Marcin SZCZEPANIAK¹, Roman ROGACKI¹, Paweł DUDZIŃSKI¹, Miłosz OLEJNICZAK²

¹ Industrial Institute of Agricultural Engineering
ul. Starołęcka 31, 60-963 Poznań, Poland
e-mail: office@pimr.poznan.pl
² State University in Applied Sciences in Konin
ul. Przyjaźni 1, 62-510 Konin, Poland

APPLICATION OF THE CONCURRENT DESIGNING IN VIRTUAL MODEL DEVELOPMENT OF A NEW GENERATION OF CEREAL DRILL CONSTRUCTION

Summary

The article presents one of the methods of construction verification connected with a designing process of the tilling-and-sowing combined machine. In the developed seeder a mechatronic control system was used which allows to increase the working speed and to increase the accuracy of sowing. Construction of the machine was elaborated and then its strength was analyzed. The calculations showed the effort of the construction and allowed to indicate areas with exceeded stress limits. It also allowed to make modifications in the construction at the designing stage. The next stage was fatigue strength analysis of the tilling-and-sowing combined machine carrying structure.

Key words: seed drill, seeder, tilling-and-sowing combined machine, construction, fatigue analysis

ZASTOSOWANIE PROJEKTOWANIA WSPÓŁBIEŻNEGO DO OPRACOWANIA WIRTUALNEGO MODELU KONSTRUKCJI SIEWNIKA ZBOŻOWEGO NOWEJ GENERACJI

Streszczenie

W artykule przedstawiono jedną z metod weryfikacji konstrukcji związanej z projektowaniem agregatu uprawowo-siewnego. W opracowanym siewniku zastosowano mechatroniczny układ sterowania umożliwiający zwiększenie prędkości roboczej i podwyższenie dokładności wysiewu. Opracowano konstrukcję maszyny i poddano ją analizie wytrzymałościowej. Obliczenia te pokazały stan wytężenia konstrukcji i umożliwiły określenie obszarów przekroczenia dopuszczalnych naprężeń. Pozwoliło to na wprowadzenie zmian konstrukcyjnych na etapie projektowania maszyny. Następnym etapem pracy było przeprowadzenie analizy wytrzymałości zmęczeniowej konstrukcji nośnej agregatu uprawowo-siewnego.

Słowa kluczowe: siewnik, agregat uprawowo-siewny, konstrukcja, analiza wytrzymałości

1. Introduction

In order to obtain high yields of crop plants it is required to keep soil in a very good agricultural condition but also to maintain adequate arrangement of seeds below the soil surface. The optimal distances between seeds as well as the optimal depth of seeds application beneath soil surface depend on numbers of factors (e.g.: species and variety of plant, species and fertility of soil, soil preparation, weed infestation) and they are one of the basic agro-technical conditions. Sowing process is performed mechanically with the use of seeders [1].

Source: own work / Źródło: opracowanie własne

Fig. 1. The model of tilling-and-sowing combined machine
Rys. 1. Model agregatu uprawowo-siewnego

The seed drill with high accuracy of sowing, which is being designed, will be characterized by innovative solution of controlling systems of seeding processes through seeder seeding units and controlling system of coulter working depth [2]. In the proposed solution seeder is aggregated with tilling set, forming together one machine – tilling-and- sowing combined machine [3]. Model of the tilling-and-sowing combined machine is shown in fig. 1.

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In the machine an electric drive of seeding units and programmable controlling system are used. Sowing parameters like a dosage per hectare, working speed of seeder, rotational speed of sowing shaft are displayed on the control panel screen which facilitates the controling of parameters during the aggregate work.

The maintenance of a constant working depth of coulters is ensured by control system whose elements, responsible for pressing force, induce a constant pressure of depth wheel onto field surface. The force value is measured by stress gauge sensor. The sensor is mounted between the coulter guide and depth wheel arm (fig. 2).

Control system consists of programmable driver which combines properties of a measuring card capable to process information in real time. Measuring inputs of the module will be connected electrically with selected sensors. The driver will carry out up to date readings of these inputs, process the read data, present results to the operator and will influence in a certain way the sowing process by send-

ing appropriate control signals to the actuators (e.g.: pneumatic cylinders). Communication between the modules will be done by wires or wirelessly using Bluetooth network.

