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Design and FEM strength analysis of an innovative design of a front loader with an extension dedicated to the KUBOTA M5

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Abstract. Most of the front loaders are compact structures that do not allow loading at greater heights. On the Polish and foreign market, there was a need to develop a front loader design that would allow to increase the loading height. As a result, the front loader was designed a front loader with the possibility of extending the arms for the Kubota M5 agricultural tractor. The system enables unloading and loading of cubes, straw and hay bales on higher piles. Before starting the design process, the available front loader solutions were analyzed and on this basis, three concepts of design solutions were proposed. These concepts were scored on the basis of the adopted criteria and the one with the highest number of points was selected. For the selected concept, strength analytical calculations and verification calculations using the FEM method were performed. The developed loader is innovative compared to other available designs and has a good chance of implementation.

1. Introduction

There are many types of machines on the Polish market that, when combined with a farm tractor, facilitate the work of farmers during harvest, transport and earth works on farms [1]. One of them are front loaders, but these have a limited loading height, therefore the concept of design and strength analysis of a front loader with extension dedicated for the Kubota M5 agricultural tractor was born [2]. Depending on the type of work performed, it is possible to retrofit the front loader with accessories, including: bale grapple, bale fork, grapple bucket, and many other tools needed for a specific task. In practice, front loaders with extension are not found in mass production. The concept of the project was born out of the need to store straw or hay bales in an increasingly small area on fields and to load trailers with side edges at a height of 3.5 m, and in some cases even higher. To load such transport vehicles it would be necessary to purchase a telescopic loader or a standard front loader designed for a tractor with a power of at least 200 HP, which are expensive.

The aim of the work is the design and strength analysis of the design of the front loader with extension in terms of obtaining an increased loading height of piles. The designed structure of the loader is to enable loading to a height of 5.8 m.

The loader is to be supplied with hydraulic oil from the tractor's hydraulic system adapted to work under a pressure of 160 MPa. For the sake of extension, it was necessary to use flexible hoses in most of the system and to equip the system with hydraulic accumulators. The loader will also be equipped with a euro frame, which will allow you to hang various types of accessories depending on the user's needs

When designing innovative devices and machines, the finite element method (FEM) is most often used for strength analysis, which can used for dynamics, displacement, kinematics and statics analysis [3, 4, 5]. Very often, this method is used to simulate hest transport the flow of fluid and heat. Hou et al. [6] used the FEM method to analyze the stiffness of the mesh of a helical gear. It can also be used to locate mechanical damages [7] or damages to perforated materials [8]. FEM was also used for crack analysis of machine elements [9, 10] and for tests related to mutual contacts of machine elements [11]. When analyzing the literature, it is possible to find the use of FEM to determine the limit compaction stress in the dry ice agglomeration process [12], or to determine the limit stress of a tapering sleeve depending on its geometrical parameters [13]. This method is also used in the analysis of the biomechanics of head injuries [14, 15] or the reconstruction of the probable mechanism of trauma to the human body [16]. The literature also includes works devoted to the techniques of power transmission [17, 18, 19], methods of rapid prototyping [20] or measurements of innovative elements [21]. There are also studies of seismic movements using the finite element method [22].

When analyzing the available literature, attention should also be paid to the methods of checking the strength of the structure, including: preliminary strength calculations at the concept stage, simulation tests using mathematical modeling [23], and strain gauge tests [24]. Due to the popularity and credibility of the FEM method, it was decided to use it during the strength analysis of the new front loader design.

2. Material and research methods

For the main frame, the extension arm frame, the tilt mechanism of the accessories and all other elements that are not an integral part of the design of the front loader with extension, the classical strength rules were applied, based on the hypothesis of the greatest energy of shear deformation (Huber-Misses_Hencky hypothesis) [25]. The following assumption was made (1):

$$k_{dop} \leq \frac{Re}{x}, \tag{1}$$

where:

- Re - material yield point 235 MPa (for steel S235),
- X - arbitrary safety factor.

Based on the analysis of the literature and the experience of the research team performing the calculations, the following values of the safety factor were adopted:

- x material = 1.2 - for the construction material,
- x welds = 1.6 for welds.

