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STATIC ANALYSIS OF REAR SUSPENSION BEAM LOADING IN A POLISH COMBINE HARVESTER

Summary

This article shows the static analysis of rear suspension beam loading in a combine harvester manufactured by New Holland Bizon Sp. z o.o. The model of the examined machine with thresher rotor (Z110 model) was being manufactured until 2001, and further modifications of combine harvesters with the mentioned threshing system are being made so far [1]. The research conducted with the use of programs: Inventor 2017 for generating the digital model and Nastran In-CAD 2017 for simulation calculations. The aim of this article is to analyze and evaluate the accuracy of the combine harvester Bizon Z110 construction. The findings of the study suggest a possibility of stress accumulation in welded joints of construction. In result, solutions to the described problems were provided.
Key words*: combine harvester, statistic finite elements analysis, internal stresses*

ANALIZA STATYCZNA OBCIĄŻENIA BELKI NOŚNEJ WÓZKA TYLNEGO KOMBAJNU ZBOŻOWEGO PRODUKCJI POLSKIEJ

Streszczenie

Niniejszy Artykuł przedstawia analizę statyczną belki nośnej wózka tylnego kombajnu zbożowego produkowanego przez New Holland Bizon Sp. z o.o. Model analizowanej maszyny o omłocie rotorowym (wersji Z110) był produkowany do 2001 roku, a kolejne modyfikacje kombajnów zbożowych o wspomnianym systemie omłotowym produkowane są do chwili obecnej [1]. Do badań wykorzystano: pakiet Inventor 2017 dla wygenerowania modelu numerycznego, natomiast do obliczeń symulacyjnych – Nastran in Cad 2017. Celem artykułu jest analiza i ocena prawidłowości konstrukcji ramy kombajnu zbożowego Bizon Z110. Uzyskane wyniki wskazują na możliwość kumulowania się naprężeń w węzłach spawanych ramy. W konsekwencji zaproponowano możliwość rozwiązania opisywanych problemów.
Słowa kluczowe*: kombajn zbożowy, analiza statyczna metodą elementów skończonych, naprężenia własne konstrukcji*

1. Introduction

It is generally known that mechanization is being incorporated into agricultural sector relatively slowly. A combine harvester is just one example. First combine harvesters were manufactured in the 1940s in the United States of America. Their mechanism has not changed since then. However, their construction has been modified considerably. In the Polish market, Fabryka Maszyn Żniwnych in Płock was the only combine harvester manufacturer. Having no competition, the company was a monopolist. Such situation did not foster innovations and improvements of already existing machines. To give an example, Bizon Z060 was equipped with a screw conveyor moving grain to a hopper [2], but its construction had flaws and the system was removed and replaced with a paddle conveyor. However, now screw conveyors are used in high-efficiency machines of this type manufactured worldwide [1]. Moreover, due to the geopolitical situation, Poland as a country of Eastern Bloc had constricted access to computers and calculating systems. In addition, the financial crisis also affected efforts to make improvements in a negative way.

Because of the difficulties in access to computers and specialized software, the process of optimizing construction of combine harvesters was incredibly slow or even withered. Accordingly, although the construction of Bizon combine harvesters was considered successful, it was not flawless. Every user of this machine could certainly list its drawbacks, and the most burdensome ones are problems connected with cracking of rear suspension clamp system. It was problematic to such a degree that farmers had to constantly repair it or modify the construction. Unfortunately, fixing the failure by welding it does not bring the desired effect. In a short time the failure occurs again. What is more, the problem burgeons in case of mounting a straw crusher to the combine harvester. It could be therefore concluded that the cause of this difficulty lies in a faulty construction. The conducted literature research proves that the manufacturer did not try to solve this problem. Due to the above, the authors of the article decided to do a numerical analysis for a particular combine harvester manufactured in Poland and to determine the real reason of the problem occurring in the rear suspension clamp system.

2. Research methodology

On the grounds of literature premises and information from agricultural market, the object of study has been chosen, which is CNH Bizon model Z110 (Fig. 1). According to users of the machine, perpetual problems with cracking of the rear suspension clamp system are highly common. This failure occurs after usual exploitation of the combine harvester.

In order to conduct comprehensive simulation studies, a digital model of the support structure of the analyzed combine harvester was generated. The model was created with the use of Inventor 2017. Illustration of the digital model of combine harvester New Holland Bizon BS Z110 structure is presented on Figure 2. It is an accurate depiction of every dimension on a scale of 1:1. The analyzed part of the construction is presented on Figure 3. Empirical observations showed that cracking occurs on junction of bracket (1) and beam (2) with pin (3).

