

STRENGTH ANALYSIS OF THE SUPPORTING STRUCTURE OF THE ABT VEHICLE DURING CONTAINER RELOADING

Summary

The article presents the process of designing and strength analysis of the body and continuous track unit of a specialised track-laying vehicle for the transport of biomass obtained on wetlands performed within framework of the development project No. PBS2/B8/11/2013 "Autonomous technology for the transport of biomass obtained on protected wetlands" related to the removal of unwanted vegetation from protected areas, especially national parks, landscape parks and Natura 2000 areas. The new vehicle was designed by a consortium led by the Team for Power Engineering and Dynamics of Agricultural Machines at the Industrial Institute of Agricultural Engineering. Its aim is to find a solution which would significantly increase the efficiency of the process of obtaining biomass taking account of the autonomous operation of the new machine.

Key words: track-laying vehicle, autonomous vehicle, protection of wetlands, kinematic analysis, strength analysis

ANALIZA WYTRZYMAŁOŚCIOWA KONSTRUKCJI NOŚNEJ POJAZDU ATTB PODCZAS WYKONYWANIA OPERACJI PRZEŁADUNKU KONTENERÓW

Streszczenie

W artykule przedstawiono proces projektowania i weryfikacji wytrzymałości kadłuba oraz układu bieżnego specjalizowanego pojazdu gąsienicowego dla technologii transportu biomasy na terenach wodno-błotnych, realizowanego w ramach projektu rozwojowego nr PBS2/B8/11/2013 pt.: „Autonomiczna technologia transportu biomasy pozyskiwanej na chronionych obszarach wodno-błotnych”, związanego z usuwaniem niepożądanego rośliności z chronionych terenów, zwłaszcza parków narodowych, parków krajobrazowych oraz obszarów Natura 2000. Projekt nowego pojazdu opracowany został przez konsorcjum, którego liderem jest Zespół ds. Energetyki i Dynamiki Maszyn Rolniczych PIMR w Poznaniu. Jego zadaniem jest znalezienie rozwiązania, które pozwoliłoby znacząco podnieść wydajność procesu pozyskiwania biomasy przy uwzględnieniu autonomiczności działania powstałej konstrukcji.

Słowa kluczowe: pojazd gąsienicowy, pojazd autonomiczny, ochrona obszarów wodno-błotnych, analiza kinematyczna, analiza wytrzymałościowa

1. Introduction

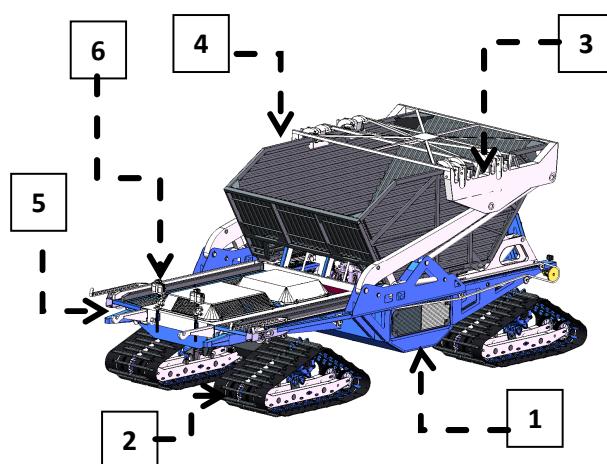
The model and design of the autonomous platform technology for the transport of biomass on wetlands was developed as part of the Project No. PBS2/B8/11/2013 [1] implemented at the Industrial Institute of Agricultural Engineering (PIMR) [8] in Poznań by the Team for Power Engineering and Dynamics of Agricultural Engineering. As was already described in the previously presented article published in the international periodical Agricultural Mechanization [6], the vehicle comprises 6 main units (Fig. 1) constructed by the Industrial Institute of Agricultural Engineering, Military University of Technology (WAT) [10] and the Industrial Research Institute for Automation and Measurements (PIAP) [7]. The article presents the process of designing and strength analysis of the vehicle's body and axles (constructed by PIMR-BE) based on the forces determined by a kinematic analysis of the reloading unit (constructed by WAT).

