

Arkadiusz STACHOWIAK, *

Marcin SZCZEPANIAK, **

(Paper received on 24.03.2016, Paper accepted for publication on 06.06.2016)

APPLICATION OF COMPUTER SIMULATION IN DESIGNING AGRICULTURAL MACHINERY

In recent years, the development of computer-aided design systems and manufacturing changes significantly the method of structural and technological works. Method that allows for the rapid introduction of a new product on the market is concurrent engineering. Due to the high costs of hardware and software and the lack of appropriate staff this method is not available to many, especially small manufacturing plants. Effective, although to a less extent, a tool to improve quality and shorten the design time can be individual modules as well as computer programs. The article presents examples of how use the program of "virtual prototyping" to solid modeling, kinematics simulation and stress analysis by finite element method. The results of presented analysis enabled the redesign of few elements of potato planter construction: support frame in fastening stationary tank place and side walls of the movable tank.

Keywords: computer simulations, strength analysis, virtual prototyping, potato planter

1. INTRODUCTION

The use of a computer system for engineering analysis in the field of agricultural machinery causes significant changes in the methods of structural and technological works. This is due to the development of computer-aided design systems and manufacturing. It can be said that also in Polish enterprises is widespread awareness of the need to amend the existing working methods. It arises from the experience gained from the cooperation with partners from the highly

* Institute of Machines and Motor Vehicles, Poznan University of Technology.

** Industrial Institute of Agricultural Engineering in Poznan.

industrialized countries and the growing belief that it is a necessary condition for the development of the company.

However, the introduction of modern, computerized tools encounters often in Polish enterprises on the barrier difficult to overcome. They are of the material, organizational and personal nature. Material, because the hardware and software, allow to effectively improve work efficiency are expensive. Purchase the full version of the software and powerful computer configurations sometimes exceeds the capabilities of enterprises, especially the smallest ones. Arises therefore the problem of choosing such a system or its modules, that will be the best and at the same time as cheaply as possible realize the real needs of the company.

Using these tools allows you to perform effective simulation of behavior designed machine, basing on the virtual model, already in the early phases of design. The main advantage of this method is possibility re-designing of a virtual model, and not the machine prototype [Zienkiewicz i Taylor 2000].

Performing such simulations requires combining knowledge from many disciplines of science in order to perform analysis of the boundary conditions and events occurring during the use of the designed machine.

2. SOME ASPECTS OF THE COMPREHENSIVE COMPUTERIZATION OF DESIGN WORKS

Currently there is difficult achieve success on the world market of agricultural machinery. In most companies the employees know how the product should look like to be able to be sold and how to organize the company, to the product could be produced. It is well known that we momentary upturn associated with the specificity of the market, satisfaction of users, the cost of the product or any other selected feature will soon disappear, thanks to the activities of competition. The only significant factor differentiating companies is time-to-market. This is the response time of the company on a temporary economic situation, new method and new technical solutions. The company, which first corresponds to the new challenge, take the majority of profit, increases production series and winning new measures can improve their production.

The method which can greatly reduce the time to market is a so called Concurrent Engineering. It consist in parallel conducting a process of engineering design and preparatory processes of project management (defining, planning and organizing) [Trocki 2012].

Concurrent Engineering is a management technique that focuses company resources to introduce new products to market as quickly and at a profit as soon as these measures permit.

Concurrent engineering is an expensive solution and is largely limits its application. It requires both appropriately trained personnel as expensive

equipment and software, as well as the fulfillment of a number of organizational requirements. It is therefore not yet available for the majority of Polish companies. Effective, although to a lesser extent, the tool improve the quality and reduce the design time can be also single modules or programs, which communicate with each other by means of appropriate interfaces, or by the data input by the user. There is a few advantages of the introduction of computer-aided design:

- the use of computer-aided design enables automatic changes in all parts of the subsidiaries in the project; it reduces errors and speeds up putting the product on the market; simply connect the parts and assemblies together by a project dependencies and changes made in part will be reflected in the assembly and in the associated drawing files,

- structural changes increase the cost and delay the reimbursement of capital expenditures; errors made at design time are cumulative and increase the cost, the values of which in critical situations can't be even reasonably estimated; this applies especially situation, when an error is detected after the start of production.

