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Design of handling equipment for logistics operations

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Keywords: flow of material, logistics, lifting mechanisms, stress analysis, optimization.
Abstract: The article deals with the design of a lifting mechanism for trailer trucks used in various logistics operations, e.g. forestry, farms and other areas. The study also includes a demonstration of lifting mechanisms for various logistics operations and their technical description. The lifting mechanisms are used to load loads onto a trolley or to unload loads from a trolley. Lifting mechanisms are usually driven by a separate motor unit. The transmission of forces is provided by hydraulic cylinders. The lifting arm and its parts are modelled in SolidWorks. Material characteristics are assigned to the designed mechanism and the links between the individual structural elements are defined. By meshing the model and modifying the mesh at certain critical points, the lifting mechanism is ready for stress analysis calculation. The results are von Mises stresses, displacements at individual points of the system and total deformations. The critical stresses are removed by optimization, which means designing the best possible dimensions or adjusting the geometry of the arm so that the mechanism is functional and safe. The final section deals with the various accessories that can be easily mounted on the lifting mechanism.

1 Introduction

The subject of work is the design of lifting mechanism for trailer trucks. The lifting mechanism is to be used for loading and unloading of loads from the aforementioned trolleys. The advantage of the arm is its light weight and general use, since different types of accessories can be installed on the end part of the arm for different logistic operations. Different types of lifting mechanisms can be found on the market. However, the advantage of the proposed mechanism is its simple construction, which represents a low cost of its production. The practical part enumerates the products found on the market with their descriptions and their technical parameters are also tabulated. The design of the arm itself, its stress analysis and optimization is solved using SolidWorks software. Voltage concentrators in critical sections are removed. The result of the work is the dependence of the load capacity on the load. It indicates the weight that can be loaded on the lifting mechanism in a given position.

1.1 Hydraulic arms for forestry

Hydraulic arms are used in forestry in the primary timber processing cycle (Figure 1). They are most often used in the logging sector and also in the subsequent transport of timber. Currently, there are a variety of hydraulic arms ranging from small to gigantic [1-6]. Forestry is a global industry where high productivity is required every day. Forestry machinery operators need versatile equipment to ensure smooth logging and logistics of timber transportation. Forestry cranes are used right at the start of the tree felling and transport process.

The weight and reliability of trailers with hydraulic arms are very important factors. Due to their low weight, small trailers can move faster and do not leave such a noticeable trace in the countryside as large machines. Trailers can be pulled by ATVs, UTVs, small tractors and the like. Thanks to their versatility, trailers together with hydraulic arms can be used for various purposes not only in forestry, but also in agriculture, construction, road maintenance and so on.

Figure 1 Trailer with forestry crane behind the ATV

1.2 The current range of products on the market

VahvaJussi 2000+

It is the latest type in the range of professional small balancers (Table 1, Figure 2), which in combination with an ATV, UTV or small tractor makes a very manoeuvrable balancing rig. A new feature is the Knott ramp brake. Also improved and more protected is the all-wheel drive of the balancer, which is additionally available in two variants (200 or 400 cc). Of course, there are swivel tandem axles, heavy-duty 8-ply tyres and a swivel hitch. A wide range of accessories can be purchased for the balancer to make this machine more useful, e.g. hydraulically folding bucket, remote-controlled hydraulic winch, swivel hook, hay bale loader, telescopic hydraulic arm extension, bulk loader, soil drills, splitter head, etc. [7].

Table 1 Technical parameters VAHVA JUSSI 2000+

Weight	**440 kg**
Carrying capacity	**2000 kg**
Low pressure off-road tyres	**STARCOSG 300/65-12-8**
Hydraulic arm reach	**3,2 m**
Lifting force of the hydraulic arm	**410 kg/2 m; 260 kg/3,2 m**
Hydraulic system drive	**Honda GX 200**
Maximum lifting force of the hydraulic arm	**530 kg**

Figure 2 VahvaJussi 2000+

Avesta 4.2

The trolley is equipped with its own petrol unit providing movement of the hydraulic arm, hydraulic winch and wheel drive. When attached behind an ATV, UTV or small tractor, you get an 8×8 powered balancing rig. Up to 2m^3 of timber with a length of 5.5m can be loaded on this Swedish balancer behind an ATV (Table 2, Figure 3). The construction of the balancer is galvanised and it has a practical, swivelling hitch. It includes swing axles and low-pressure, high-load tyres [8]. Various accessories can be purchased for the balancer.