Source: own work / Źródło: opracowanie własne

Fig. 1. The object of study - combine harvester New Holland Bizon BS Z110
Rys. 1. Badany obiekt - kombajn zbożowy New Holland Bizon BS Z110

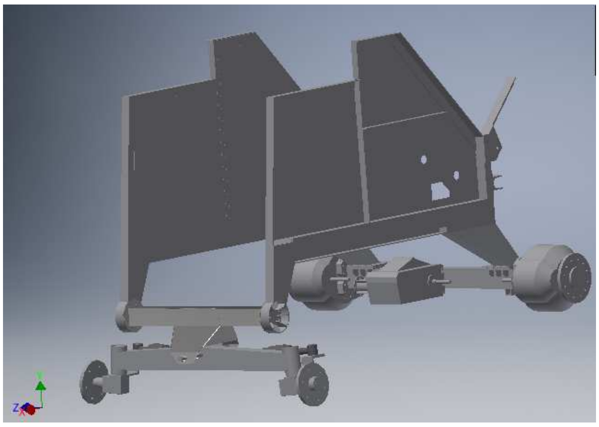

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Fig. 2. Digital model of support structure of combine harvester
Rys. 2. Model numeryczny całej ramy nośnej kombajnu zbożowego

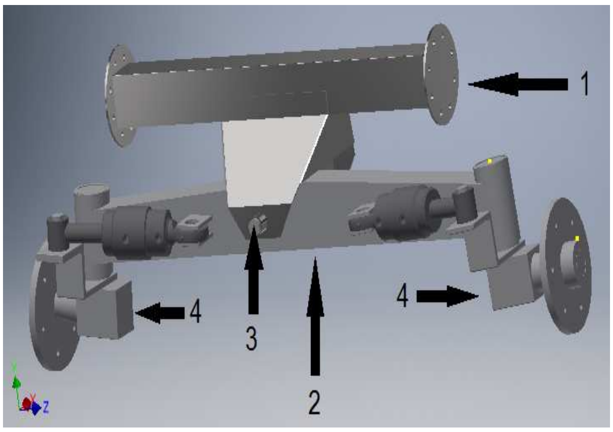

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Fig. 3. Rear suspension of combine harvester
Rys. 3. Tylne zawieszenie kombajnu zbożowego

Digital simulations of stress distribution were created in Nastran In-CAD 2017. This program enables making calculations with the use of finite element method (FEM). Linear elastic modulus described by Von Mises equation is used in the program as a default model. This shows the dependence between mass of the machine and stress in the analyzed joint.

For the purpose of making calculations it was assumed that the construction support is based on overlapping fixed block joints in place of steering knuckles (7) (Fig. 4). The authors presumed that there is no need to examine steering knuckles, as no defect in their construction has been detected. Thereby elements of hydraulic cylinder and their clamping are excluded from the analysis. Forces (6) were placed on lateral flat surfaces of suspension bracket in compliance with force direction (Fig. 4). After input of initial and boundary conditions to the modulus, a mesh consisting of 69089 elements linked together with 131376 joints was generated.

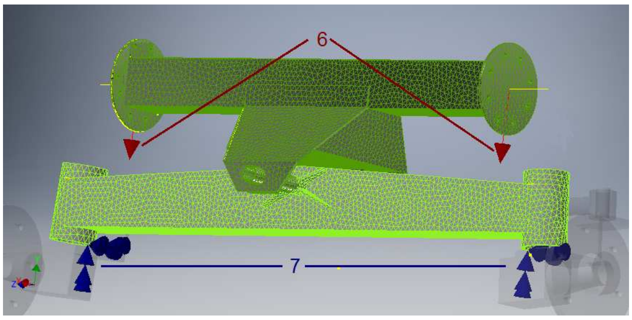

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Fig. 4. Placement of forces and struts in the digital model
Rys. 4. Umiejscowienie sił i podpór w prezentowanym modelu numerycznym

In accordance with the technical specification of the combine harvester [5] - the material of the modelled element is high-strength low-alloy steel St 35/ S235JR, whose values are [6]:

- elastic limit (Re) = 235 MPa,
- strength limit (Rm) = 380 MPa,
- Poisson's ratio = 0.3,
- Young's modulus - $210 \cdot 10^3$ MPa.