Hence, after rounding:

$$k_{dop\_material} = 195 \text{ MPa},$$
$$k_{dop\_welds} = 146 \text{ MPa}$$

During the construction of the computational model, the standard procedure of dividingselected volumes with finite elements was used, while maintaining a high reflection of the geometric form of the analyzed structure. For the purposes of discretization, three-dimensional pyramidal elements of the second order were used and a mesh of medium density was used.

FEM calculations were made in autodesk Inventor. For the purposes of the strength analysis of the frame model of the front loader with extension, the following boundary conditions were assumed: pivoting support in the place where the pin connecting the main loader arm is used, support in the place of the hydraulic cylinder pin and the load on the structure with a force equal to 22,000N (symmetrically 11,000N for each arm). The 3D CAD model of the designed front loader with extension is shown in Fig. 1, while the restraints as well as the applied forces and the generated mesh are shown in Fig. 2.

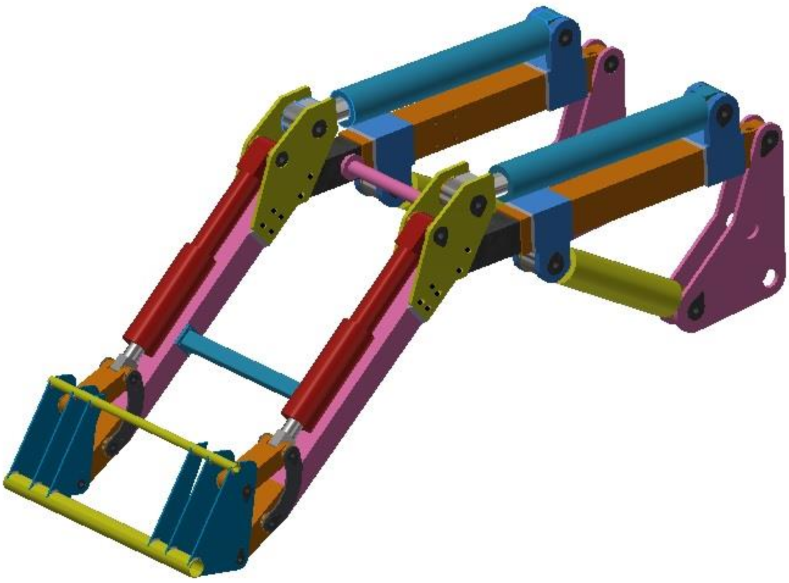

Figure 1. 3D CAD model of the designed loader with extension

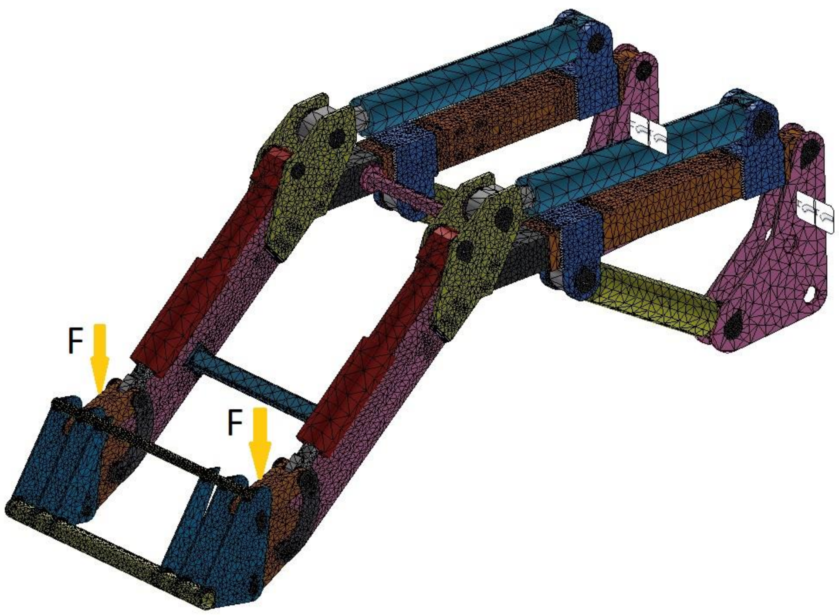

Figure 2. View of the distribution of loads, places of fixing the frame and the generated mesh

During the development of the computational model, simplifications were introduced in the design of the front loader arm with an extension, consisting in the removal of small roundings, undercuts and chamfers [9]. The 3D meshes were applied to the elements with the use of tools for automatic volume filling with finite elements. For the purposes of discretization, three-dimensional pyramidal elements of the second order and a medium-dense mesh were used.