Table 2 Technical parameters AVESTA 4.2

Weight	**400 kg**
Carrying capacity	**1800 kg**
Low pressure off-road tyres	**22×11×8**
Hydraulic arm reach	**4,2 m**
Lifting force of the hydraulic arm	**340 kg/1,7 m; 170 kg/3 m**
Hydraulic system drive	**Honda 6,5 hp**
Dimensions	**3200 (4100) × 1350 mm**

Figure 3 Avesta 4.2

2 Handling equipment model design

The handling equipment designed for the outboard trucks (Figure 4), or timber trucks, is to be used for loading, unloading timber, bulk materials and other loads depending on the situation where the lifting mechanism is to be used.

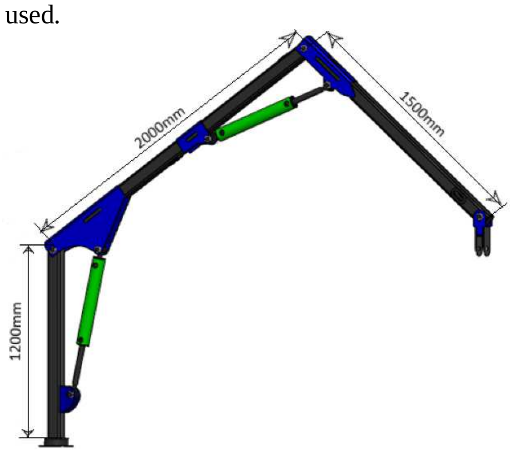
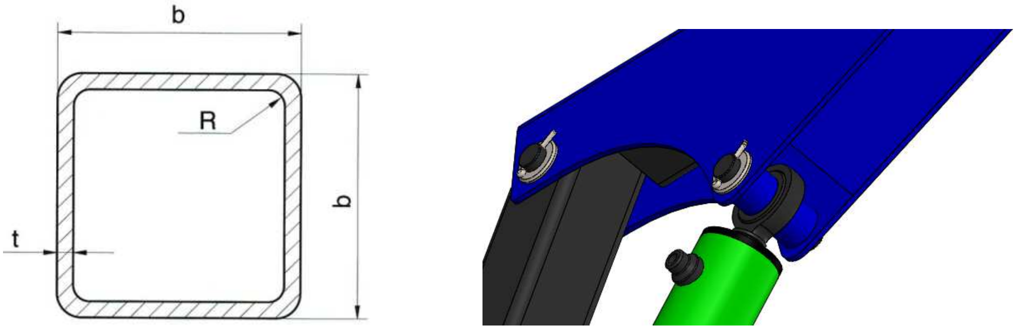


Figure 4 Proposed hydraulic arm

2.1 Design of handling equipment

The lifting arm is attached to the trailer with bolts and nuts. At the bottom of the arm there is a swivel device which is driven by a motor. The basic parts are standardised profiles 80×80×5 mm. They are closed profiles with a square cross-section of grade 11, hot rolled (Figure 5a) marked STN 426937 [9]. The theoretical weight of the profile is 11.3 kg per metre of length. Depending on the location of the hydraulic hoses, oval holes are designed in the profiles to hide the hoses and also to protect them against external damage and wear. There is a pin fit between the profiles (Figure 5b).



a ***b***

Figure 5 a,b Closed profile with square cross-section and fit detail

The diameter of the pin is 30 mm. A 25 mm diameter pin is designed at the end link where the last part of the proposed lifting mechanism connects to the rotator. This is due to the assumption that a BALTROTORS GR10 rotator will be used for the arm in question, where the entry hole for the pin is just 25 mm, on which various accessories can be mounted. The rotator in question has unlimited rotation for both directions. The maximum static axial load is 1000kg, with dynamic load (rotation), it is possible to move a load of 500kg. The transition parts between the profiles as well as the attachment of the hydrovalves is solved by welding of 5 mm thick bent plates (Figure 6).