For obtaining a proper accuracy of calculations, actual values of forces affecting the object were determined. In this situation forces determined by the combine harvester mass are the load of analyzed joints. According to the manufacturer, the mass distribution is: 70% on the front axle and 30% on the rear axle, considering the variant with a straw crusher and aggregated with auger header, which is presented on Figure 5. The combine harvester mass with empty grain tank equals to 9940 kg, the mass of the auger header is 1420 kg, and the grain tank capacity is 5000 dm^3 which corresponds to the mass of 4000 kg in case of the heaviest possible grain which is pea. It is because of the fact that 1 dm^3 of grain has its average mass of 0.8 kg [3].

On the basis of evaluated masses, it was determined that their total amount equals to 11360 kg for an empty grain tank and 15360 kg for a full grain tank. This was the ground for estimating the mass (30%) which loads the rear suspension: 3408 kg for an empty grain tank and 4608 kg for a full grain tank. Masses values are presented on Table 1. Forces which load the digital model of the rear beam were calculated based on the mass. The values of forces are 34080 N and 46080 N. For the purpose of illustrating visible differences which occur in the machine load for empty and full grain tank, separate analyses were conducted.

Table 1. Evaluation of masses loading the combine harvester [5]
Tab. 1. Oszacowane wartości mas obciążających kombajn zbożowy [5]

Mass type	Mass value (kg)
Combine harvester mass	9940
Auger header mass	1420
Maximum mass of pea in grain tank	4000
Mass of the combine harvester with auger header (empty tank)	11360
Mass of the combine harvester with auger header (full tank)	15360
Mass on the rear axle (empty tank)	3408
Mass on the rear axle (full tank)	4608

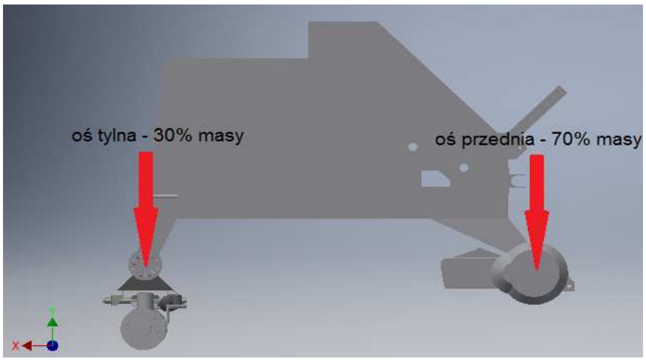

Fig. 5. Distribution of mass of the machine according to the manufacturer [5]
Rys. 5. Rozkład masy maszyny wg producenta [5]

3. Research results

The numerical analysis of stress distribution was conducted for a statistical model. Calculations provided the value of maximum stress (Von Mises) in the troublesome spot of the construction. For the joint presented on Figures 2 and 3 the value equals respectively to: 235.5 MPa for the combine harvester with full grain tank and 160.1 MPa for the variant with empty grain tank. Accumulation of stresses in the analyzed spot of the machine with full load passes the elastic limit marginally, which may cause the failure of the joint. It is worth noting that the obtained values result from a linear static analysis. Therefore the authors provide for the possibility that stresses values can be considerably higher during the working of the machine under field conditions, or because of vibration caused by the work of subassemblies. As to attain reliability of the construction, the stress value must be related to appropriate safety factor. On the grounds of established norms regarding the choice of safety factor [the 4th norm], considering the probability of occurring measurement and material uncertainty, there is a need to multiply the results by the factor whose quantity is between 1.5 and 1.7. Such a factor is used with accuracy of calculations and the possibility to gauge forces and stresses [4]. The factor chosen here is 1.7. Consequently, obtained values increased respectively to 400.35 MPa for full grain tank and 272.17 MPa for empty grain tank, which is presented on Table 2.

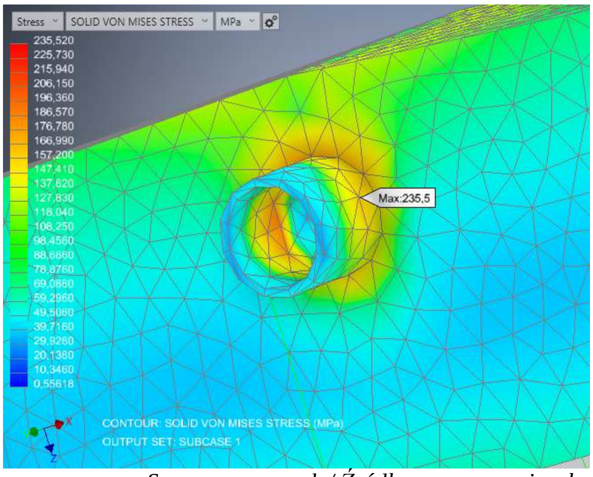

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Fig. 6. Simulation results for the variant with full tank
Rys. 6. Wyniki symulacji dla wariantu pełnego zbiornika