For the purposes of this project, a material was selected (steel S235) with the following parameters: Density - 7.850 g / cm3; Young's modulus - 290 Gpa; Poisson's ratio - 0.32; Yield point - 235 MPa; Tensile strength - 360 MPa.

3. Results

As part of the strength tests, an analysis of the reduced Von Missesa stress was performed in the Autodesk Inventor program. Figure 3 presents the analysis of the reduced Von Misses stress for a single limb, which shows that the most loaded stressed nodes are in the upper part of the bending profile with the stress equal to and amount to 122.4 MPa.

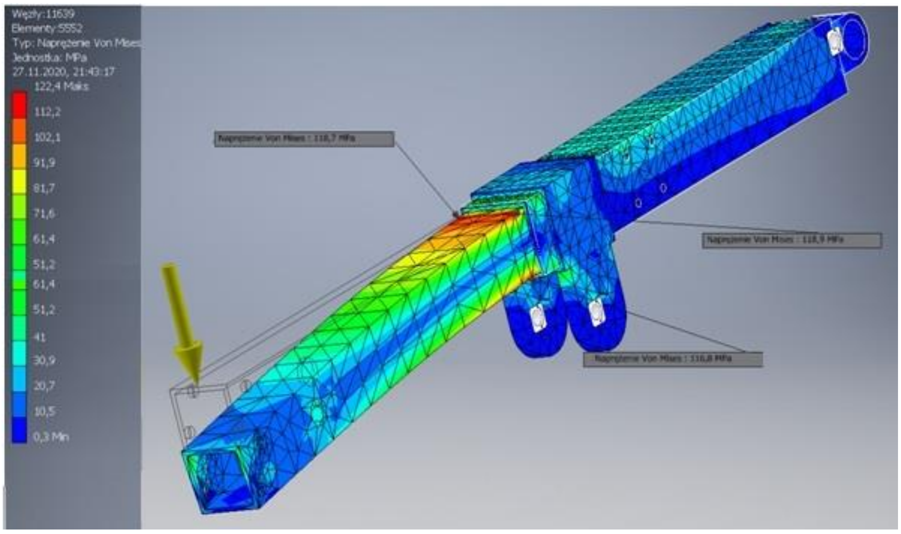

Figure 3. Stress analysis of a single limb: the maximum stress is 122.4 MPa.

The analysis of the displacements of the frame of the new design of the front loader with the extension is shown in Fig. 4 and Fig. 5. The assumptions for this analysis are the same as in the case of reduced stresses, and the maximum displacements with the folded frame are 3.4 mm (see Fig. 4), while the maximum displacements are the displacements with the extended frame and equal to 10.61 mm (see Fig. 5).