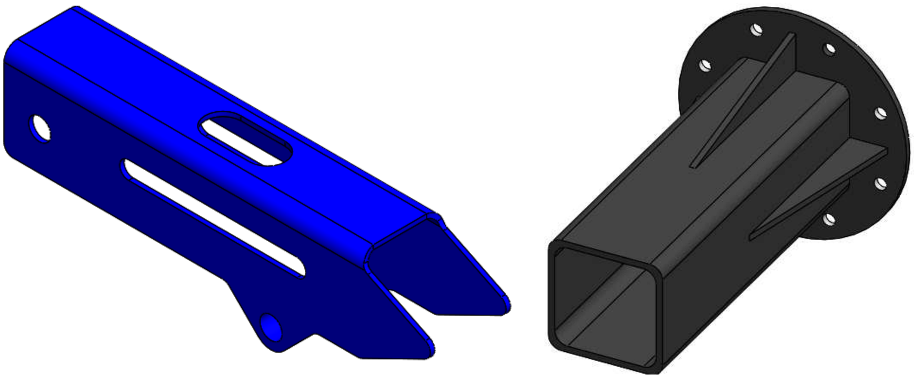


Figure 6 Transition between profiles

Straight-acting double-acting hydraulic cylinders are used to transfer the forces, converting the pressure energy into mechanical energy. Hydraulics are basically divided into stationary (presses, lifts ...) and mobile (agricultural, construction machinery, lifting arms). Mobile hydraulics move mostly on wheels, where control elements such as valves and distributors are operated directly by hand. On the other hand, in stationary hydraulic mechanisms, they are mostly operated electromagnetically. Hydraulic-based mechanisms use fluid to transfer energy. The energy is manifested in the resulting axial force acting on the piston rod. For the lifting arm, the PH-1 63×32/500 111 111 straight-acting double-acting hydraulic cylinders are the most suitable choice (Figure 7). The cylinder pressure rating is 16 MPa and with a maximum working pressure of 20 MPa. The piston speed is 0.5 m/s (Table 3). Two identical hydraulic motors are used for the proposed arm. The advantages of hydraulics are the possibility of transferring large forces using relatively small components, starting from rest can occur even at maximum load, self-lubrication, adjustability, controllability, easy overload protection. Disadvantages are the threat of contamination by the flowing fluid, sensitivity to temperature changes of the fluid under pressure. Hydraulic systems are sensitive to contaminants [10].

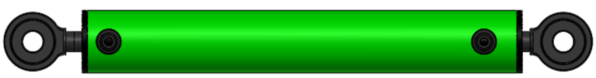


Figure 7 Hydraulic cylinder PH-1

Table 3 Technical parameters of double-acting hydraulic cylinder

Rated pressure	**16 MPa**
Maximum working pressure	**20 MPa**
Static test pressure	**24 MPa**
Working speed of piston	**0.5 m/s**
Working fluid temperature	**-20 to +80 °C**
Working environment temperature	**-20 to + 55 °C**

