DESIGN AND ANALYSIS OF THE HYDRAULIC ARM FOR MOUNTING ON A LIGHT GOODS VEHICLE

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Abstract: This paper is focused on numerical analysis of a hydraulic arm for use on a light goods vehicle. The designed arm is used for loading and manipulation with load up to 300 kg. Its load capacity depends on the light goods vehicle to be placed on. Great operability of this mechanism predetermines its wide application, e.g. in construction, transport, business etc. Firstly, analytical calculations of the forces, moments and reactions are introduced. Further, locations and values of the maximum stress in the structure of the designed hydraulic arm are calculated using the FEM software. These results determine the relevant data necessary for correct design functioning of the machine. After carrying out all the analyses and calculations we will be able to determine the safe use of the designed handling machine and put it into operation.

Keywords: HYDRAULIC ARM, FINITE ELEMENT METHOD, CALCULATION, COMPUTER SIMULATION

1. Introduction

An important role of engineers is to analyse the existing and newly-designed working processes in order to find an optimal way of executing the given operation. The best working process is generally considered the one that minimises the cost of performance, which can be achieved by mechanisation.

Mechanisation is an important means of increasing productivity, quality and production competitiveness. Successful introduction of mechanisation requires knowledge and understanding of physical dependencies of executed operations. Operations are executed by transfer of mechanical, electrical, pneumatic or hydraulic energy.

The aim of this paper is to achieve by analytical dimensional calculation needed dimensions of the middle part of the arm in fig. 1 (needed areas of section) and so to design lifting rotary arm, which will be placed on the pick-up automobile trailer.

After specifying of the dimensions will be possible to create the construction in CAD programme and subsequently by importing of a model into FEM programme verify the real values of stress in designed construction, already with the values, which are not at disposal at preliminary design (E.g. own mass of the construction).

2. Process of a hydraulic arm geometry design

Every transport and handling machine consists of three main parts:

- steel structure,
- driving mechanisms, and
- other parts (e.g. cab, steps, etc.).

The aim of this work is to design and analyse the middle part of a hydraulic arm steel structure to be mounted on a particular light goods vehicle (Fig. 1). The whole mechanism consists of three parts of steel structure. The advantage of this solution is that the operator needs driving license only for vehicles with total mass up to 3500 kg.

Fig. 1 *Pick-up platform for mounting the designed hydraulic arm*

2.1. Analysis of forces, moments and reaction on a hydraulic arm using the principle of superposition

Such a means of mechanisation utilisable not only in transport is the designed hydraulic arm, which significantly simplifies manipulation with great operativeness. With the requirement of minimum production costs we reach the most gainful output/costs ratio.

In this chapter are introduced calculations of forces and moments in joints in the entire structure. Results are necessary for cross sections design of hydraulic arm parts and also were used as the boundary conditions in the FE analysis.

Designed lengths of individual parts, resulting from construction of hydraulic cylinders in Figure 2, are as follows: c_1 = 1150 mm, c_2 = 1150 mm, c_3 = 1180 mm, $e_1 = e_2 = e_3$ = 75 mm, a_1 = a_2 = 210 mm, b_1 = 774 mm.

We consider the whole structure as mechanism with one degree of freedom. For solution of the greatest force effects the functional calculation was performed in the most efficient position of a load (Fig. 2). In this step we also obtain the needed forces of hydraulic cylinders for the equilibrium.

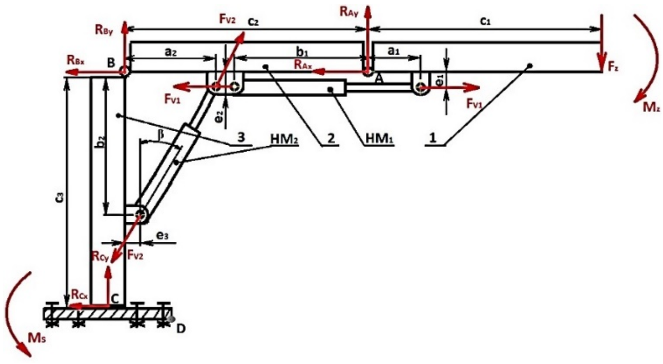

Fig. 2 *Free diagram of the designed hydraulic arm*

In the calculation we start form three basic equilibrium equations:

$$\sum F_{ix} = 0, \quad (1)$$

$$\sum F_{iy} = 0, \quad (2)$$

$$\sum M_i = 0. \quad (3)$$

Firstly, forces and reactions in the first part of the hydraulic arm are given (Fig. 3):

$$\sum F_{ix} = 0 \,, \Rightarrow F_{V1} - R_{Ax} = 0, \Rightarrow R_{Ax} = F_{V1}, \tag{5}$$

$$\sum F_{iy} = 0, \Rightarrow R_{Ay} - F_z = 0, \Rightarrow R_{Ay} = F_z = m.g = 300.9{,}81 = 2\,943\ N, \tag{6}$$

$$\sum M_{iA} = 0, \Rightarrow -F_z.c_1 + F_{V1}.e_1 = 0, \Rightarrow F_{V1} = \frac{F_z.c_1}{e_1} = \frac{2\,943.1\,150}{75} = 45\,126\ N. \tag{7}$$

Calculation of reaction values in the middle part of the hydraulic arm is based on Fig 4.

The angle β we calculate according to eq. (8)

$$\beta = tg^{-1}.\frac{a_2 - e_3}{b_2 - e_2} = tg^{-1}.\frac{210 - 75}{774 - 75} = 10{,}931°. \tag{8}$$

Then, from equilibrium equations we obtain:

$$\sum F_{ix} = 0 \ \Rightarrow R_{Ax} - R_{Bx} + F_{V2}.sin\beta - F_{V1} = 0 \ \Rightarrow R_{Bx} = R_{Ax} + F_{V2}.sin\beta - F_{V1}, \tag{9}$$

$$\sum F_{iy} = 0, \Rightarrow -R_{Ay} - R_{By} + F_{V2}.cos\beta = 0 \ \Rightarrow R_{By} = F_{V2}.cos\beta - R_{Ay}, \tag{10}$$

$$\sum M_{iB} = 0 \ \Rightarrow F_{V2}.a_2.cos\beta + F_{V2}.e_2.sin\beta - R_{Ay}.c_2 - F_{V1}.e_1 = 0$$

$$\Rightarrow F_{V2} = \frac{R_{Ay}.c_2 + F_{V1}.e_1}{cos\beta.a_2 + sin\beta.e_1} = \frac{2\,943\ .\ 1\,150 + 45\,126\ .\ 75}{cos10{,}931°.210 + sin10{,}931°.75} \tag{11}$$

$$F_{V2} = 30\,710{,}241\ N.$$

$$\Rightarrow R_{Bx} = 45\,126 + 30\,710{,}241.sin10{,}931° - 45\,126 = 5\,823{,}482\ N, \tag{12}$$

$$\Rightarrow R_{By} = 30\,710{,}241.cos10{,}931° - 2\,943 = 27\,210{,}042\ N. \tag{13}$$

Finally, calculation of forces and reactions are (Fig. 5):

$$\sum F_{ix} = 0, \Rightarrow R_{Bx} - F_{V2}.sin\beta + R_{Cx} = 0 \Rightarrow R_{Cx} = F_{V2}.sin\beta - R_{Bx} \tag{14}$$

$$R_{Bx} = 30\,710{,}241.sin10{,}931° - 5\,823{,}482 = 0\ N,$$

$$\sum F_{iy} = 0, \Rightarrow R_{By} - F_{V2}.cos\beta + R_{Cy} = 0, \Rightarrow R_{Cy} = F_{V2}.cos\beta - R_{By} \tag{15}$$

$$R_{Cy} = 30\,710{,}241.cos10{,}931° - 27\,210{,}042 = 2\,943\ N,$$

$$\sum M_{iC} = 0, \Rightarrow R_{Bx}.c_3 + F_{V2}.cos\beta.e_3 - F_{V2}.sin\beta.(c_3 - b_2) - M_s = 0 \tag{16}$$

$$M_s = R_{Bx}.c_3 + F_{V2}.cos\beta.e_3 - F_{V2}.sin\beta.(c_3 - b_2)$$

$$M_s = 5\,823{,}482\ .1\,150 + 30\,710{,}241\ .cos + 10{,}931°.75 - 30\,710{,}241\ .\ sin10{,}931°.(1\,150 - 774) = 6\,768{,}9\ Nm.$$

