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MODELING AND EMPIRICAL VERIFICATION OF UNIVERSAL CARRYING FRAMES FOR AGRICULTURAL MACHINERY

Summary

The paper presents application of the FEM method to develop universal carrying frames for agricultural machinery and their empirical verification. To perform stress analysis there were developed computational models basing on geometrical 3D models. Identification of strenuous of framework design was defined by adopting different load cases. In the nodes which revealed excessive stress levels, the frame structure was changed. In experimental research in real conditions the results of FEM stress analysis were verified. The verification showed that developed universal carrying frames for agricultural machinery are characterized by correctness of endurance structure and confirmed the appropriateness of the design solutions.
***Key words**: agricultural machinery, carrying frames, stress analysis, method of FEM, computational models, empirical verification*

MODELOWANIE I WERYFIKACJA EMPIRYCZNA UNIWERSALNYCH RAM NOŚNYCH MASZYN ROLNICZYCH

Streszczenie

Przedstawiono zastosowanie metody FEM do opracowania uniwersalnych ram nośnych maszyn rolniczych oraz i jej weryfikację empiryczną. Do przeprowadzenia analiz wytrzymałościowych opracowano modele obliczeniowe na bazie modeli 3D. Identyfikację wytężenia konstrukcji ram zidentyfikowano przyjmując różne przypadki obciążeń. W węzłach, w których odnotowano nadmierne poziomy naprężenia zredukowanego zmieniono konstrukcję ramy. W przeprowadzonych badaniach eksperymentalnych w warunkach rzeczywistych dokonano weryfikacji empirycznej wyników analiz wytrzymałościowych. Weryfikacja wykazała, że opracowane uniwersalne ramy nośne maszyn rolniczych cechują się poprawnością struktury wytrzymałościowej i tym samym potwierdziły poprawność przyjętych rozwiązań konstrukcyjnych.
***Słowa kluczowe**: maszyny rolnicze, ramy nośne, analiza wytrzymałościowa, metoda FEM, modele obliczeniowe, weryfikacja empiryczna*

1. Introduction

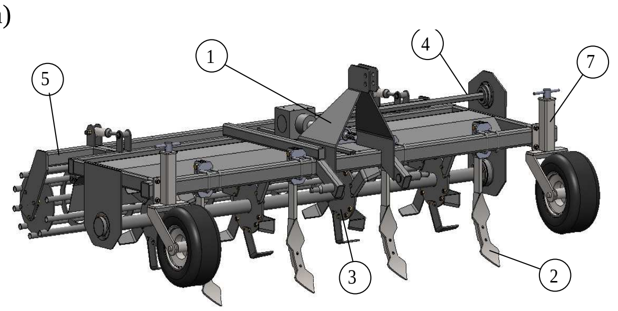
High requirements in terms of strength and stiffness are made for frame structure supporting the agricultural machine. These requirements increase when interchangeably and different working tools are mounted on them. Therefore, to prepare an universal framework for agricultural machinery, subjected to different and varying loads during operation, there was applied numerical methods of MES. It allows to develop a rigid carrying frame of machines which is resistant to changing exploatation loads [1]. FEM methods applied Wang Li-rui [2], Gaduš [3] to optimize the carrying frame of a motor vehicle and agricultural trailer. Also Łowiński [4] and Zbytek [5] applied the FEM method to analysis loads of carrying frame of agricultural machinery, during working and transportation. Łowiński [6] applied the FEM method to the analysis of stress level in the construction of frame for machine which was mounted on front three point hitch of tractor. In all of the above applications of MES there was recieved such a solution of the carrying frame, which corresponds to the high strength requirements and allows the weight reduction of the frame [3], which did not impair the structural integrity of the machine. Thus, the use of FEM numerical methods for the design of carrying frames allowed to the multi-option choice of profiles and structural materials for the construction of the frame and effectively eliminated construction joints that have excessive stress. A very important stage of research is empirical verification of developed frames, performed in real working conditions [7]. In these tests carrying frames of machines were subjected to different real loads that are transmitted to it by the installed working elements.