2. Reloading unit of the ABT vehicle

The function of the reloading unit (Fig. 2) is to move containers between the ABT platform and the transport module (MT) of the ZPG vehicle [4, 6]. The unit operates the following systems:

- empty container transfer,

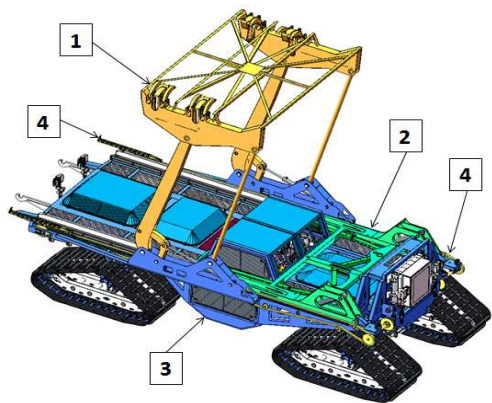
- full container pulling,
- full container unloading (with an integrated bolting system).



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Fig. 1. Main units of the ABT vehicle: 1 - vehicle body, 2 - continuous track, 3 - reloading unit, 4 - transport container, 5 - coupling unit, 6 - vehicle control system

Rys. 1. Główne zespoły pojazdu ATTB: 1 - kadłub pojazdu, 2 - układ bieżny, 3 - układ przeładunkowy, 4 - kontener transportowy, 5 - układ sprzęgający, 6 - system sterowania pojazdem



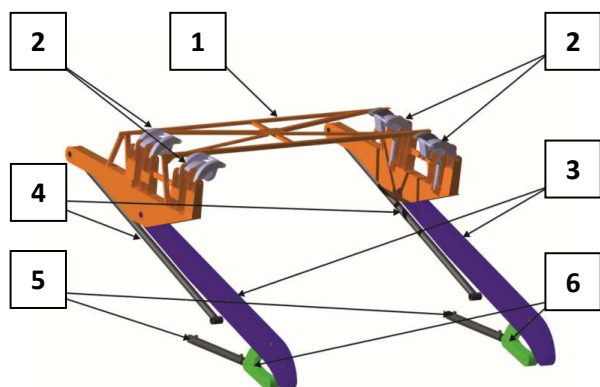
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Fig. 2. Reloading unit: 1 - empty container transfer system, 2 - full container unloading system, 3 - supporting structure of the ABT platform, 4 - container pulling system

Rys. 2. Układ przeładunkowy: 1 – system przenoszenia kontenera pustego, 2 – system wyladunku kontenera pełnego, 3 – konstrukcja nośna platformy ATTB, 4 – system przeciągania kontenera

An empty container is transferred at a height sufficient for a full container to be pulled underneath. This is made possible by a structure with one degree of freedom and a straight line kinematic mechanism. The entire system consists of a connector, four hook mechanisms which lock onto the container at points designed specifically for this purpose, straight line elements, hydraulic actuators and lever elements (Fig. 3). Thanks to this solution, the container is moved in parallel to the frame of the vehicle (Fig. 4).

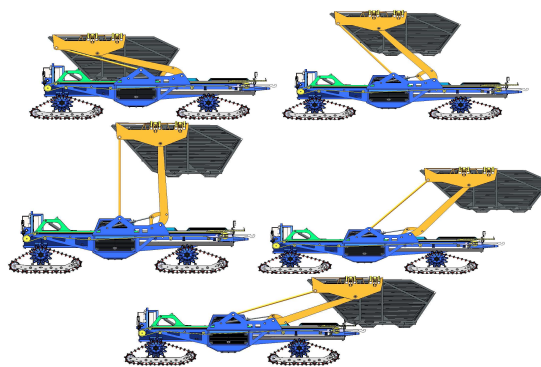
A container filled with biomass is pulled by two chain conveyors located symmetrically along the lateral edges of the ABT vehicle (Fig. 5). The chains are integrated with ratchet mechanisms which grab the container by specially adapted grips. After the ABT and MT vehicles become coupled together, the ratchet mechanisms of the conveyor are moved towards the container until the ratchets lock (Fig. 6) onto the grips on the container. The container is then pulled to the position where it is bolted onto the ABT vehicle (Fig. 7). Each of the conveyors is powered by a separate hydraulic engine. In order to synchronise the work of the ratchet mechanisms, both sides of the belt conveyors are linked with a synchronising shaft.