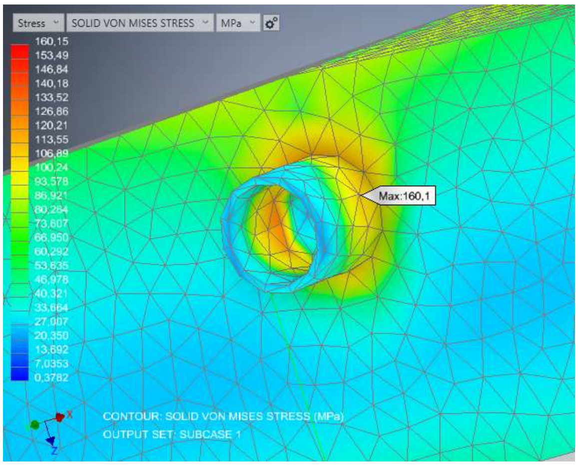

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Fig. 7. Simulation results for the variant with empty tank
Rys. 7. Wyniki symulacji dla wariantu pustego zbiornika

Table 2. Stresses values obtained in static analysis
Tab. 2. Wartości naprężeń uzyskane w analizie statycznej

Variant of calculations	Obtained stresses (MPa)	Stresses with the safety factor 1.7 (MPa)
Empty tank	160.1	272.17
Full tank	235.5	400.35

Source: own work / Źródło: opracowanie własne

In order to prevent the element from failure and, in consequence, to avoid damage of the combine harvester construction, the authors propose the employment of ribs strengthening conjunctions of pin bushing with beam. This is only one of all possible solutions of reducing maximum stresses in the examined part of the construction. After modifying the digital model of the construction (Fig. 8.), a new finite elements mesh was generated and numerical calculations were conducted again. It was determined that ribs will be fastened with the use of fillet welding. The analysis skips weld modelling, as its strength was assumed to be equal to the strength of the vernacular material [4]. The mesh presenting modifications is made of 68292 elements and 133656 joints.

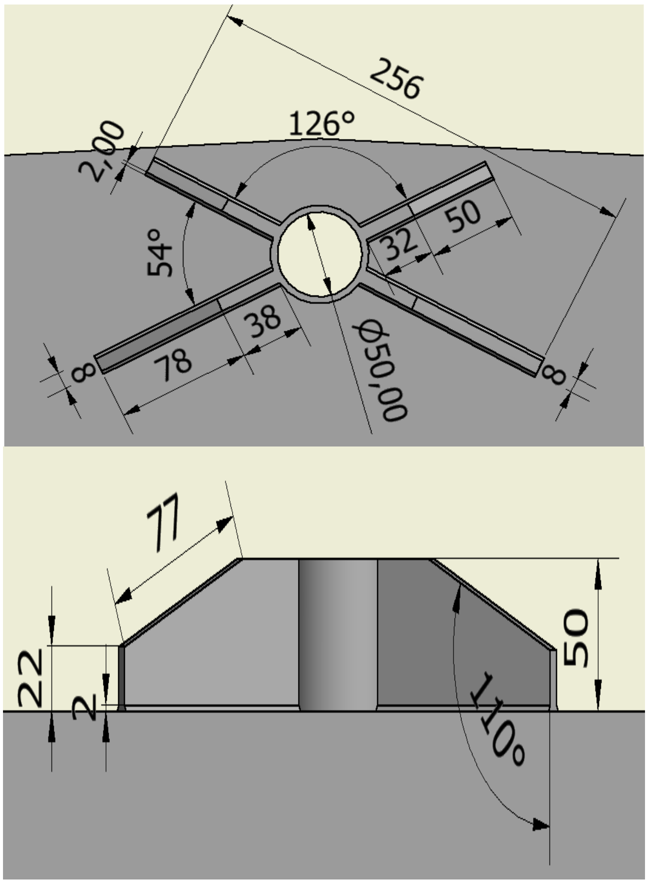

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Fig. 8. Modification of clamp system of the rear suspension beam, overview drawing
Rys. 8. Modyfikacja systemu mocowania belki nośnej tylnego wózka kombajnu, rysunek poglądowy