Fig. 2. General view of the disc coulter with system responsible for maintaining a constant sowing depth
Rys. 2. Widok redlicy talerzowej z układem zapewniającym utrzymanie stałej głębokości siewu

2. Choose of the research method

Operational tests (field tests under real working conditions) are the most reliable method of analysis and evaluation of the carrying structures of agricultural machines. The primary negative features of such research are: time duration resulting from agro-technical cycle and high costs. Also bench tests, as an alternative to the field tests, despite many advantages have unfavorable features as well. To conduct a research it is required in many applications to use expensive testing stand, prepare a program of research, which have to remap closely real working conditions. The use of experimental methods can be employed only after the construction of a machine prototype. During experimental studies, energy flow of human body model of the unit operator can be determined [4].

The above-mentioned disadvantages of the time and cost of experimental studies suggest the use other methods which are based mainly on the achievements of modern computer technology of the design process for this purpose. Concurrent engineering is a good method allowing to shorten the duration of the project. It consists in parallel running process of design object and preparatory processes of project management (defining, planning and organizing) [5]. One of the methods used in the concurrent engineering is strength analysis based on the finite element method (FEM).

3. Computational model of the carrying structure

Carrying structures of agricultural machines are usually spatial, welded constructions or assemblies connected with bolted joints, built of steel profiles. The construction of computational models with such (spatial) geometric form causes many problems, especially when it is required to use a variety of finite elements.

In the carrying structure of the tilling-and-sowing combined machine various kinds of sheet metals, square and rectangular profiles made of steel S355 are used. Solid model of the machine, developed in SolidWorks computer system is shown in fig. 1.
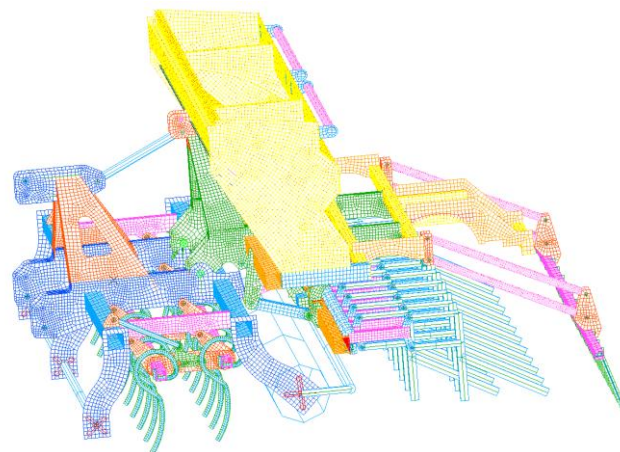
Fig. 3. Model of the tilling-and-sowing combined machine discretized using plate and shell elements
Rys. 3. Model agregatu uprawowo-siewnego zdyskretyzowany elementami płytowo-powłokowymi

During development of the seeder computational model the main emphasis was put on analysis accuracy with particular focus on the accuracy of geometry mapping and the nature and size of loads. Properly thick finite elements should tolerably faithfully reproduce the actual shape of the considered object.

Computer model was developed using I-DEAS NX6.1 computer system. On the basis of the geometric model of carrying structure discrete model shown in fig. 3 was developed. For its construction triangular and rectangular surface elements (plate and shell) were used. Working groups and other structural elements not constituting the carrying frame structure were modeled as beam elements [6].

The aim of the computations was to carry out strength analysis of tilling-and-sowing combined machine based on the finite element method (FEM) [6].

4. Load cases

For the purpose of strength analysis a number of computing cases were developed for tilling-and-sowing combined machine:

- LC1 – road transport, (dynamic surplus 1.4),
- LC2 – transport with side inclination 8,5°, (dynamic surplus 1.4),
- LC3 – transport with rear inclination 8,5°, (dynamic surplus 1.4),
- LC4 – transport with front inclination 8,5°, (dynamic surplus 1.4),
- LC5 – during work (rear inclination 1.3 for operating resistance).

The first four cases concern transport of the aggregate in transport position. The fifth case concerns aggregate during work. It uses the same boundary conditions as used in the transport cases. In case LC5 (work) a dynamic surplus 1.3 was set for operating resistance, both for aggregate and seeder, according to study [7].

For the above-described cases, auxiliary (supplementary) cases were also developed which will help to determine average stresses for the studied machine. They were named vertical loads. These cases will have no dynamic surpluses and they will bring information about stress maps and will allow to determine the average stresses. Below two

cases are shown of so-called vertical loads which will be a base for the stress analysis of cases with a dynamic surplus:

- LC01 – vertical load – transport,
- LC02 – vertical load - work.