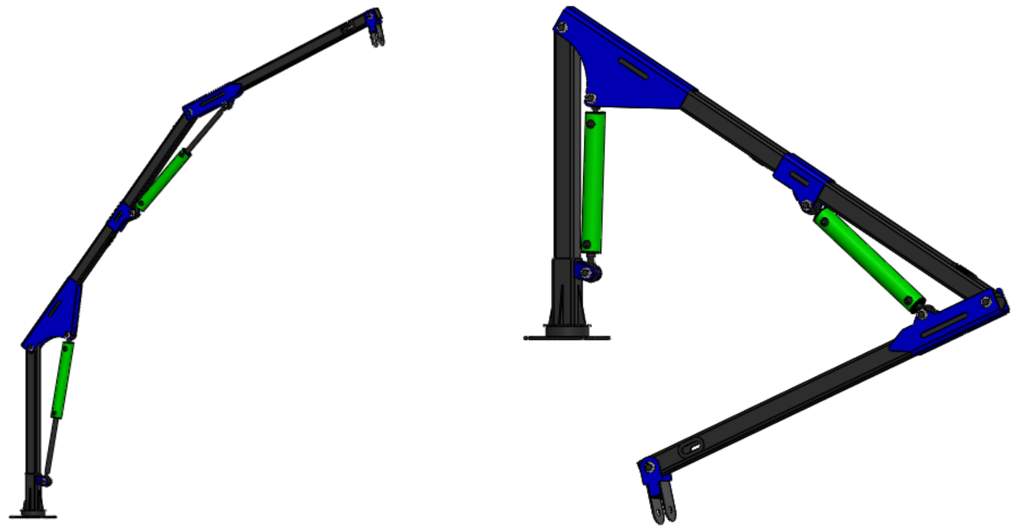
The hydraulic system is driven by a 4-stroke single-cylinder HONDA GX 200 (Figure 8, Table 4) with an output of 4.1 kW at 3,600 rpm, which has an efficient combustion, high power to displacement ratio. The engine is easy to start, consumes little fuel and engine oil. The engine is relatively quiet [10].

Figure 8 Honda GX 200 engine

Table 4 Honda GX 200 engine specifications

Engine category	**GX**
Engine type	**4-stroke single cylinder OHV**
Stroke volume	**196 cm^3**
Maximum performance	**4.1 kW at 3600 rpm**
Cooling	**by air**
Ignition	**transistor**
Weight	**16 kg**
Shaft type	**horizontal**

The arm of model is a simple welded construction. In the open position, when both hydraulic cylinders are extended to their maximum (Figure 9 a), it is possible to lift the load to a height of 3400 mm from the trailer floor. The handling device can move about its axis and within 280°, but this is dependent on the type of trailer where the arm will be positioned. If both hydraulic cylinders are at minimum (Figure 9 b), the height of the arm is 1255 mm. The advantage of using a hydraulic motor is that even at maximum load the motors can operate reliably. The designed arm is analyzed in SolidWorks in all critical positions in the next part of the work.

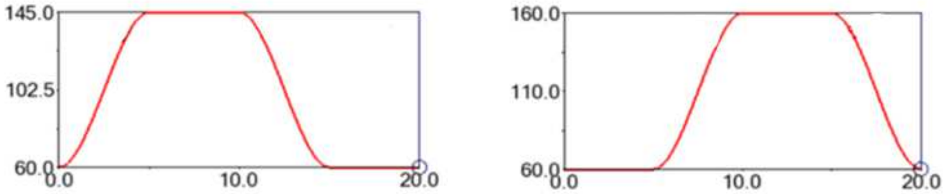


a b

Figure 9 Maximum (a) and minimum (b) arm range

2.2 Kinematic analysis

A simplified model of the arm is created in the Adams computer program and subjected to kinematic analysis. The length of the first vertical beam is equal to 1200 mm. Together with a second beam of length 2000 mm, they form an angle of 60° at the lowest position. With the hydraulic cylinder extended, this value is equal to 145° (Figure 10 a). The third beam, 1500 mm long, makes an angle of 60° with beam number two when the hydraulic cylinder is retracted. When the piston rod is maximally extended from the cylinder, the angle is equal to 160° (Figure 10 b).



a) **b)**

Figure 10a,b Angles between beams versus time t

The simulation is run when both piston rods are inside the hydrovalves. Within a time period of five seconds, the first of the hydromotors is extended to the maximum position. The second hydraulic motor then starts its operation until it reaches the peak position. The next step is to lower the first thruster to the zero position within a time period of 5 seconds. The last part is the pulling in of the second hydrovalve. The whole cycle takes 20 seconds (Figure 11) The result is the workspace of the proposed arm (Figure 12). The analysis does not consider the rotation about the proper axis of the arm.