2. Goal and scope and object of the study

Objective of the study was to evaluate the durability of design solution for universal carrying frame of an agricultural machine. The accepted concepts of carrying frames allow for interchangeability of mounted working tools. It allowed the use of machines in various of agricultural seasons. A new solution of carrying frame designed for strip-tillage and mechanical care of the inter-row* was developed. The tool is active, in the first option it is equipped with the tines with coulters, milling unit, stringring roller and supporting wheel. In the second option of tools on the frame there is mounted milling tool, plant cover, depth wheels and harrow. Milling shafts vary a spacing between knife discs. Another universal carrying frame was used to mount double-version stubble cultivator with a variable working width (3 to 3.8 m), cooperating with the roller or harrow and a 4-row ridger, equipped with a ridge forming unit. A frame was also developed. It allows the adaptation to equipped aggregate for simultaneous cultivation and sowing and the precision seedbed cultivation. In the first version of the aggregate was mounted on the frame, a front rollers section, the cultivator, the string shaft and coupling to the drill. In the second version of the machine it can be mounted a front roller, drag, cultivator section and two rear rollers. Adopted in the calculation that all researching carrying frames are made from S355J0 steel.

Before the calculations, here were analytically determined loads for different combinations of universal frames with mounted working tools. In the considering there were included only those cases which are considered likely to occur during the real work conditions for machines. Then there were calculated conceptual models of the respondents support frames with mounted on them working elements (Fig. 1).

a)



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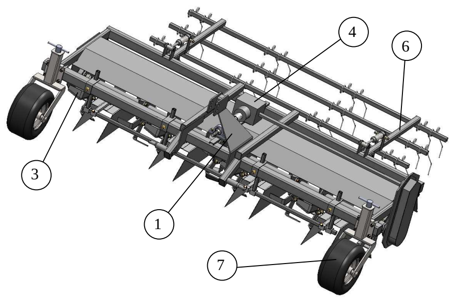


Fig. 1. Conceptual model of a universal tool to: a - strip-tillage, b - for mechanical interrow cultivation (1 - carrying frame with a hitch, 2 - tine with coulters, 3 - milling drum 4 - drive system, 5 and 6 - string-ring roller or harrow, 7 - depth wheel)

3. Implementation of the load in a calculation model

The boundary conditions which are implemented for each designed frame it contains the load from the weight of the modeled and no-modeled elements and load from the working resistance of tools. Computational FEM models include, depending on necessity, all carrying structure or a selected sub-assembly for all version of the tools. To build computational models of universal carrying frames mainly there were used finite thin-shell elements, beam elements and rod elements.

In order to implement of boundary conditions for the MES model there was applied concentrated mass corresponding to the weight of the of tools elements which have not been modeled. There were considered such calculation cases as: work and driving in the transport position for all version of the tool. Therefore, for the carrying frame of universal care-cultivation tool examined six load cases, for the stubble cultivator frame and ridger and for frame of universal cultivation aggregate adopted 5 calculation cases. Taken into account the load cases include work and transportation of researched frames with mounted various working tools (Fig. 2).