Case LC01 is a vertical load for road transport for which average stresses will be determined and applied in cases LC1-LC4. These stresses will allow to assess amplitude stresses for such cases as: road transport, side inclination 8,5°, rear inclination 8,5°, front inclination 8,5°. Boundary conditions for this case will be identical as these used in LC1-LC4, with the exception of dynamic surplus use.

Case LC02, whereas, describes the vertical load used to determine average stresses for case LC5. This case will be a base for amplitude stresses determination for work conditions. In this case, dynamic surplus is not taken into account for operating resistance of the aggregate.

## 5. Strength analysis of the construction

The conducted strength analysis allowed to determine stress distribution and displacements in the structure of the machine carrying frame. Exemplary results in the form of stress maps are shown in fig. 4 for transport case and in fig. 5 for work case.
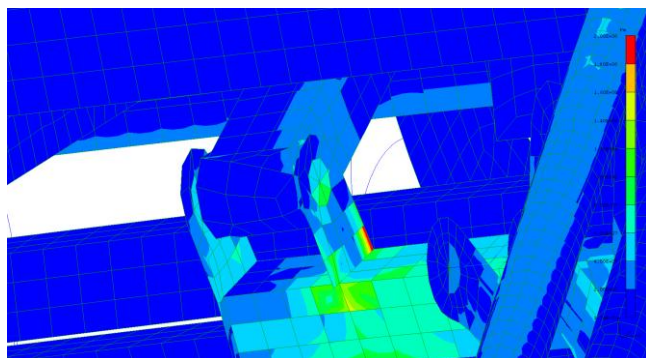
Source: own work / Źródło: opracowanie własne

Fig. 4. Reduced stresses [Pa], case LC1, beam handle of seeder adjustment
Rys. 4. Naprężenia zredukowane [Pa], przypadek LC1, uchwyt belki regulacji siewnika
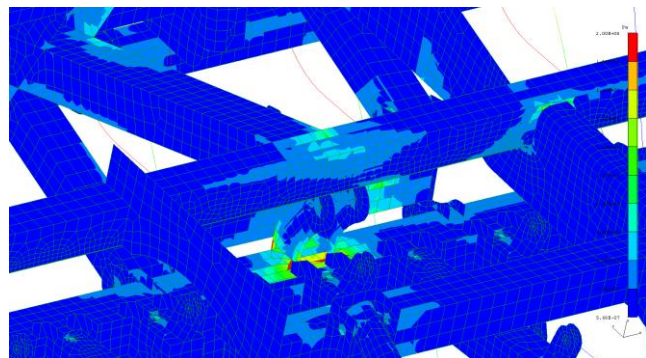
Source: own work / Źródło: opracowanie własne

Fig. 5. Reduced stresses [Pa], case LC5, upper view of carrying beam of sowing section
Rys. 5. Naprężenia zredukowane [Pa], przypadek LC5, widok z góry na belkę nośną sekcji wysiewającej
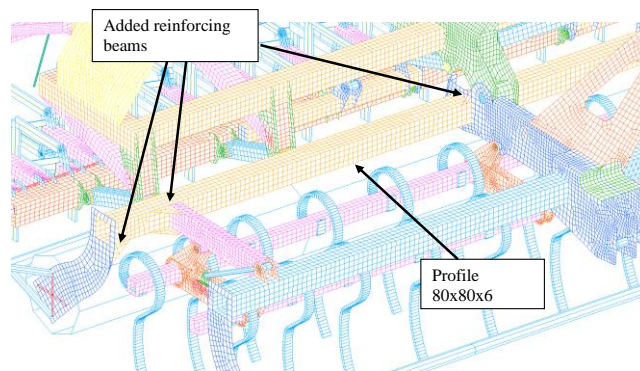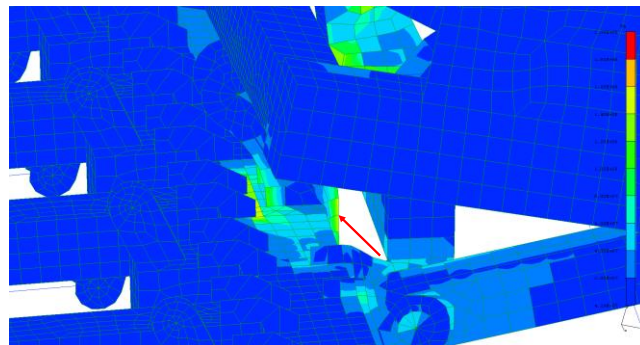