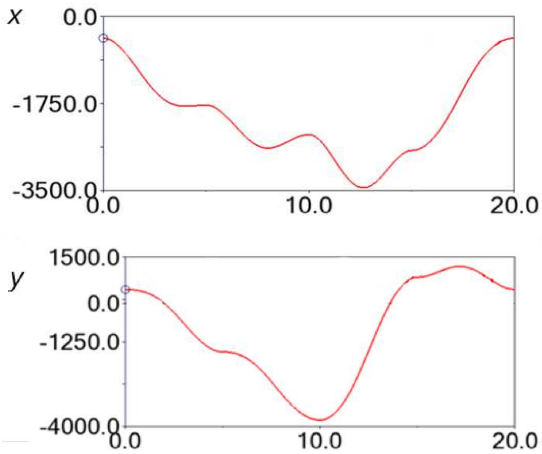


Figure 11 Extension of the arm in the x and y axis direction as a function of time t

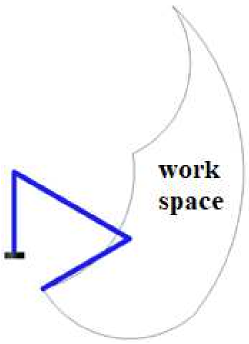


Figure 12 Working space of the proposed mechanism in the plane

2.3 *Stress analysis*

Stress analysis allows to verify the quality and safety of the product during the design process. The proposed model of the lifting arm for the outboard trucks needs to have initial conditions defined before the actual stress analysis can be run. The analysis is also performed in SolidWorks. Using the stress analysis, the total stresses and strains at different points of the structural system can be calculated in the program [11-15]. The assembly deforms under load with small rotations and also displacements. In the analysis, the effects always remain static, neglecting or ignoring any inertia. The effects remain constant over time [16,17].

The SolidWorks simulation uses the finite element analysis method. The goal of the method is to decode structural elements into solid components or beams using linear stress analysis when the elements or assemblies are subjected to the effects of: force, pressure, acceleration, temperature, and contacts between components. Forces can be imported from a variety of studies including thermal, flow and motion. This is in order to be able to perform multiphase analysis. When defining the conditions, one of the most important parts is the input of material properties, e.g. from the SolidWorks library [18].

For the proposed mechanism, the material from the SolidWorks library was used, namely AISI 1020 steel (Figure 13), which represents the material according to the Slovak technical standard - STN426937 [9]. The ultimate strength of the material is 351.57 MPa, which means that the maximum value of the conventional stress under maximum load must not exceed the given value.

Property	Value	Units
Elastic Modulus	2e+011	N/m^2
Poisson's Ratio	0.29	N/A
Shear Modulus	7.7e+010	N/m^2
Mass Density	7900	kg/m^3
Tensile Strength	420507000	N/m^2
Compressive Strength		N/m^2
Yield Strength	351571000	N/m^2
Thermal Expansion Coefficient	1.5e-005	/K
Thermal Conductivity	47	W/(m·K)

Figure 13 Material characteristic of AISI 1020 steel from SolidWorks software

The connection between the components of the system is a "bonded" bond, which interprets a welded joint. In places where square section profiles are connected by means of pins together with the connecting parts, a socalled "no penetration" bond is used. Since hydraulic cylinders are not included in the stress analysis, the "rigid" bond has been used as a substitute. The lowermost part of the assembly, where the lifting mechanism is fixed using bolts and nuts against the trailer trolley, is the fixed part. The load is applied to the end pin in the assembly. Depending on the distance of the end part relative to the base beam, the loads are applied progressively [19,20]. Once all the conditions are satisfied, the designed model can be meshed. The elements that do not satisfy the first meshing stage are meshed separately (Figure 14).

