduce the weight of the structure to 212 kg.

4. Results and their discussion
1. The use of analytical methods of calculation in the design of structures for technological equipment of forest machines does not always enable to obtain efficient structures. Therefore, very often the designer goes along the path of unjustified reinforcement and, as a consequence, the overweight of the structure. At the same time, there are reserves for reducing metal consumption without sacrificing reliability indicators. It is possible with the widespread use of CAD.
2. Application of topological optimization of CAD Altair Inspire 2018.3 allows for optimal placement of the boom structure material. With an increase in strength and a decrease in the magnitude of deformations, the weight of the structure decreases from 385 kg to 212 or by 45%.
3. A decrease in the mass of the technological equipment of logging machines will have a very favorable effect on the indicators of maneuverability and the level of soil compaction, will reduce the negative load on forest soils, undergrowth of economically valuable forest species.

References
[1] Global forest resources assessment 2015. How are the world’s forests changing? [Electronic resource]. - Rome: UN FAO, 2015. – www.fao.org/forestry/FRA2015/dataset
[2] Overview of the timber industry complex in Russia 2018. M.: EY, ASBO, 2018. 40 p.
[3] Kolesnikov P.G., Moiseev G.D. Design of technological equipment for harvesters using CAD/CAE systems // Actual problems of forestry complex, 2017. No. 50. pp. 9 – 11.
[4] Dolmatov S.N., Kolesnikov P.G. Topological optimization by designing structural elements of logging machine manipulators. Journal of Physics: Conference Series 2020. Ser. 1515
[5] Optimization of the mass of box-section bar structural elements with linings. G.D. Moiseev, P.G. Kolesnikov, N.E. Petrunin. Journal of Advanced Research in Technical Science. 2018. No. 11. pp. 41 - 43
[6] Bendsoe M.P., Sigmund O. Topology Optimization: Theory, Methods and Applications. Springer-Verlag Berlin Heidelberg, 2003. 370 p.
[7] J. Chen. Shape optimization with topological changes and parametric control. English. International Journal for Numerical Methods in Engineering 71.3 (2007), pp. 313 – 346
[8] Eschenauer H., Olhoff N. Topology Optimization of Continuum Structures: A Review//ASME Applied Mechanics Reviews. 2001. Vol. 54, No. 4. pp. 331-390.
[9] Saadlaoui Y., Milan J.-L., Rossi J.-M., Chabrand P. Topology Optimization and Additive Manufacturing: Comparison of Conception Methods Using Industrial Codes//Journal of Manufacturing Systems. 2017. Vol. 43. pp. 178-186.
[10] Robin Larsson. Methodology for topology and shape optimization: application to a rear lower control arm / Chalmers University of Technology. - Goteborg, Sweden, 2016. - 53 p.
[11] Site of Altair Inspire software system developer - Altair Engineering company - www.altair.com.
[12] Site of Altair solidThinking software systems family, including Altair Inspire – www.solidthinking.com.
[13] Maximov P.V., Fetisov K.V. Analysis of methods for finalizing the finite element model after topological optimization // International scientific research journal. - 2016. – No. 9 (51), part 2. - pp. 58-60.