Proper implementation of hardware and software, even only for some phases of design, will allow the company to avoid these disadvantages and to expect tangible benefits such as:

- shortening design time, modify, and consequently shorten time to market,
- adapting the product to the specific requirements of the user,
- enabling quality improvement.

3. EXAMPLE OF COMPUTERIZATION DESIGN WORKS

Kinematic analysis allows to determine the location of elements in the accepted frame of reference and the speed and acceleration of kinematic pairs, points and parts of the mechanism without considering the mass and the forces acting on. But, in the dynamic analysis the relationships between the parameters of the kinematic elements of the machine and their masses and the forces acting on it are examined [Miller 1996].

One of the methods used in the early stages of design, before construction of the prototype technique is virtual prototyping. This technique concerns the process of creating and testing a virtual prototype. This method allows for the construction of three-dimensional solid models, simulation study of properties (eg. strength, functionality, etc.) and the visualization of the movements of the model. It allows modeling of mechanical systems and visualize the behavior of the model in answer to setting extortion. The models are formed as a geometric solids reflecting the shape of tested object. Motion simulation may be carried out in the range of large displacements. The use of such systems enables the modeling of the working elements and of various kinds of drives, for example hydraulic cylinders, engines

pneumatic or electric. An additional advantage is the ability to exchange data with other computer systems. It allows, on the one hand, consideration of spring mass members in the virtual model, on the other hand, allows you to prepare data loads for computer systems of strength analysis.

3.1. Model of potato planter aggregate

The article presents an example of the use of methods kinematic simulation during designing the potato planter, taking into account the actual operating conditions. Developed CAD-3D models (Fig. 1) of potato planter and its assemblies will allow for the analysis of its kinematic and dynamic.

Potato planter aggregate consists of four row potato planter, rotary harrow, roller to secondary tillage, dressing machine, fertilizers distributor and equipment for forming ridges, planter drawbar, wishbone rear wheels and three cylinders (Fig. 1). Rotary harrow with the roller to secondary tillage is suspended on the tractor rear three point linkage [Szczepaniak et al. 2011]. This machine is used in farms specializing in the production of potatoes. It is designed for work with the tractor, and its design allows for the efficient execution of field work, such as soil cultivation, planting potatoes with the dressing, sowing mineral fertilizers and forming ridges [Dreszer et al. 2014].

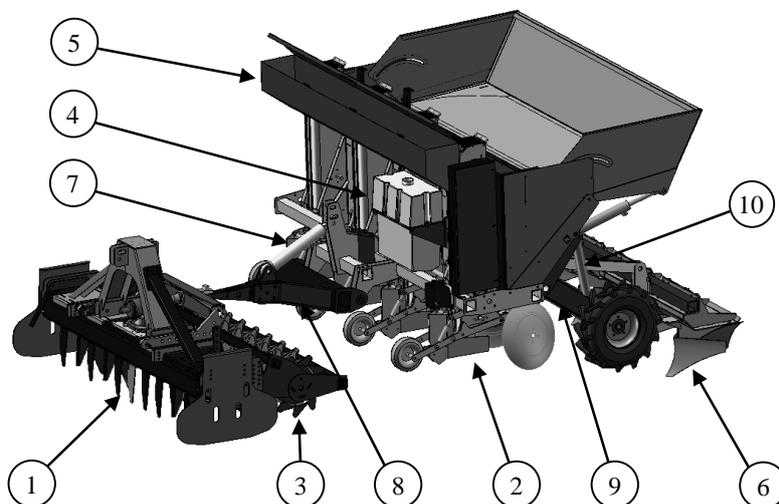


Fig. 1. General view of the model of unit for planting potatoes:

- 1 – rotary harrow, 2 – potato planter, 3 – roller to secondary tillage, 4 – dressing machine, 5 – fertilizers distributor, 6 – a device for forming ridges, 7 – actuator shaft, 8 – planter drawbar, 9 – wishbone rear wheels planters, 10 – actuator mounted on planter rear wheels [Szczepaniak, Wasieczko i Rogacki 2012]

One of the requirements for the said structure is raising the machine on the headland to the so-called transport position. Lifting the machine is done by a servo on the planter drawbar and two actuators positioned in the rear driving road system.