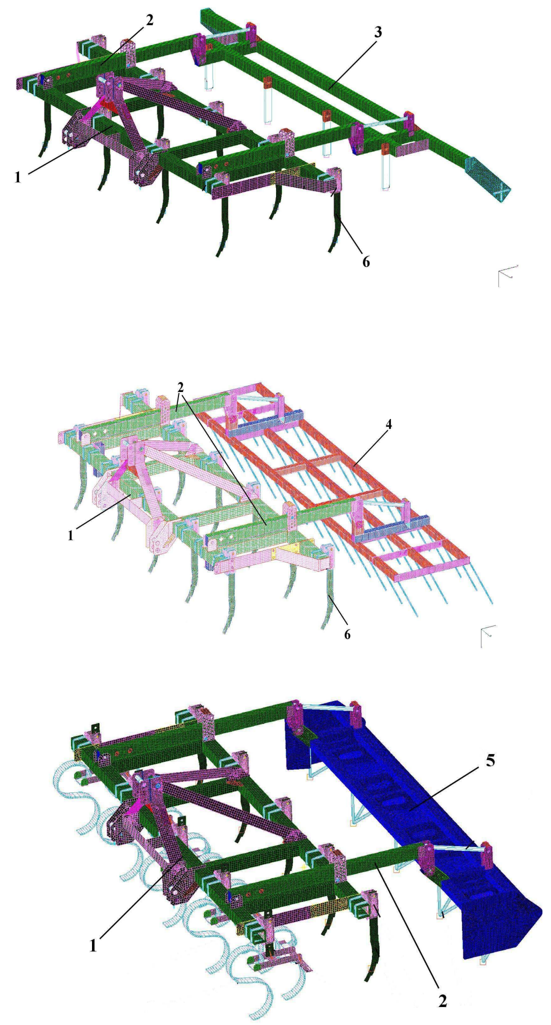


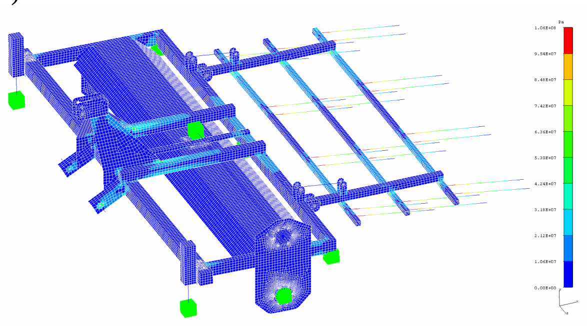
Fig. 2. Example of the calculation model of universal carrying frame of double-version stubble cultivator with the possibility of conversion to ridger (1 - carrying frame, 2 - connection arm, 3 - roller frame, 4 - harrow frame, 5 - ridge forming unit, 6 - stem of tine)

4. Results of FEM analysis

The calculations made it possible to evaluate the strenuously of carrying frames for the adopted design solutions in while of work and transporting. As a result, the maps of stresses were generated on each node of designed frame. In FEM models of specific frames there was take into account the gravity force, assuming a ratio of dynamic surplus of 1.2.

Stresses distribution maps for universal care-cultivation tool showed areas where the maximum equivalent stresses were 166 MPa (Fig. 3), for the adopted threshold of 90% Re for steel S355J0, 320 MPa. A similar level of stresses value was obtained for double-version stubble cultivator. Results of strength calculations for aggregate which was convert to four-row ridger for potato with ridge forming unit showed that higher local stresses appeared in the outside fixing points of the half-body of ridge forming units (Fig. 4).

a)



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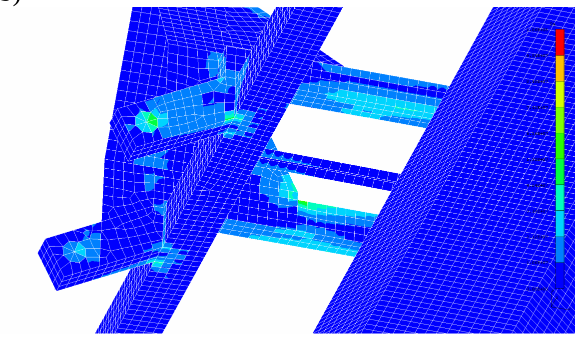
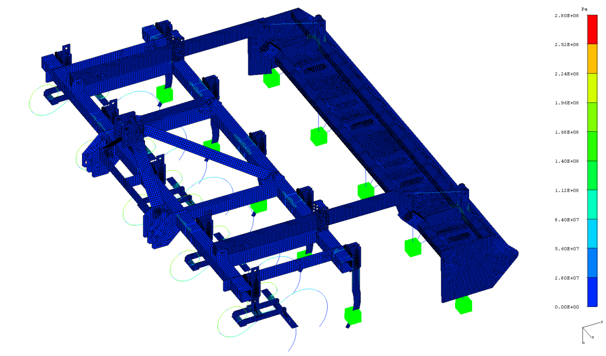


Fig. 3. Distribution of reduced stresses [Pa] in the model of carrying frame for tools for mechanical cultivation during operation: a) top view, b) view of the lower hitch brackets

a)



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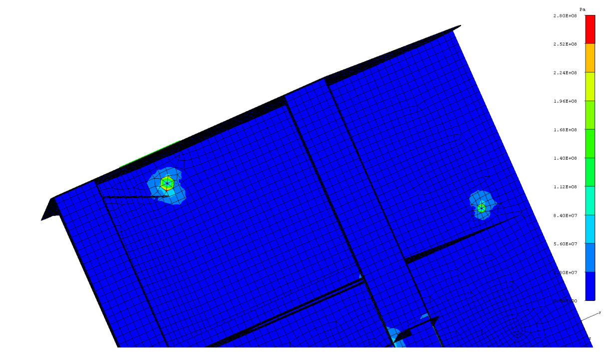
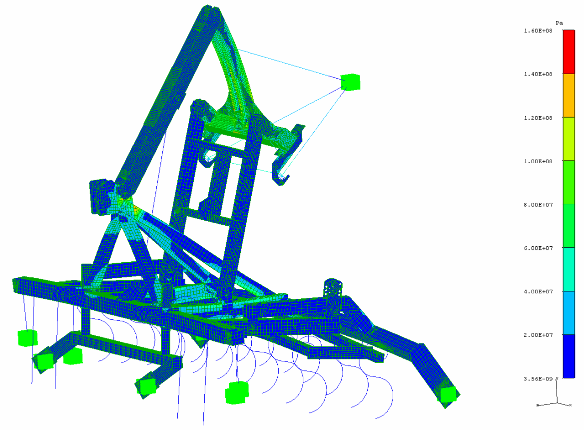