Figure 14 Solidworks mesh modeling of lifting mechanism

The simulation is then run. In the most ideal case, which represents the smallest distance between the end point of the arm and the axis of the base beam, the assembly can be loaded with 5500 N, which is approximately 550 kg. The stress according to von Mises will be equal to approximately 340 MPa at the critical point, which is still lower than the specified ultimate strength (Figure 15) [16].

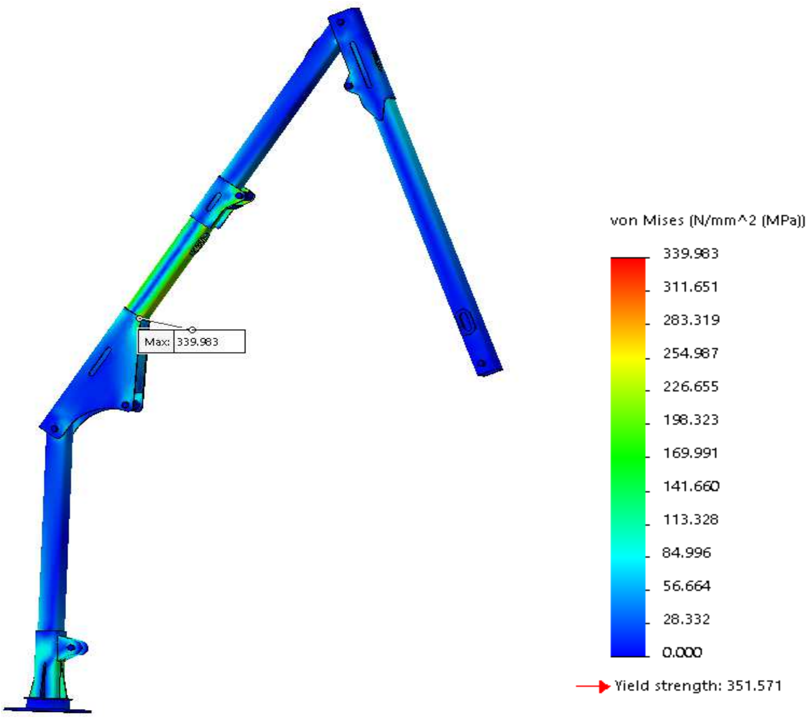


Figure 15 The von-Mises field of principal stresses

When the arm is at the position of greatest reach (Figure 16), i.e. the 3370 mm value of the end of the lifting mechanism from the axis of the base vertical beam, the proposed assembly is loaded with a force of 2500 Newtons, which is approximately 250 kg. The maximum stress in this case is 305 MPa.

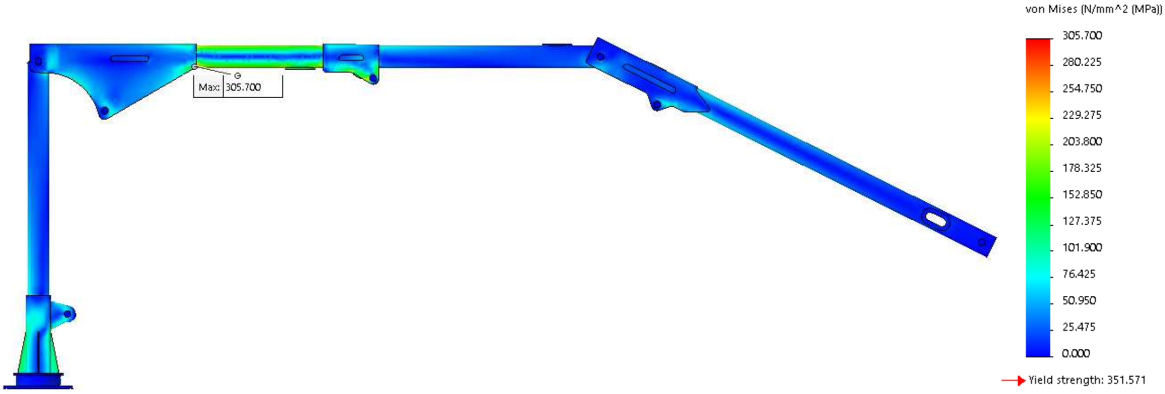


Figure 16 Main stress field at maximum arm reach

By successively loading the proposed model at minimum and maximum range, I have arrived at the results as shown below (Table 5, Table 6).