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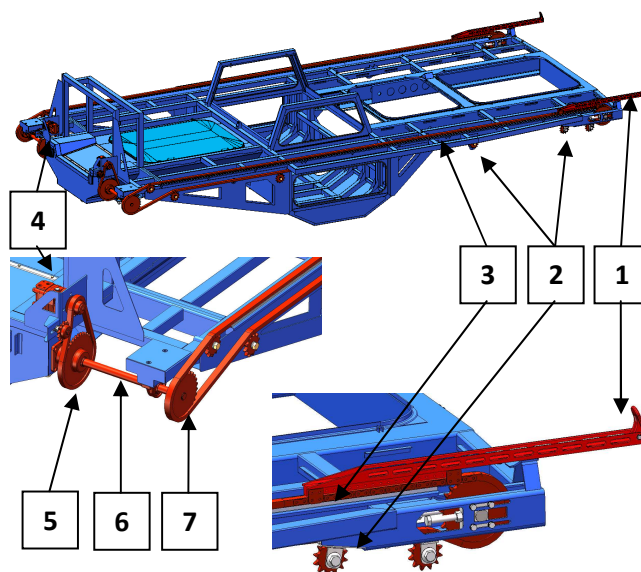
Fig. 3. Empty container transfer system: 1 - connector, 2 - hook mechanism, 3 - extension arms, 4 - straight line elements, 5 - hydraulic actuators, 6 - lever elements [1]

Rys. 3. System przenoszenia pustego kontenera: 1 – łącznik, 2 – mechanizm hakowy, 3 – wysięgniki, 4 – elementy prostokątne, 5 – siłowniki hydrauliczne, 6 – elementy dźwigniowe [1]



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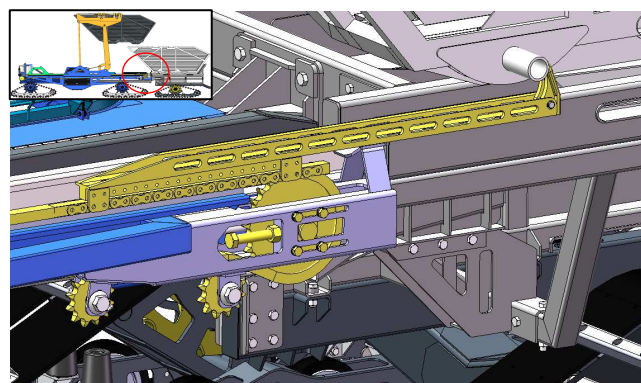
Fig. 4. Moving of an empty container during reloading
Rys. 4. Prowadzenie pustego kontenera podczas przeładunku



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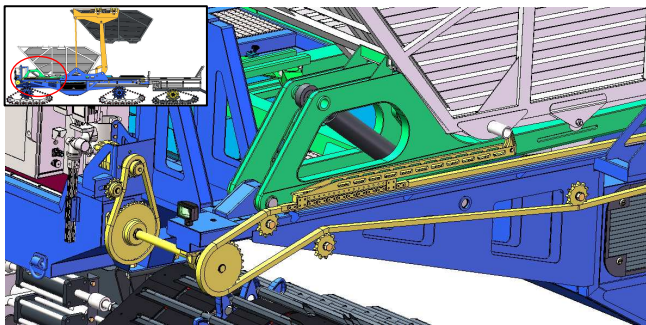
Fig. 5. Full container pulling system mounted on the vehicle frame: 1 - ratchet mechanism, 2 - tighteners, 3 - chain sliders, 4 - hydraulic engine, 5 - drive transmission from the engine to the chain, 6 - synchronising shaft, 7 - chain

Rys. 5. System przeciągania pełnego kontenera zamocowany na ramie pojazdu: 1 – mechanizm zapadkowy, 2 – napinacze, 3 – ślizgi łańcucha, 4 – silnik hydrauliczny, 5 – przeniesienie napędu z silnika na łańcuch, 6 – wał synchronizacyjny, 7 – łańcuch



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Fig. 6. Moment when the container is gripped from MT
Rys. 6. Moment uchwycenia kontenera z MT



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Fig. 7. Container pulled to the reloading unit
Rys. 7. Przeciągnięty kontener do systemu wyładunku

The container is unloaded by tilting the unloading unit frame 92 degrees in relation to its initial position by means of hydraulic actuators. During unloading, the container is kept in the unloading position (Fig. 8) by a bolting system (Fig. 9) which is designed to protect the container against a runaway slip from the ABT platform both during transport and unloading of biomass. The suggested solution consists of four bolts powered rotationally by a hydraulic actuator through a set of strings and levers.