Fig. 4. Distribution of reduced stresses [Pa] in the model of carrying frame with ridger and ridge forming unit during work: a) top view, b) view to outside fixing points of ridge forming unit

Most adverse stress values obtained in the carrying frame of cultivation aggregate in cultivating-seeding version. They were found in the hitch for drill when the drill is filled with grain and lifted to transport position (Fig. 5).

a)



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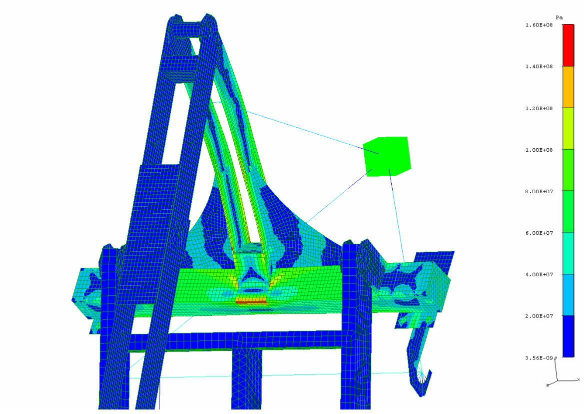

Fig. 5. Distribution of reduced stresses [Pa] in a model of carrying frame for cultivating-seeding aggregate during operation: a) general view, b) view of the transverse beam of drill hitch

The occurrence of high levels of reduced stress required to take action to seek a more favorable design solutions to eliminating high stress. They mainly focused on increasing the thickness of the hitch beam and additional inserts between the transverse and longitudinal beam of carrying frame. After the changes the calculation model of carrying frame was FEM reanalyzed. It has been found that the changes in the frame structure allowed to elimination of high stress levels in some nodes of carrying frame.

5. Experimental studies in the context of verification of the calculation model

Experimental tests included on determination of the stresses at selected points of the carrying frame, which occur during operating and transportation. For recording and processing of measurement signals there was applied set of data acquisition, comprising a measuring apparatus and software from Hottinger, and used for measuring strain gauges which are used to measure strain in a single direction. Active strain gauges were glued at selected measuring points which are found high stress values. Compensation strain gauges glued on metal plates, which was placed near the measure points. The obtained values of the measured stress is presented by graphs. Comparisons experimentally obtained stress values with the calculated is showed on graph (Fig. 6).

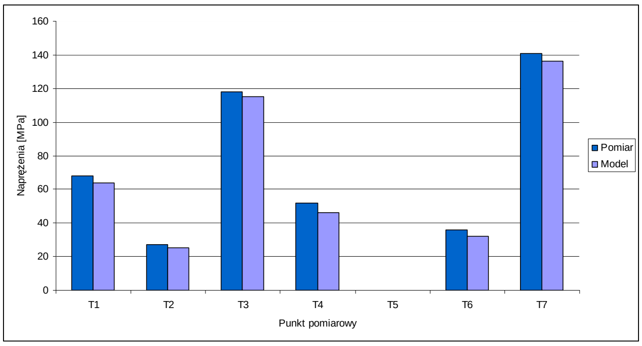

Fig. 6. Example of comparison of the results obtained during the measurement and the calculation model of cultivating-seeding aggregate during transport (T1-T7 point strain gauges, T5 damaged strain gauge)

There were obtained a slight discrepancy between the results of computer simulations and experimental research. These differences may be due to the simplifications adopted in the calculation model and unavoidable measurement inaccuracies. It is assumed that the accuracy of the results at the level of 80% is very good.

6. Conclusions

The use of FEM analysis to calculate the universal carrying frame for agricultural tools enabled to generate maps of stress and to identify each node of carrying frame in which appeared too high concetration of stresses. Developed maps of stress at the design stage enables to make changes in developed carrying frames to achieve the solution which is according to the requirements. Empirical verification showed the correctness of the durability of universal carrying frames for agricultural tools. The research involving numerical analysis using computer techniques and empirical verification of design solutions for carrying frame of agricultural tools provides that in a short time we can get the best solutions of frame in respect of durability.

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