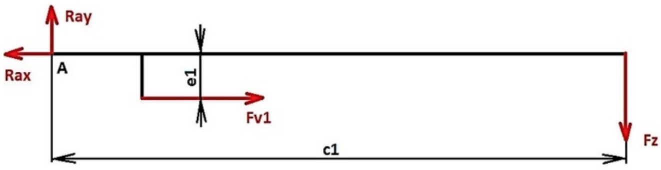

Fig. 3 *Forces and reactions in the first part of the hydraulic arm*

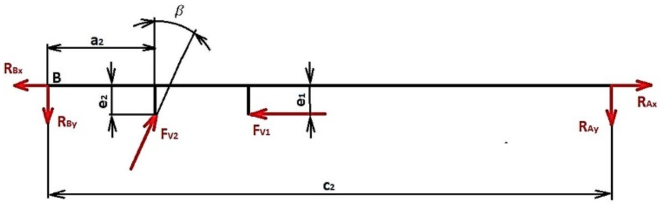

Fig. 4 *Forces and reactions in the middle part of the hydraulic arm*

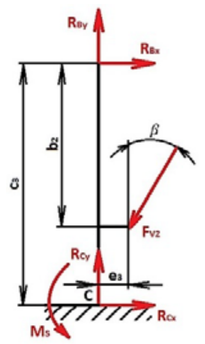

Fig. 5 *Forces and reactions in the third part of the hydraulic arm*

Therefore, calculated inner force effects of the mechanism (see Fig. 2) are: F_z = 2943 N, F_{v1} = 45,126 N, R_{Ax} = 45,126 N, R_{Ay} = 2943 N, β = 10.931°, F_{v2} = 30,710 N, R_{Bx} = 5824 N, R_{By} = 27,210 N, R_{Cy} = 2943 N.

2.2. Choice of material, profile and dimensions of a hydraulic arm

In production of steel construction a material STN 11 423 was chosen, because of its suitable mechanical properties, guaranteed weldability and relatively low cost. Normalised hot drawn square seamless steel tubes were chosen. Provisionally, it is chosen profile TR4 HR 120x100x6-11 423.0 STN 42 5720.

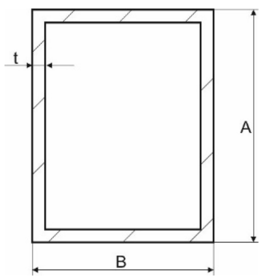

Fig. 6 *Chosen steel profile for the hydraulic arm structure*

Allowed combined loading of the steel construction with consideration of the safety factor is $\sigma_{red\ dov}$ = *120 MPa*. To determine a value of stress in the middle part of the arm, an analytical calculation by classic theory of elasticity and strength is carried out. The body considering as a beam with exact geometry and load, which value was solved in the previous step.

After defining the cross-section dimensions by analytical calculation, it is possible to build a 3D model of the hydraulic arm in CAD software. In Fig. 7 the three-dimensional model of the middle part of the hydraulic arm is shown.

The whole arm consists of three parts and to simplify the problem, numerical analysis of each part of the arm is made separately.

Further as an example, analytical calculation of the middle part of the hydraulic arm is indicated (Fig. 8). In this section the analytic calculation of the middle part of a hydraulic arm is described. Firstly, it is necessary to perform initial analytical calculation of the hydraulic arm structure. In this point we determine strain behaviour in the middle part of the hydraulic arm. Based on them the required dimensions will be it will be defined. The safety coefficient was chosen k = 1.5 [-].

Fig. 7 *3D model of the middle part of the hydraulic arm*

Calculation of the bending moment as a dominant loading is carried out by method of virtual cut. The beam is cut as many times as it is divided by outer loading, inner loading and by geometry, i.e. three times (Fig. 8).

In critical section, besides bending stress also tensile stress from normal force F_N = 5 824 N acts. The total stress then is (1):

$$\sigma_c = \frac{M_{omax}}{W_o} + \frac{F_N}{S} \qquad (1)$$

$$\sigma_c = \frac{M_{o\,max}}{W_o} + \frac{F_N}{S} \qquad (2)$$

By solving the equation (1), we get a value of total stress σ_c = 73.8 MPa. Force from the hydro motor F_{V1} then loads the critical section through holder by shear stress parallel with the length of the construction and force from the hydro motor F_{V2} loads the critical section through the holder also by shear stress, but perpendicular to the length of the construction.