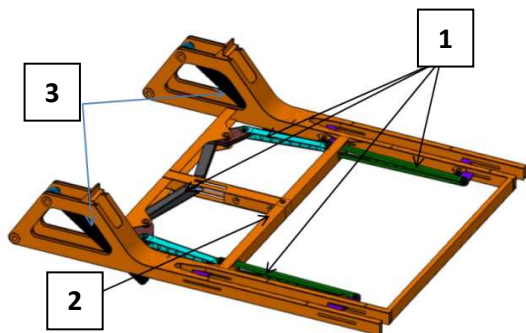


Fig. 8. Full container unloading system: 1 - elements of the bolting system, 2 - supporting frame of the reloading system, 3 - hydraulic actuators [1]

Rys. 8. System wyładunku pełnego kontenera: 1 - elementy systemu ryglowania, 2 - rama nośna systemu wyładunku, 3 - silowniki hydrauliczne [1]

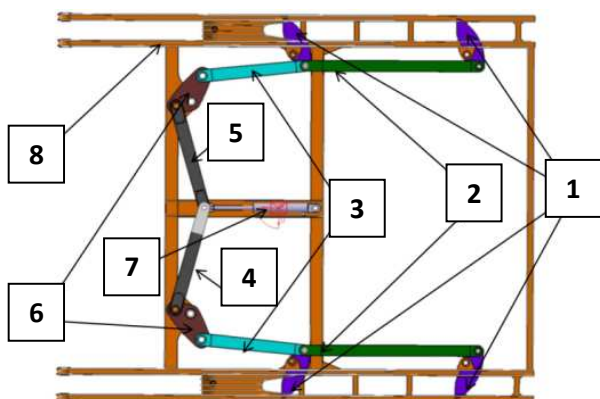


Fig. 9. Container bolting system: 1 - bolts, 2 - string 1, 3 - string 2, 4 - string 3, 5 - string 4, 6 - lever, 7 - hydraulic actuator, 8 - supporting frame of the full container unloading system [1]

Rys. 9. System ryglowania kontenera: 1 - rygle, 2 - ciągnio 1, 3 - ciągnio 2, 4 - ciągnio 3, 5 - ciągnio 4, 6 - dźwignia, 7 - silownik hydrauliczny, 8 - rama nośna systemu wyładunku pełnego kontenera [1]

3. Determination of forces acting on the supporting structure of the vehicle

Before strength calculations, we defined forces acting on the supporting structure of the vehicle. The forces can be divided into:

- fixed forces – independent of the actual position of the actuators in individual mechanisms,
- changing forces – dependent on the position of actuators in ABT vehicle systems and units.

Fixed forces include loading forces (related to gravity) derived from the mass of the body (ca. 1700 kilograms), full tank of hydraulic oil (ca. 300 kilograms), full tank of fuel (ca. 300 kilograms), combustion engine unit of the main drive with a system of hydraulic pumps (ca. 1100 kilograms), control unit cabinet (ca. 150 kilograms) and shields (ca. 200 kilograms).

Changing forces were determined for individual mechanisms using the SOLIDWORKS Motion module of the SOLIDWORKS programme [3] at the different nodes - points at which the unloading system is locked onto the vehicle body. Results of these analyses were plotted onto force graphs (function of time) for individual nodes, which were divided into two components - vertical and horizontal.

Based on the force graphs (Fig. 10), we prepared a table presenting the most disadvantageous cases of loading (Table 1).