3.2. Analysis of positioning of the actuators

The simulation of working movements of the planter was carried out for force in the actuator resulting from delivery of a tractor pump. Plot of the actuator force for the rear part of the planter (before the design change) during lifting is shown in Fig. 2. Plot of force during the lifting cylinder on the drawbar planting is shown on Fig. 3. In contrast, Fig. 4 shows the force values when lifting planters on the rear wheels.

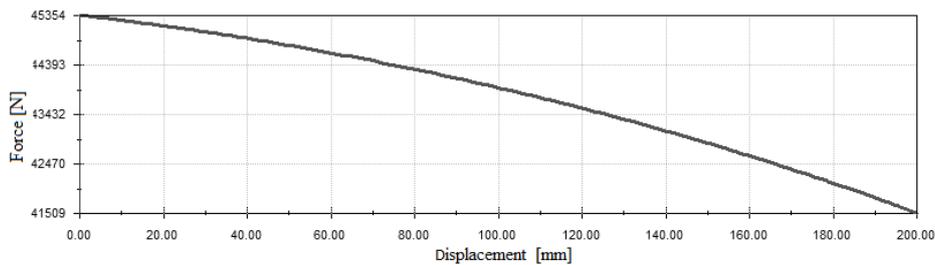


Fig. 2. The course of force in the actuator during lifting planters on the rear wheels before the change

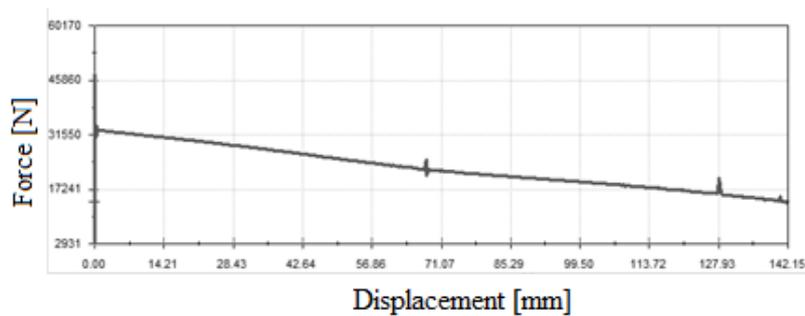


Fig. 3. The course of force in the actuator during lifting planters on the drawbar after changes [Szczepaniak et al. 2011]

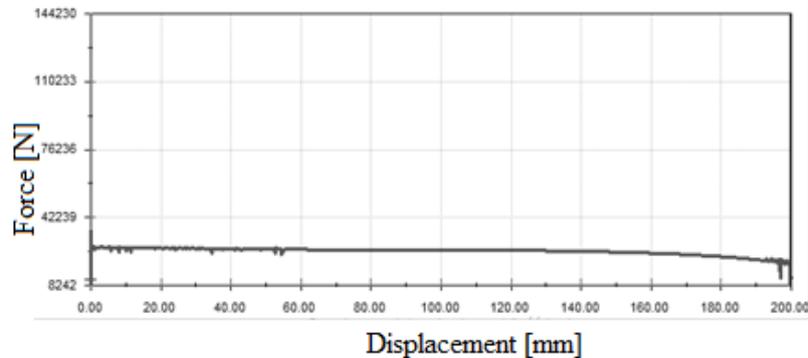


Fig. 4. The course of force in the actuator during lifting planters on the rear wheels after the changes [Szczepaniak et al. 2011]

In order to check the possibility of increasing the planter capacity, without any substantive changes in its structure (constraint, imposed by the manufacturer, concerning the size of actuators) we carried out an analysis of the impact of the location of the rear actuators on the axis forces acting on actuator was carried out. The maximum lifting height of the machine was maintained during calculation. The first change involved shortening the of the handle for cylinder mounting – dimension D1 (Fig. 5). Then the lower attachment point of the actuator arm – dimension D2 was changed. Shortening caused necessity of use the actuator S1 to a lower pitch, and hence lesser flow of oil in the hydraulic system of the machine.