Source: own work / Źródło: opracowanie własne

Fig. 6. Reinforced carrying frame
Rys. 6. Wzmocnienie ramy nośnej agregatu

Originally, in analyzed construction exceeded values of allowable stresses were found. Number of changes were introduced in order to reduce stress concentrations which were presented in the paper. For example, in the carrying frame of aggregate (fig. 6) additional reinforcing ribs were used and profiles were thickened.

Subsequently, a fatigue analysis was carried out of the aggregate construction. In order to conduct the analysis it is required to have information concerning levels of average stresses as well as character of cyclic stresses. The average values were adopted as stress values obtained for the case of vertical load (case LC01). Stresses amplitude, whereas, was determined as a difference between road transport case stresses and vertical stress case.

Source: own work / Źródło: opracowanie własne

Fig. 7. Reduced stresses [Pa], case LC1, view of the adjustment beam handle
*Rys. 7. Naprężenia zredukowane [Pa], przypadek LC1, widok na uchwyt belki regulacji*
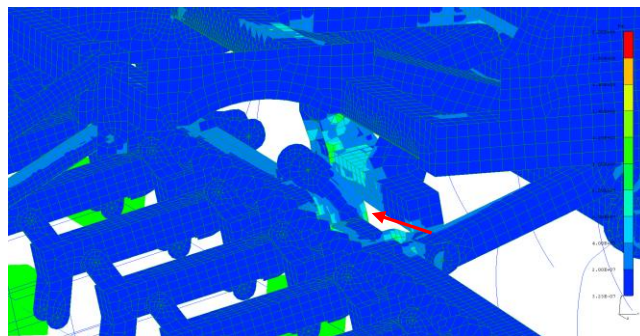
Source: own work / Źródło: opracowanie własne

Fig. 8. Reduced stresses [Pa], case LC01, view of the adjustment beam of sowing section
Rys. 8. Naprężenia zredukowane [Pa], przypadek LC01, widok na belkę regulacji sekcji wysiewającej

In fig. 7-8 nodes are shown (red arrows) in which maximal values of stresses were noted for all mentioned cases. Then, amplitude stresses were determined for areas where limited fatigue strength may occur. Reduced stress were read in every point for upper and lower element layer (amplitude stresses were calculated in the same manner).
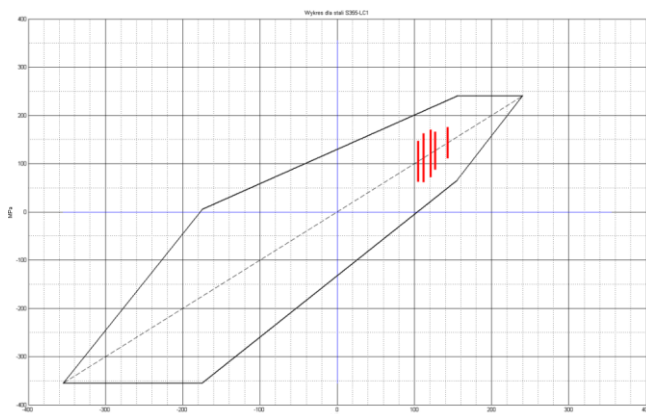
Source: own work / Źródło: opracowanie własne

Fig. 9. Smith's graph for steel S355, graphical representation of the biggest stress for road transport case
Rys. 9. Wykres Smitha dla stali S355, graficzne przedstawienie wyników największego naprężenia dla transportu po drogach

Obtained results were implemented to Matlab software, where, with the use of own written script, Smith's graph was generated. Determined amplitude and average stresses were combined with Smith's graphs for steel S355 (fig. 9). Maximal and minimal stresses did not exceed allowed limit values for road transport cases.

6. Summary

Ultimate strength and fatigue strength analysis of tilling-and-sowing combined machine's carrying frame was carried out at assumed loads for road transport and working conditions.

As a result of conducted strength studies, information concerning machine functionality and critical stress-strain state of the construction was provided. These studies enabled to re-design construction at the designing stage and allowed to avoid costly modifications in the machine prototype.

7. References

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