Table 1. Selected extreme cases of structure loading
Tab. 1. Wybrane graniczne przypadki obciążenia konstrukcji

Item	Graphical presentation of the calculation cases for the body	Node	Horizontal component force [kN]	Vertical component force [kN]
1		1	-100	40
		2	100	-90
2		1	190	-90
		2	-190	55
3		3	-90	-6
		4	-23	8
		5	72	-15
		6	45	9
4		3	0	0
		4	0	5
		5	0	0
		6	0	-10
5		3	125	20
		4	5	3
		5	-50	-60
		6	-80	33

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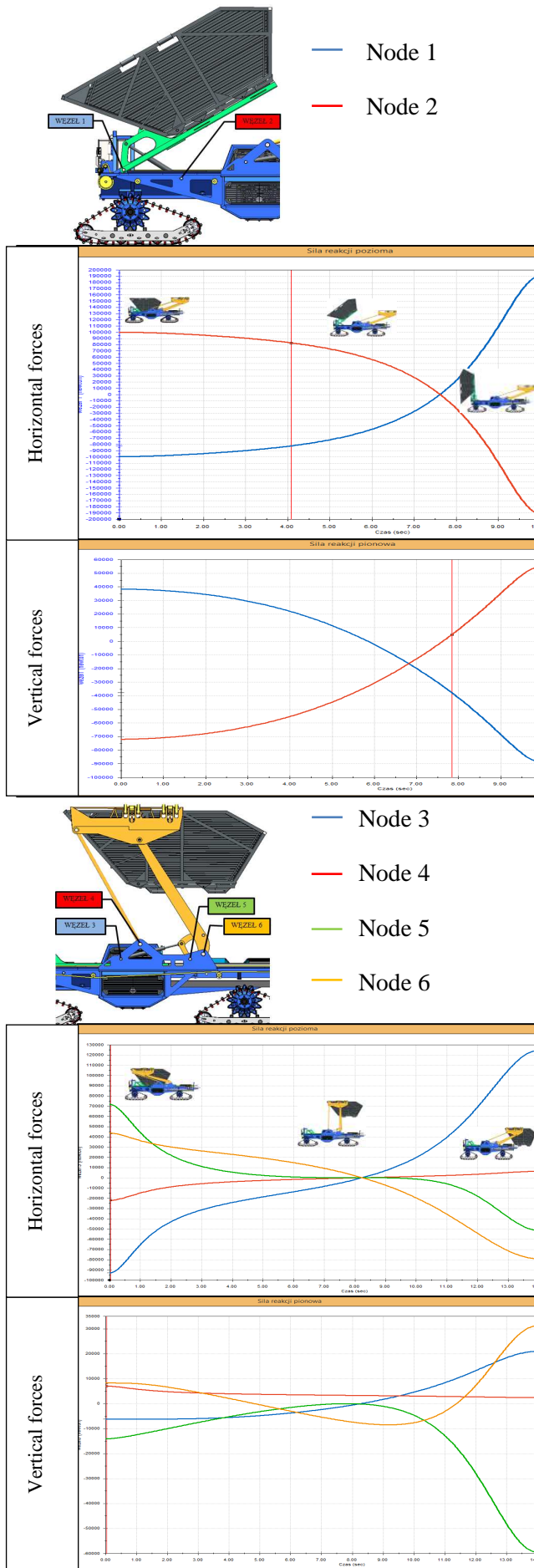
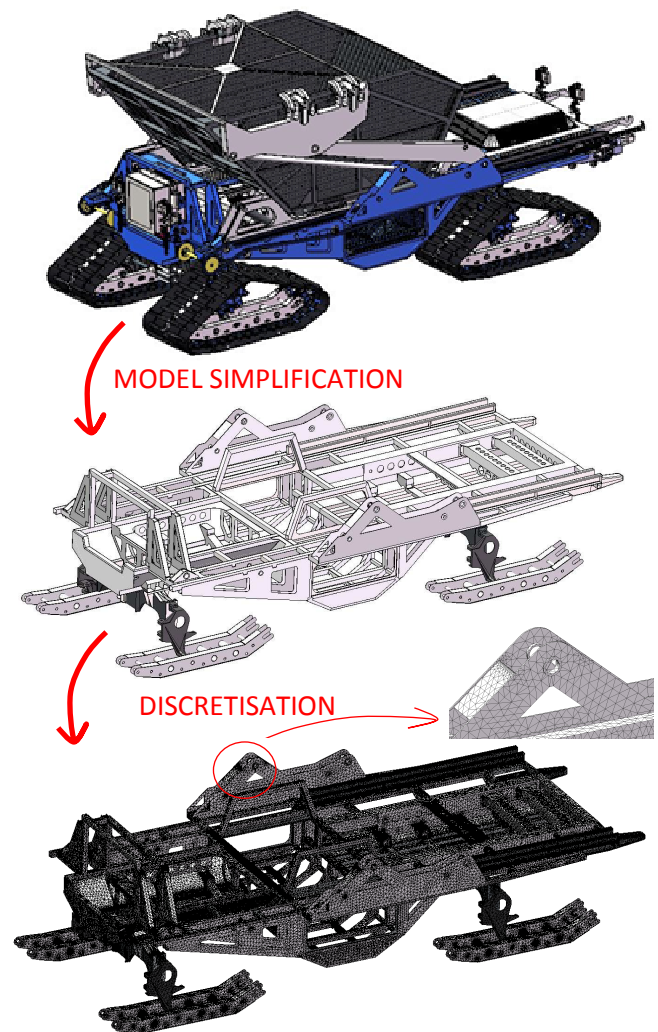