Shortening of the actuator was associated with shift of point A (Fig. 5) by 350 mm (difference between length of original actuator S1 and the length of new shorter actuator S2 which was imposed by the manufacturer (Fig. 6). Design parameter which was adopted as a variable in the kinematic analysis was DV2 – coordinate of joint between actuator and rear rocker (point B on Fig. 6). This variable must be so chosen to get the required height of lifting the machine to the transport position.

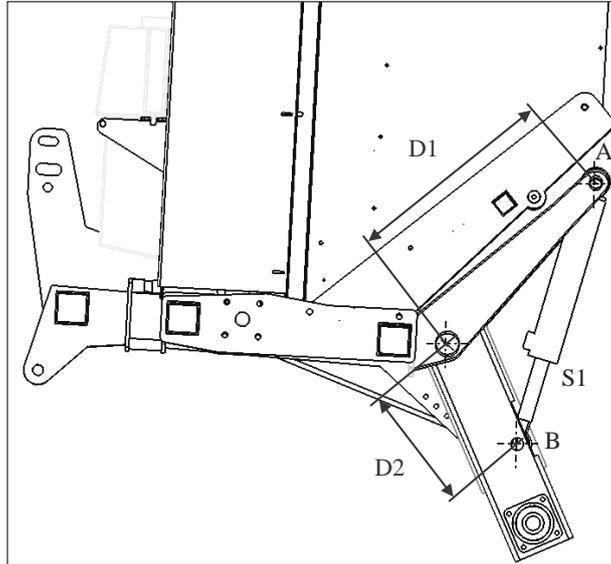


Fig. 5. Design parameters of positioning of joint of actuator and rear rocker before the change: D1, D2 – dimensions, S1 – actuator in original version, A – point of join of actuator and upper bracket of potato planter, B – point of join of actuator and of rear rocker

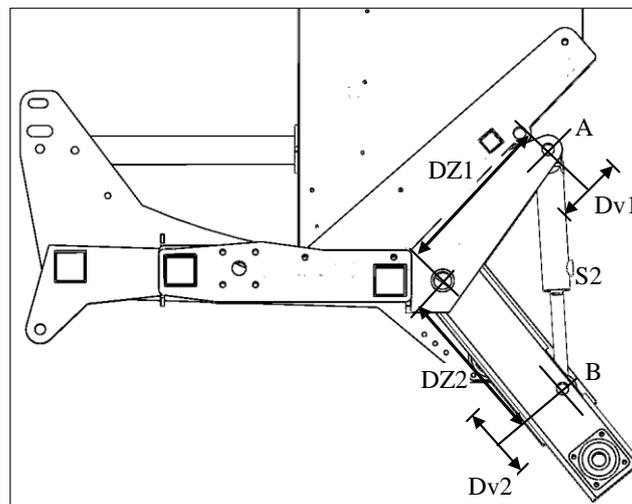


Fig. 6. Variable design parameters of rear rocker actuator position: DZ1, DZ2 – the dimensions after the changes, S2 – short (new) actuator, A – point of join of actuator and upper bracket of potato planter, B – point of join of actuator and of rear rocker, DV1 – range of variation position of point A, DV2 – range of variation position of point B

Point A of join of actuator and upper bracket of potato planter is by a constant distance from the point B of join of actuator and rear rocker. As a result of changes in the coordinates of the points A and B, a reduction force in actuator from 45354 N (Fig. 2) to the value of 32362 N (Fig. 4) was obtained.