Table 5 Stresses according to von Mises at minimum arm reach

Load	Stress according to von Mises
5500 N	340 MPa
4500 N	278 MPa
3500 N	216 MPa
2500 N	154 MPa
1500 N	92 MPa

Table 6 Stresses according to von Mises at maximum arm reach

Load	Stress according to von Mises
2500 N	305 MPa
1500 N	183 MPa
500 N	61 MPa

The weight of the system is approximately 82 kg. However, this weight does not include the weights of the accessories and the fluid medium in the hydraulic cylinders.

2.4 Optimisation of the arm model

Optimization in short means that we are looking for the optimal solution so that the product meets the initial requirements, so that the production costs are as low as possible, so that the product meets the safety regulations and many others. There are several ways to achieve improved values. It is possible to change the part design, shape or dimensions. Design changes are represented by parameters that change during optimization - topological optimization - represented by material density in the design domain. Element removal is represented by assigning a weight and stiffness small enough to not contribute to the response. Shape optimization is represented by displacements of nodes on the surface of the component. Optimal design is achieved by shifting the nodes on the surface of the component to local concentrators. In dimensional optimization, the dimensions of the component are changed to increase the stiffness of the whole system. It is possible to vary sheet thickness, length, cross section, etc. In the case of the proposed mechanism, these are mostly subtle adjustments, namely rounding at critical locations where stress concentrators occur (if possible), or minor adjustments to the geometry of the model to avoid high stresses. After running the first simulation, the maximum stress was at 704 MPa, which is almost twice the allowable limit. The stress concentrator was created at the edge of the bracket, where the first of the two hydraulic cylinders is located (Figure 18).

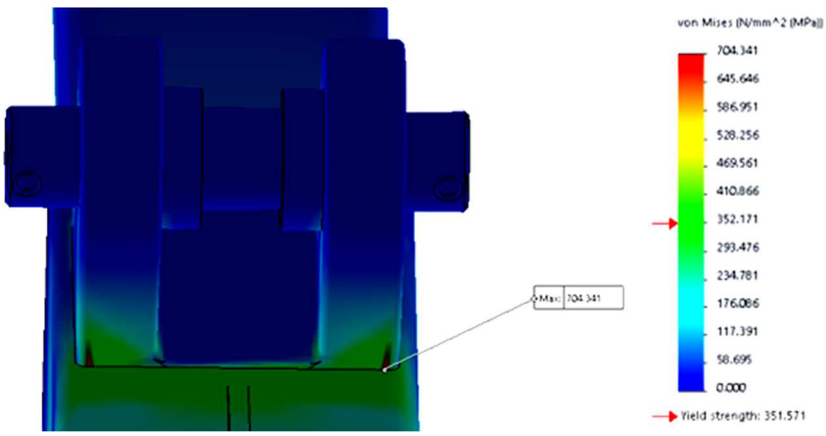


Figure 17 Critical point of the model assembly

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After optimizing the bracket, the voltages have dropped significantly and no longer represent a critical point in the assembly. On the contrary, there were other places where the component shapes needed to be adjusted. Mostly, however, these were curvatures. After the optimization of the lifting mechanism was carried out, there were no critical places with high stresses on the model. These are evenly distributed over the entire arm, so further optimization would be in changing the smaller cross-section profiles to larger ones, as well as the other parts. However, this is not necessary for our model as the initial conditions are satisfied (Table 7).