Fig. 10. Results of kinematic analysis [1]
Rys. 10. Wyniki analizy kinematycznej [1]

4. Strength analysis for the body and axles

Strength analysis of the structure was carried out on the basis of the finite element method (FEM) using the SIMULATION module of the SOLIDWORKS programme [9]. As the period of time for calculations verifying the ABT vehicle structure was reduced, it was necessary to develop a calculation model (Fig. 11) in which some component elements of the vehicle structure were replaced and forces derived from their mass were applied at the points where such elements were mounted (the fixed forces mentioned in the previous point). Next, the calculation model was discretised with border conditions imposed (degrees of freedom were removed, forces were applied).



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Fig. 11. Calculation model for the body and axles of the ABT vehicle
Rys. 11. Model obliczeniowy kadłuba i osi jezdnych pojazdu ATTB

Results were analysed based on the Huber-Mises-Hencky tension hypothesis [5] where stress complexity is reduced to one stress σ_{zast} having made sure that the stress is below the assumed allowable stress k (1).

$$\sigma_{zast} = \sqrt{\frac{(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2}{2} + 3(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)}$$

$$\sigma_{zast} \leq k$$

(1)

where: $\sigma_x, \sigma_y, \sigma_z$ - normal stress (perpendicular) in the calculated section, $\tau_{xy}, \tau_{yz}, \tau_{zx}$ - shear stress in the calculated section.

Allowable stress for parent material was determined on the basis of the equation below (2), dangerous stress σ_{nieb} being fixed at the yield stress point R_e for this material. The safety index x of 1.3 was adopted.

$$R_e = \frac{\sigma_{nieb}}{x} \quad (2)$$

Allowable stresses in weld joints were also established on the basis of the equation above (2), but their value was divided into sections depending on the value of dangerous stress for welded material and the type of weld.

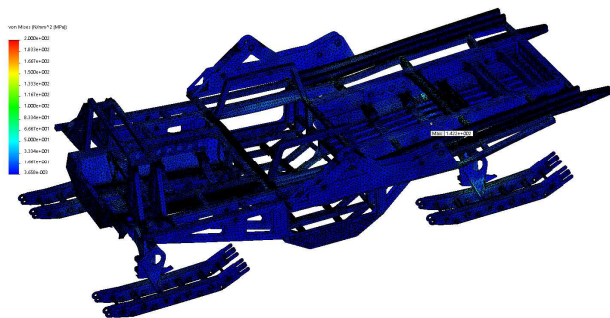
Table 2. Values of the safety index depending on the value of the yield stress R_e of welded materials [3, 5]

Tab. 2. Wartości współczynnika bezpieczeństwa w zależności od wartości granicy plastyczności R_e spawanych materiałów [3, 5]

Weld type	x		
	$R_e \leq 255 \text{ MPa}$	$255 < R_e \leq 355 \text{ MPa}$	$R_e > 355 \text{ MPa}$
Butt weld	1.65	1.65	1.65
Fillet weld	1.25	1.4	1.65