Thus obtained data on kinematics system and loads, can easily be used when analyzing the strength of MES as load parameters of support frame structure.

3.3. Strength analysis of unit for planting potatoes

After the modifications described above, analysis of the testing unit for planting potatoes was carried out by FEM method. In calculation various load cases were used. In the case of symmetric load, the gravitational force was applied in the axis of symmetry of the planters. In unsymmetrical loads, the model was tilted in various directions by an angle of 8.5 [Rogacki et al. 2012].

Digitizing the 3D model and topological description of model is made by the IDEAS NX6 system. Example of obtained from Finite Element Method (FEM) calculation distribution of reduced stress is shown on Fig. 7 and 8.

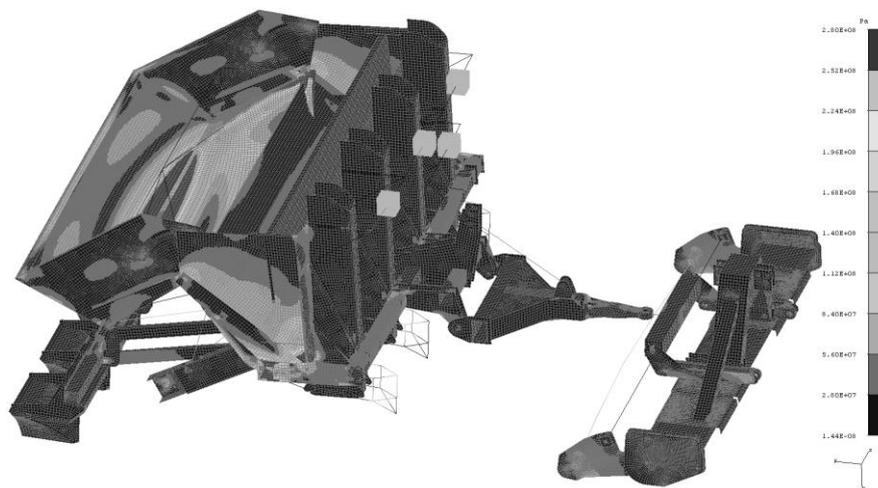


Fig. 7. Results obtained from FEM calculation reduced stress distribution in model of potato planter set [Rogacki et al. 2012]

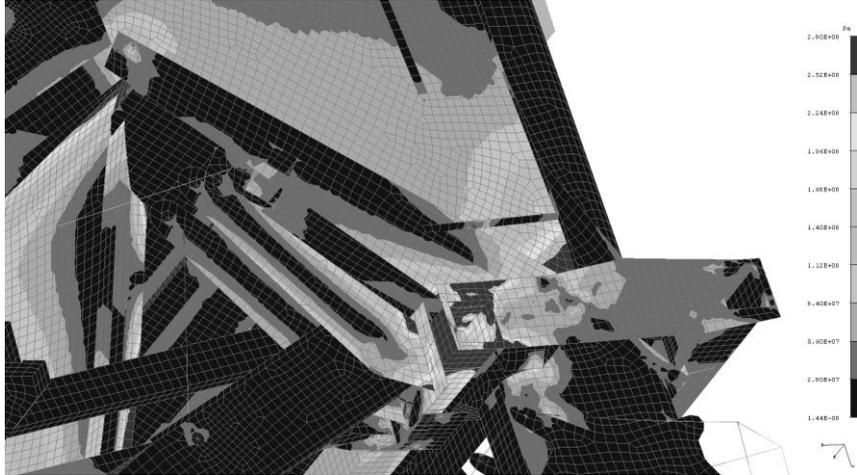


Fig. 8. Reduced stresses [Pa], loading case LC2, the rear beam of support frame – the view from the bottom

The aggregate was built with steel S355J. The structure, both during operation and transport is subject to dynamic loads. As a criterion for fulfilment the of conditions of fatigue strength we took allowable stress for fatigue loads unilaterally changing Z_{rj} .