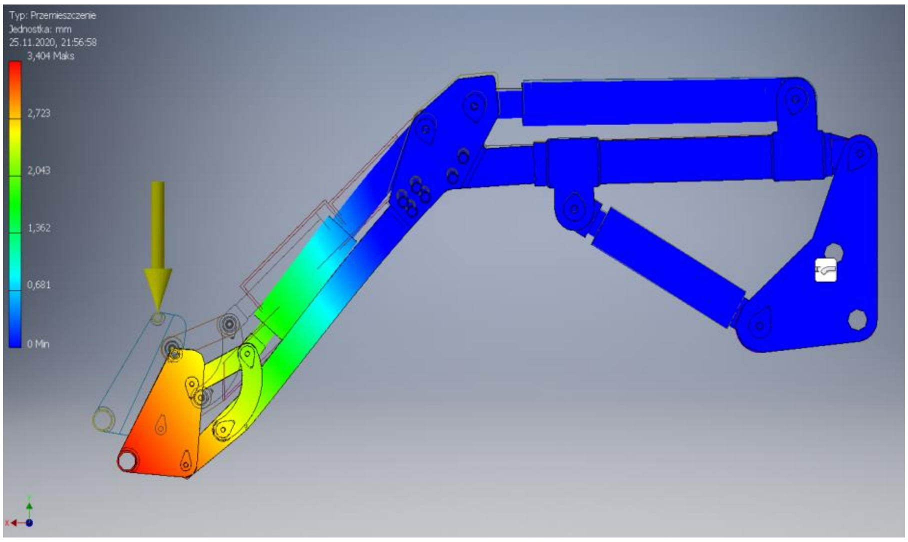

Figure 4. Displacement analysis: the maximum displacement with the retracted frame (the shortest) is 3.4 mm

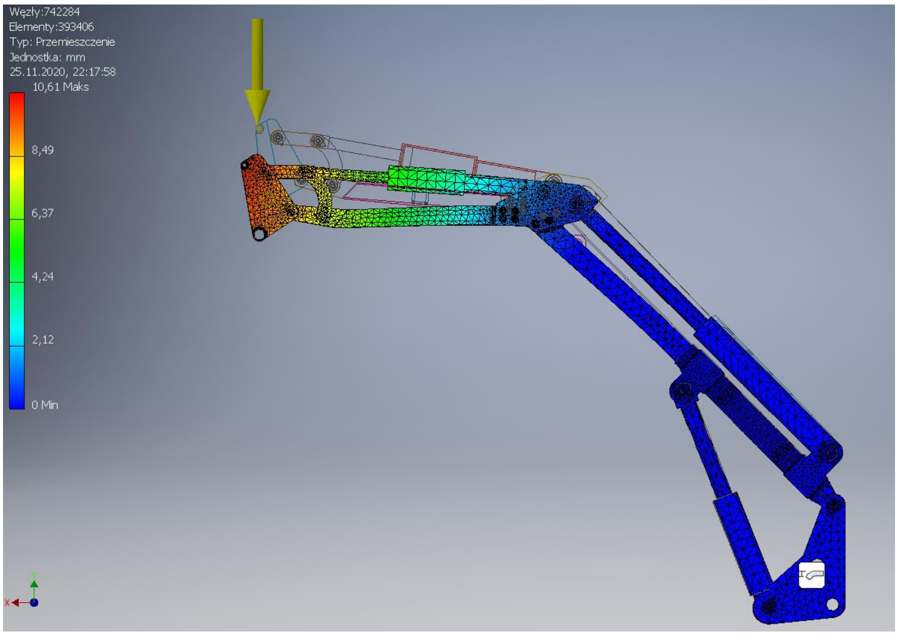

Figure 5. Displacement analysis: the maximum displacement with the extended frame (the longest) is 10.61 mm

4. Conclusions

Based on the stress results obtained in the structure of the front loader with extension, it is concluded that it meets the strength criteria (2, 3, 4):

$$\sigma_{H-M} = \sqrt{\sigma_b^2 + 3\tau_s^2} \le k_b \tag{2}$$

$$k_b = k_{dop\_material} \tag{3}$$

$$\sigma_{H-M} \le k_{dop\_weld} \tag{4}$$

The method used is consistent with the methodology adopted in the work of Truta et al. [26] on the strength of the adaptation table and the work carried out by Chodurski et al. [27] presenting the strength analysis of the robot frame. In the analyzed model, no places were noticed where the stresses would reach a value greater than 53% of the value of the allowable stresses in the material structure and 71% of the value of the allowable stresses in the structure of welds. The analyzed structure of the frame of the front loader with extension has an acceptable stiffness and resistance to deformation. Therefore, it is possible to optimize in the direction of reducing its mass through the use of beams and sheets with smaller crosssections and strength indicators. In order to finally validate the presented FEM analyzes, a prototype should be built and tests performed using the strain gauge method. The designed structure of the front loader fulfills the assumed functions. Using the new design of the loader with extension, it is possible to load and unload higher piles (straw, hay) and use proposed connstruction in high-bay warehouses.

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