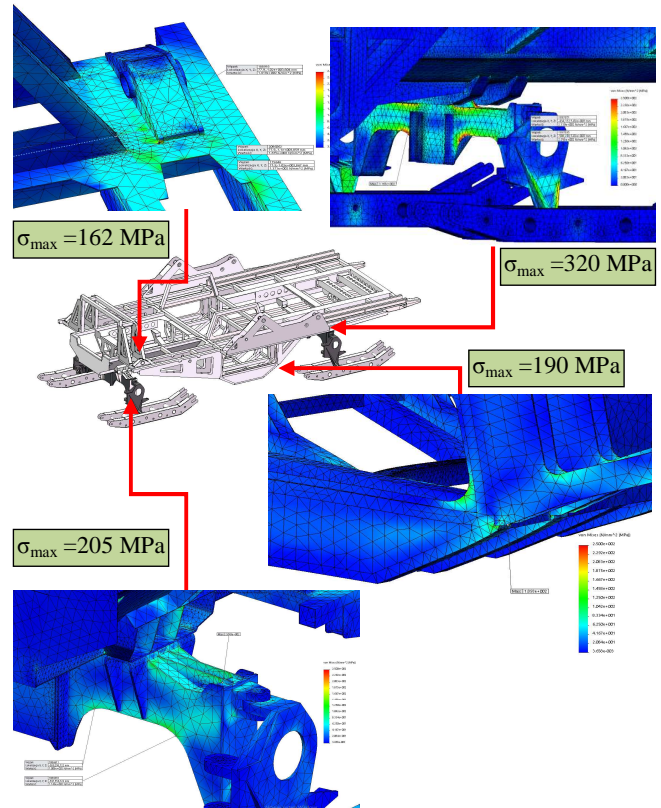
Initially, simulation results were unsatisfactory – maximal reduced stresses σ_{max} were several times higher than assumed allowable stresses. It was therefore necessary to strengthen the structure by increasing its thickness or adding ribs in places of stress concentration. This enabled us to achieve acceptable values of stress in the analysed structures (Fig. 12, 13). Due to considerable stress values for axles (Fig. 13) and an unacceptable increase in their weight following an increase in thickness, it was necessary to use an enhanced strength material STRENX 600 for their construction.

Structure shape before and after strength analysis (Fig. 14) is not much different. Following the addition of the necessary supporting elements, the mass of the model increased to ca. 150 kilograms.



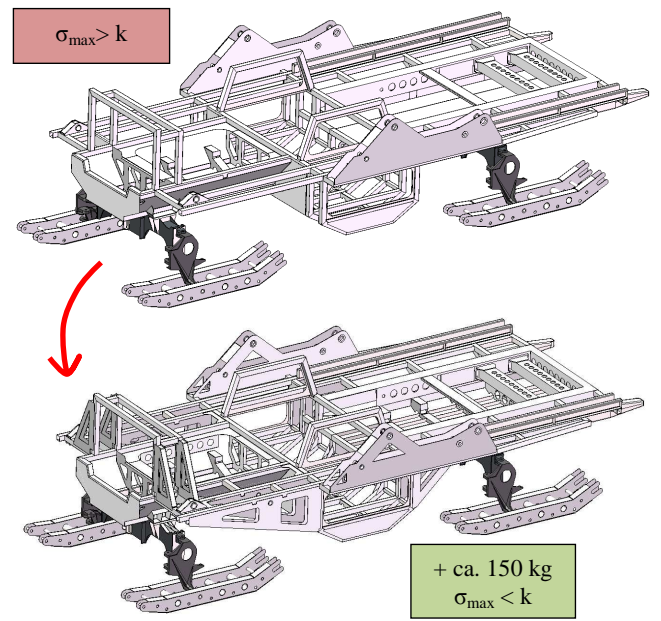
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Fig. 12. Analysis results: graph presenting the values of reduced stress
Rys. 12. Wynik analizy: wykres wartości naprężeń zredukowanych



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Fig. 13. Places of stress concentration for analysed cases of loading
Rys. 13. Miejsca koncentracji naprężeń dla analizowanych przypadków obciążenia