Due to the nature of operational use of the planting potatoes unit, multi-variant loads were applied in calculating. It includes:

- load derived from the elements modeled; the loads are automatically generated by the system based on the volume of the modeled elements and assumed material density,
- load coming from the working units and components not modeled parts affecting the strain and stress of the machine structure.

Loads derived from the elements don't constituting the support structure were accounted in the calculation model in the form of lump masses or external forces. These include: the weight of potatoes in the stationary tank and in movable tank and rolling resistance of planters wheels. In addition for the individual load cases, forces came from the resistance of the working assemblies of machine: rotary harrows, the roller, coulter, furrow, the unit forming ridges.

The results of stress analysis, presented in the form of maps indicate exceeding the allowable stress (Fig. 7 and 8). Areas of occurrence of too high stresses are the: rear beam of the support frame at a place of joint with stationary tank (Fig. 8), side walls of the stationary tank and the movable tank. From this it follows that the structure of proposed, initial version does not meet the conditions of strength for assumed load conditions.

On the basis of the obtained results (Fig. 7 and 8) proposes to introduce structural changes to reduce occurring stress concentration.

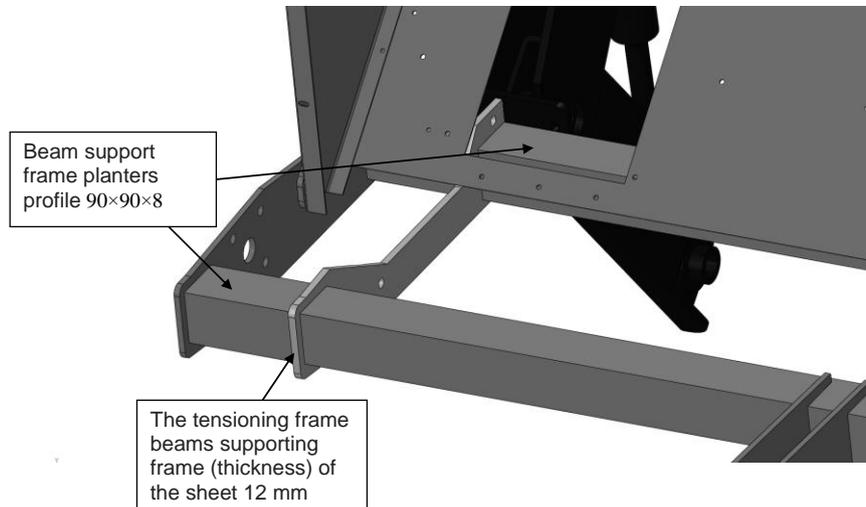


Fig. 9. View of design changes in the planter: use the brace between the beams of the support frame and change of the beams thickness [Rogacki at el. 2012]

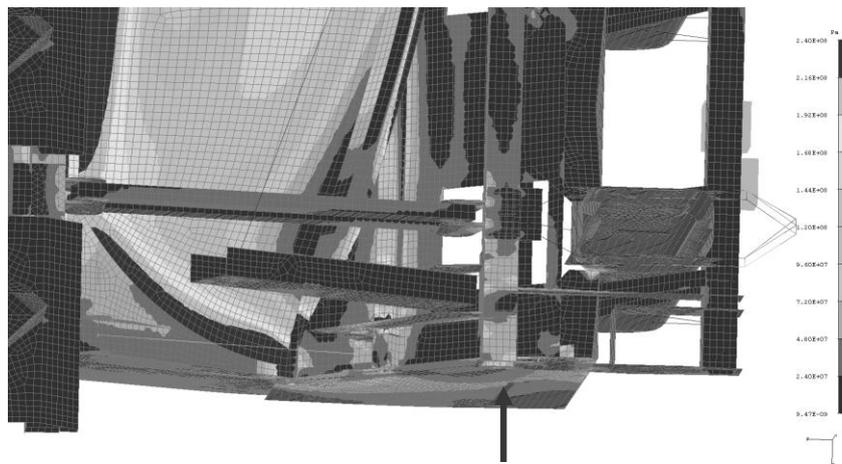


Fig. 10. Reduced stresses [MPa] – loading case LC2 – modified model, point to the changed items

In order to eliminate stress concentrations which occurred, inter alia, in the rear beam of the support frame (Fig. 8), the arm (clamping ring) coupling both beams (Fig. 9) was used. In addition, the thickness of the support frame beams (Fig. 9) was increased from 6 mm to 8 mm [Rogacki at el. 2012]. With the introduction of only the changes, stress distribution shown in Fig. 10 was obtained.