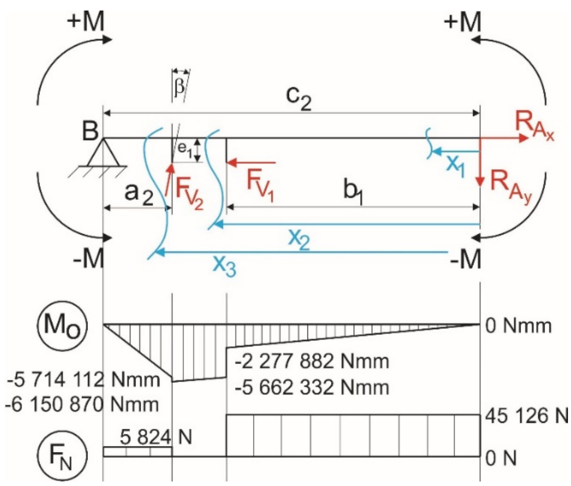

Fig. 8 *Pick-up platform for mounting the designed hydraulic arm*

Value of the resultant shear stress is found out from the equation (2):

$$\tau_s = \sqrt{\tau_{s//}^2 + \tau_{s\perp}^2} \qquad (3)$$

The resultant shear stress in the critical section then is τ_s = 9 MPa. Effective stress in the critical section is calculated according to HMH hypothesis (3):

$$\sigma_{RED} = \sqrt{\sigma_c^2 + 3.\tau_s^2} \qquad (4)$$

Value of the effective stress in a weld reaches by analytical method of calculation σ_{RED} = 75,5 MPa. However, value of the resultant stress will grow because of non-considering of.

3. Analysis of the hydraulic arm using Finite Element Method

In this chapter, the analysis of the hydraulic arm is carried out using the FEM software.

In the programme, there was input material properties to it (elasticity modulus E = 2.1 x 10^{11} Pa, density 7 850 kg.m^{-3}, Poisson's ratio 0.3). Input boundary conditions and meshed shell construction is shown in Fig. 9. Four nodes tetrahedron elements with density of mesh 4 mm were used at meshing.

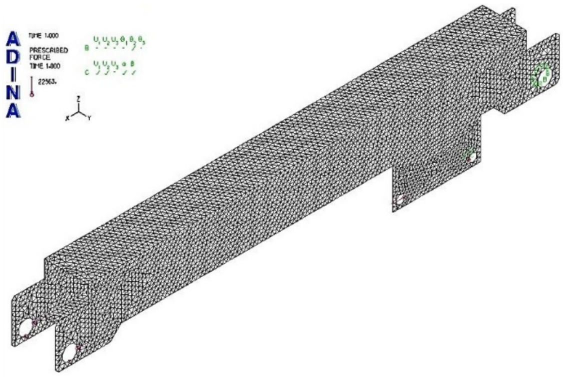

Fig. 9 *Mesh and boundary conditions in the middle part of the hydraulic arm*

After triggering of the solver it is possible to show results in the post-processor and so von Mises's stress in the first part and in the middle part of the hydraulic arm (Fig. 10, Fig. 11, Fig. 12, Fig. 13).