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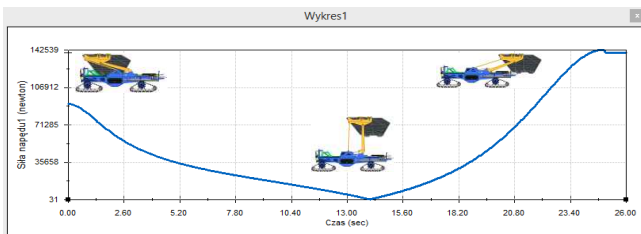
Fig. 14. Changes in the body structure and axles following strength analysis
Rys. 14. Zmiany w konstrukcji kadłuba oraz osi jezdnych po procesie weryfikacji wytrzymałościowej

5. Conclusions

Thanks to the kinematic simulation of the container unloading unit, it was possible to verify whether each system functions correctly and whether the elements of the analysed structure do not interfere with one another.

The simulation also enabled us to establish forces necessary to generate movement in a given mechanism and, consequently, to choose the right size of the actuator/engine generating the movement. The maximal force necessary to generate movement in the empty container transfer system amounts to ca. 143 kN (Fig. 15). Taking this information into account and knowing that the system comprises two actuators mounted symmetrically while the pressure of operating hydraulic unit is 200 bars, we determined the diameter of the piston and the piston rod at 80/50 mm. Other hydraulic actuators of the ABT vehicle were selected analogously (Table 3).

Having determined reaction forces at selected nodes, we were able to check the supporting structure of the ABT vehicle for shear strength of each obtained load case and optimise the strength by adding ribs or decreasing / increasing the thickness of individual elements.



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Fig. 15. Results for the forces generated in the actuator for the empty container transfer system

Rys. 15. Wyniki powstałych sił w siłowniku dla systemu przenoszenia pustego kontenera

Table 3. Parameters of the hydraulic actuators for reloading systems in the ABT vehicle

Tab. 3. Parametry hydraulicznych elementów wykonawczych dla systemu przeładunku pojazdu ATTB

Item	Subassembly name	Hydraulic actuator	Description
1.	Unloading system integrated with the bolting system	2 tilting actuators	Cylinder 80/40 Stroke 560 mm
		1 actuator bolting the container	Cylinder 50/25 Stroke 250 mm

2.	Empty container transfer system	2 rotating actuators	Cylinder 80/50 Stroke 620 mm
		4 gripping actuators	Cylinder 32/20 Stroke 130 mm
3.	Full container pulling system	2 hydraulic engines	Assumed absorbing capacity $Q = 9,6 \text{ dm}^3/\text{min}$ max. moment 224 Nm

Source: own work / Źródło: opracowanie własne

Although the strength analysis presented in the article only refers to situations of handling containers by means of the reloading system, the structure of the vehicle itself was also checked for other cases of shear load (coupling ABT with MT [2], uneven loading of the vehicle, moving on a slope) and fatigue analysis [1].

The actual model of the vehicle will undergo comprehensive field tests planned for the second half of 2016.

6. References

- [1] Development project No. PBS2/B8/11/2013: "Autonomous technology for the transport of biomass obtained on protected wetlands"; project led by dr inż. Krzysztof Zembrowski.
- [2] Płocharz W., Zembrowski K., Krogul P.: Unmanned platform for biomass transportation. Proceedings of 19-th International Scientific Conference. Transport Means, 2015.
- [3] Polska Norma PN-90/B-03200: Konstrukcje stalowe. Obliczenia statyczne i projektowanie. PKNMiJ, 1990.
- [4] Research project No. WND_POIG.01.03.01-00-164/09: "Integrated Technology for the Protection of wetlands from vegetal succession leading to the deepening degradation of the natural element", project is headed by dr inż. Krzysztof Zembrowski.
- [5] Wolny S., Siemieniec A.: Wytrzymałość materiałów. Cz. I. Teoria, zastosowanie. Kraków: Wydawnictwa AGH, 2002.
- [6] Zembrowski K., Sobocki S., Pawłowski T., Rakowicz A., Siczynski Ł.: Autonomous platform technology for biomass transport. IV International Technical Congress. Agricultural Machinery. Varna, Bulgaria, 2016.
- [7] <http://www.piap.pl/>
- [8] <http://www.pimr.poznan.pl/>
- [9] <http://www.solidworks.pl/>
- [10] <http://www.wat.edu.pl/>