Apart from that, a number of changes detailed in the paper [Rogacki at el. 2012] were made in the entire structure. It included: strengthening the stationary tank

with the use of additional beam, stiffening planter frame with the use of additional beam, the rib reinforcing movable tank was added.

The greatest stresses before changes was caused by the bending of the frame under the influence of loads taking into account dynamic surplus. They were determined on the base of the analysis of the load case for transport (see Fig. 11). Reduced stresses exceeded the limit values reaching 254 MPa for beam support frame and 252 MPa for stationary tank (Fig. 11).

After all the changes and re-calculating the model reached the maximum effort of the construction of 95 MPa for the beam of the support frame and 161 MPa in the stationary tank (Fig. 12), for the same measurement points. Calculations have shown that the stresses in the planter support structure were reduced by 62% – in the beam of the support frame and by 35% – in the side walls of the planter container.

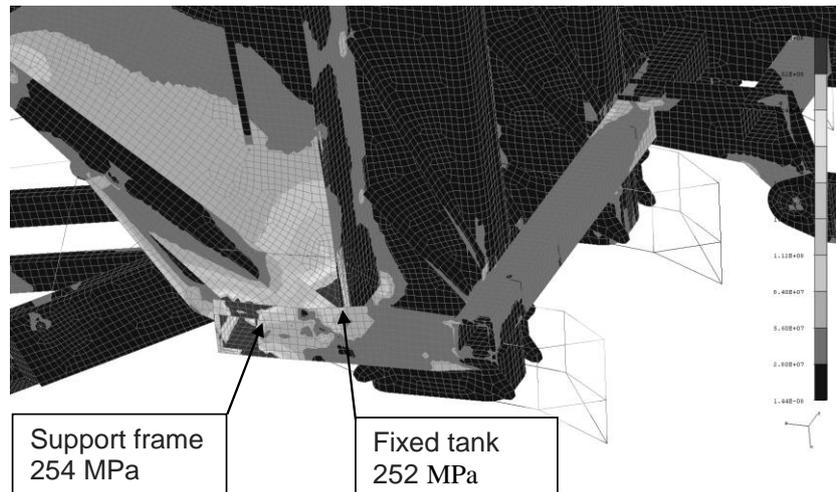


Fig. 11. Reduced stresses [MPa] before changes, side view of the planter

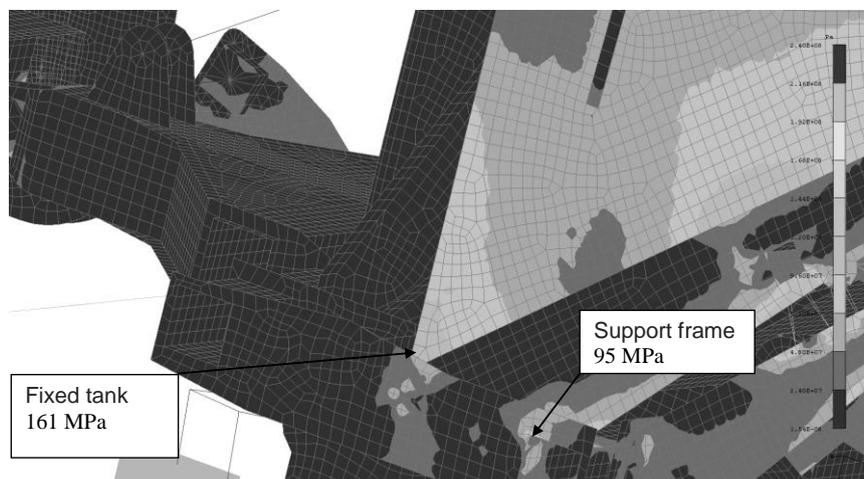


Fig. 12. Reduced stresses [MPa] after changes, side view of the planter

4. SUMMARY

Presented over the way of use of the CAD systems allows for quick and easy to obtain information on the load of mechanical systems. This method avoids the cumbersome analytical calculations and making costly and lengthy field tests of the prototype. It is also possible to carry out optimization calculations, which already at the design stage allow to make significant design changes. Ease of data exchange between the NX system (modelling of geometry) and IDEAS NX system (computer simulation) makes it possible effective analysis of different design variants by means of two systems. These simulations allow you to make changes at the design stage and avoid costly modifications in the prototype of machine.

REFERENCES

- Dreszer K., Pawłowski T., Szczepaniak J., Szymanek M., Tanaś W., 2014, *Maszyny rolnicze*, Wydawca PIMR, Poznań.
- Miller S., 1996, *Teoria maszyn i mechanizmów: analiza układów kinematycznych*, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław.