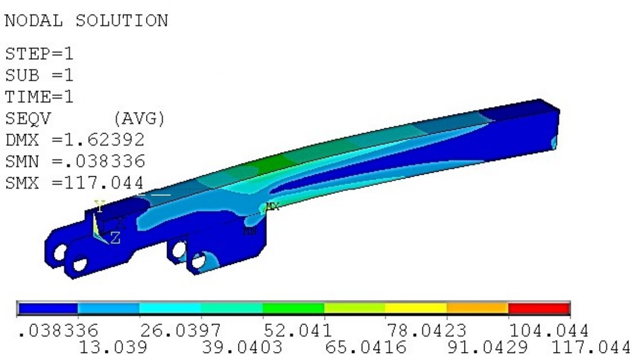

Fig. 10 *Distribution of* effective von Mises's stress in the first part

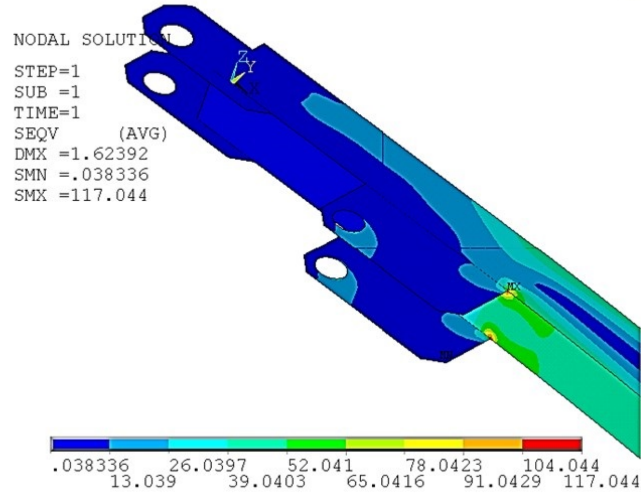

Fig. 11 *Detail of the critical section in the first part*

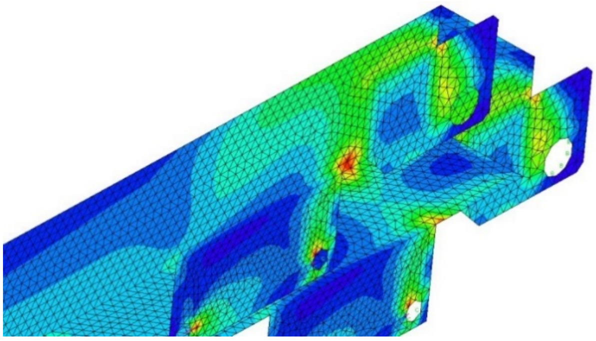

Fig. 12 Effective von Mises's stress in the middle part of the hydraulic part

Values as well as place of the maximal stress detected by FEM programme are practically identical with those achieved by analytical calculation. Values of the stress in the critical section may be determined in FEM programme in interval 80 – 86 MPa in comparison with 75.5 MPa from analytical calculation. A detail of the critical section with distribution of the effective stress is shown in fig. 7.

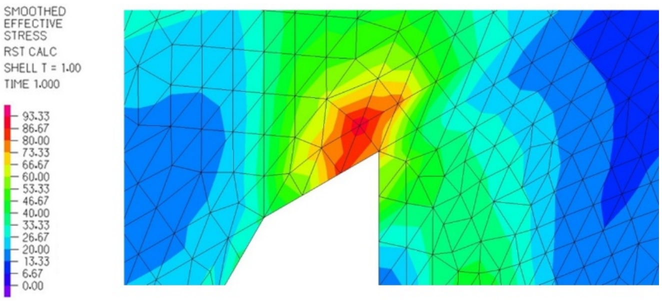

Fig. 13 *Detail of distribution of the effective stress in the critical section*

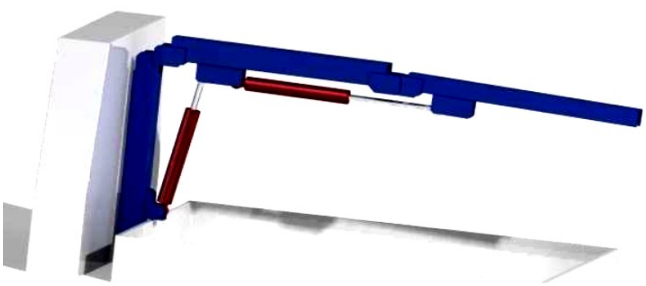

Fig. 14 *Lifting pivot arm with pick-up bed*

Conclusion

In the presented paper was performed design, analysis and calculation of the hydraulic arm, which was designed for mounting on a light goods vehicle. As a suitable platform for installation this arm the chassis of the off-road vehicle can be used. This equipment of a vehicle improves it operability, makes easier manipulation with loads and reduces the operational time. Although the designed structure causes decreasing the vehicle payload, still the vehicle load is enough.

As the every structure as this hydraulic arm has to be submitted analytical calculation and analyses. Well-defined force effects in the proposed mechanism is a necessary precondition for the safe operation of this device. The next step of the performing of this task is an analytical calculation of the cross-sectional dimension of each arms by using of conventional methods of elasticity and strength of material.

After designing of all dimensions creation of the 3D model was possible in a CAD software (Fig. 14). And then, the CAD model was imported into a FEM software. In this way, we could obtain adequate results of the structure strength, etc. Comparison of these two methods allows to find the overall accuracy of the solution. If unsatisfactory results had been identified, the task we could optimize before the expensive production, which in turn will contribute to the cost saving in the production of this mechanism.

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