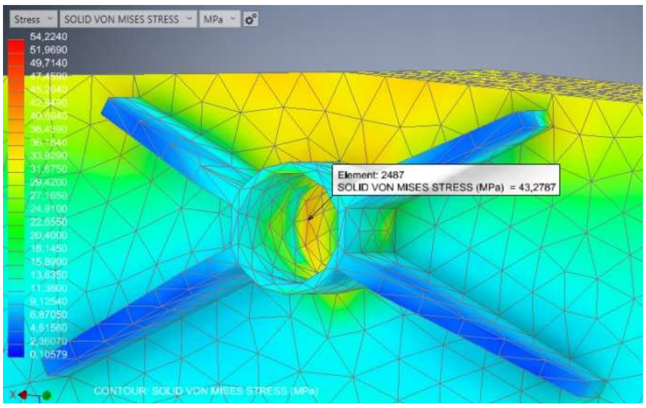

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Fig. 9. Stresses values (Von Mises) after modification, variant with empty tank
Rys. 9. Wartość naprężeń (Von Mises'a) po modyfikacji, wariant pustego zbiornika

The static reanalysis conducted with the use of numerical method provides that stresses are respectively: 57.5 MPa for the force 46080 N (full tank) (Fig. 10) and 43.3 MPa for the force 34080 N (empty tank) (Fig. 9). Considering the safety factor 1.7, the values are respectively: 97.74 MPa and 73.61 MPa. It was therefore assumed that obtained values keep within safety and strength limits. All the values obtained from static analyses are presented on Table 3.

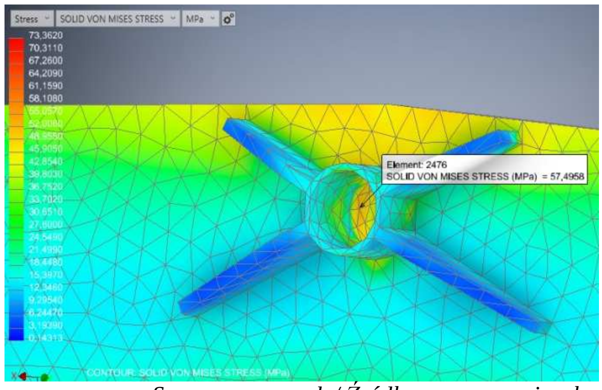

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Fig. 10. Stresses values (Von Mises) after modification, variant with full tank
Rys. 10. Wartość naprężeń (Von Mises'a) po modyfikacji, wariant pełnego zbiornika

Table 3. Stresses values obtained from static analysis
Tab. 3. Wartości naprężeń uzyskanych w analizie statycznej

Variant	Stress value (MPa)	Stress reduction value (%)
Stress value after modification of construction		
Empty tank	43.3	73
Full tank	57.5	75.6
Stress value considering the safety factor for the modification of construction		
Empty tank	73.61	73
Full tank	97.74	75.6

Source: own work / Źródło: opracowanie własne

The proposed solution of strengthening pin bushings in the combine harvester rear suspension was tested in practice. Figure 11 shows a modified joint in the combine harvester construction. During the field test, which was lasting over 200 mth, cracking of the beam bushing was not detected.

Source: own work / Źródło: opracowanie własne

Fig. 11. Visual presentation of part of fastening of the pin bushings in the combine harvester rear suspension
Rys. 11. Wygląd fragmentu modyfikacji mocowania tulei sworznia tylnego wózka kombajnu zbożowego

As it was mentioned before, this modification is not the only solution of the problem. However, its simplicity makes it possible to eliminate the failure without the necessity to visit auto servicing or garage.

4. Conclusions

On the grounds of the conducted examination, it can be concluded that:

- The static analysis made it able to estimate stresses in the troublesome spot of the construction, which are respectively: 235.5 MPa for combine harvester with loading and 160.1 MPa without loading, and in the first variant the stress passes the elastic limit of construction material.
- Basing on the analyses, the authors proposed modification of the construction, which reduced maximum stresses to 75.6% (combine harvester with loading) and 73% (combine harvester without loading).
- Maximum stress values obtained after modification of the construction equal respectively to 57.5 MPa and 43.3 MPa, and with the regard to the safety factor 1.7- 97.74 MPa and 73.61 MPa. These values keep within construction material strength limits with a large reserve.
- Field tests proved that the solution is firm and reliable.

5. References

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