- Rogacki R., Szczepaniak M., Wasieczko P., Bitner W., Grzechowiak R., 2012, *Wieloczynnościowy agregat do sadzenia ziemniaków, Zad. 8, Wielowariantowa analiza wytrzymałościowa i jednokryterialna optymalizacja elementów konstrukcyjnych w celu eliminacji ekstremalnych naprężeń*, PIMR, Poznań.

- Szczepaniak J., Rogacki R., Wasieczko P., Szczepaniak M., 2011, Wieloczynnościowy agregat do sadzenia ziemniaków, Zad. 7, Przeprowadzenie symulacji komputerowych w aspekcie kinematycznym i wymuszeń dla różnych modułów agregatu, PIMR, Poznań.
- Szczepaniak M., Wasieczko P., Rogacki R., 2012, Modelowanie oraz analiza wytrzymałościowa w aspekcie doboru optymalnych elementów konstrukcji na przykładzie agregatu do sadzenia ziemniaków, Technika rolnicza ogrodnicza i leśna, nr 6, Poznań, s. 25-28.
- Trocki M., 2012, Nowoczesne zarządzanie projektami, Polskie Wydawnictwo Ekonomiczne, Warszawa.
- Zienkiewicz O. C., Taylor R., 2000, The Fine Element Method, Vol. 2, Solid Mechanics, Butterworth-Heinemann.

ZASTOSOWANIE METOD SYMULACJI KOMPUTEROWEJ W PROJEKTOWANIU MASZYN ROLNICZYCH

Streszczenie

W ostatnich latach rozwój komputerowych systemów wspomagania projektowania i wytwarzania w istotny sposób zmienia metody prac konstrukcyjno technologicznych. Metodą, która pozwala na najszybsze wprowadzenie nowego produktu na rynek jest projektowanie współbieżne. Ze względu na duże koszty sprzętu komputerowego i oprogramowania oraz brak odpowiedniego personelu jest to metoda niedostępna dla wielu, szczególnie małych zakładów produkcyjnych. Skutecznym, choć w mniejszym stopniu, narzędziem służącym do poprawienia jakości i skrócenia czasu projektowania mogą być także pojedyncze moduły lub programy. W artykule przedstawiono przykłady wykorzystania programu typu wirtualnego prototypowania do modelowania bryłowego, symulacji kinematycznej oraz analiz wytrzymałościowych metodą elementów skończonych. Wyniki prezentowanych analiz umożliwiły zmianę konstrukcji: ramy nośnej analizowanej sadzarki w miejscu mocowania zbiornika stałego, w ścianach bocznych zbiornika stałego i zbiornika ruchomego.

Słowa kluczowe: Symulacje komputerowe, analiza wytrzymałościowa, wirtualne prototypowanie, sadzarka do ziemniaków