Table 7 Technical parameters of the proposed lifting mechanism

Maximum range (length)	3.3 m
Maximum range (height)	3.4 m
Maximum lifting force to 3.3 m	180 kg
Maximum lifting force to 2 m	350 kg
Maximum lifting force	5500 N

3 Accessories for various logistics operations

The model of the lifting mechanism is designed so that a range of different accessories from catalogues can be applied to it for different logistics operations. For the proposed lifting mechanism model, it is necessary to mount a rotator, which is an essential part of almost all lifting mechanisms due to its features and capabilities.

3.1 Rotators

They are used in industrial machines that require unrestricted rotation of working mechanical cranes (hydraulic arms). Thanks to their design, rotators allow a continuous supply of hydraulic oil to the necessary components without restricting rotation. They allow 360 degree rotation around their axis. They make the work easier and faster and thus reduce costs [21].

For the proposed lifting arm, the Baltrotors GR10 hydraulic rotator (Figure 19, Table 8) is the most suitable choice.

Figure 18 Rotator Baltrotors GR10

Table 8 Technical parameters of the Baltrons GR 10 rotator

Rotations	Unlimited for both directions
Maximum axial load - static	10 kN (1000 kg)
Maximum axial load - dynamic	5 kN (500 kg)
Torque at 25 MPa	350 Nm
Recommended oil flow	10 l/min
Weight	10 kg

3.2 Grapple pliers for wood VahvaJussi

Wood tongs (Figure 20, Table 9) are characterized by their minimal size and minimal weight. Their maximum spread is 75 cm. The tongs will be an accessory mainly for timber extractors [21].

Figure 19 Wood tongs VahvaJusii

Table 9 Technical parameters of pliers VahvaJussi

Maximum opening	750 mm
Weight	22 kg
Carrying capacity	1000 kg
Pressure force	8 kN
Hole for rotator	39,5 mm
Working pressure	175 bar

3.3 Loader for bulk materials FARMA 0,12

The Loader for bulk materials (Figure 21, Table 10) is a suitable complement for lifting equipment with already installed grapple tongs due to its quick installation and low weight. They can be mounted on the Baltrotors GR10 rotator [21].

Figure 20 Loader for bulk materials FARMA 0,12

Table 10 Technical parameters of loader for bulk materials FARMA 0,12

Spoon volume	58 l
Weight	36 kg
Pressure force	6.3 kN
Carrying capacity	500 kg
Working pressure	17.5 MPa

3.4 Swivel hook VahvaJussi

The hanging swivel hook (Figure 22) is the ideal complement to the hydraulic arms. The hook can easily be mounted directly on the hydraulic rotator instead of pliers or a grab.

Figure 21 Swivel hook

3.5 Soil drill

Soil drills (Figure 23) find use in many activities. They can be used effectively in the construction of protective fencing in forestry, in the construction of fences and corrals on farms, in tree planting and in agriculture. The advantage is their quick assembly and disassembly.

Figure 22 Soil drill

4 Conclusions

The task of this article was the structural design and stress analysis of a lifting mechanism for trailer trolleys, taking into account the various logistic operations performed by this equipment. The mechanism was to be of the simplest possible design with the possibility of quick disassembly. The nominal load capacity should be 400 kg. The total weight of the proposed part is 83 kg.

In the introductory part of the thesis there is a description of similar mechanisms already offered on the market. It describes their mechanical properties and their advantages. The practical part is the actual design of the lifting mechanism. In the design, closed profiles with a square cross-section are used as the main parts. The other elements are the connecting parts, which are bent. Hydraulic cylinders, pins and various other parts are incorporated into the assembly as required. The arm is designed in SolidWorks environment where stress analysis has been carried out. As a result of the work, a lifting arm with a nominal lifting capacity of 400 kg has been designed. The maximum reach of the mechanism is 3370 mm. The lifting capacity depends on the extension of the arm. At the largest extension, the aforementioned 3370 mm, loads weighing 200 kg can be lifted.

The lifting mechanism designed in this way is suitable due to the wide use of various accessories for different logistic flows used in cargo handling.

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Review process

Single-blind peer review process.