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A MODULAR LOW-BED SEMI-TRAILER FOR TRANSPORTATION OF MACHINES AND OTHER HEAVY AND BIG LOADS

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Abstract

The paper presents the assumptions made and solutions used in a newly designed low-bed semi-trailer for the transportation of heavy and oversized loads, especially heavy self-propelled road machinery. During the design phase, special attention was paid to the versatility of the semi-trailer. The semi-trailer consists of 4 main modules: a hydraulic removable gooseneck allowing for coupling the semi-trailer to a tractor unit, an extendable low bed, a 2-axle bogie and a 3-axle bogie. The modules can be combined in different ways to create different configurations of the semi-trailer. Owing to that, the carrying capacity of the semi-trailer can be easily matched to the equipment carried. Depending on the current needs, the semi-trailer can have 2, 3 or 5 axles, a payload from 28 to 65 tons, and a length from 13.2 to 20.1 m. Wheeled and caterpillar vehicles can drive onto the lowbed from the front, after the gooseneck has been detached. The length and width of the bed can be adjusted within the range of 2 and 0.6 m, respectively. An important advantage of this semi-trailer is the fact that in a 2-axle configuration it meets the regulations for standard trailers and can be driven in public roads and carry normal loads without a special permission. Thanks to the fact that all its wheels are steered and controlled by a hydraulic steering system, the semi-trailer has very good manoeuvrability despite its long length. The semi-trailer meets rigorous safety demands – it is equipped with a braking system with ABS/EBS, an advanced load fixing system, marking and lighting systems and others. Research and development experiments performed during the design process, among others those concerning the steering system and optimization of the supporting structure of the semi-trailer using FEM analysis, are characterized in this paper.

Keywords: *road transport, oversize and heavy loads, low-loader, steering system, strength analysis, FEM*

1. Introduction

In recent years, there has been a significant increase in the number of infrastructure facilities and other large installations, such as roads, bridges, public buildings and production halls built in Poland. The construction of these objects requires the use of specialized equipment and prefabricated structures of large masses and sizes. Examples of such machines include cranes, hoists, bulldozers, excavators, loaders, road rollers, specialized dumper trucks and components of steel structures, bridge spans, and large power equipment. All of these items must at some point be transported from one place to another, and generally the best way is to use road transport. Due to their weight and/or size, these devices cannot be transported using standard vehicles. Instead, specialized semi-trailers for transportation of oversize cargo are used.

Transport of some components, such as towers and blades of large wind turbines, requires highly specialized vehicles. However, most oversize freight does not require the use of such specialized vehicles. There is a high demand for semi-trailers with maximally versatile application, allowing transportation of both large building and agricultural machines, as well as structural elements, which, due to their size or weight, cannot be transported on standard semi-trailers, but which do not require the use of highly specialized semi-trailers. Such trailers are purchased by construction, manufacturing, and transport companies.

Among the manufacturers of semi-trailers for the transport of oversized loads, the dominant role on the European market is played by the Dutch and Germans. Companies such as Nooteboom, Broshuis, Faymonville, Langendorf, Goldhofer and Doll have for many years produced special trailers for the transport of oversize loads. However, there are also some manufacturers of semi-trailers from other countries.

The largest Polish manufacturer of trailers and semi-trailers, Wielton SA, has decided to join this group. In order to meet market expectations, the Wielton Company has decided to implement for production a semi-trailer for the transport of oversize cargo offering the highest possible versatility. This article presents the work done within the framework of a project implemented by Wielton in collaboration with Lublin University of Technology, which was aimed at developing a new design of a semi-trailer and preparing it for production.

2. Assumptions

An analysis of freight carriers' expectations and potential cargo indicated that the trailer should allow transportation of loads of up to 60 tons, up to 3 m wide (platform width – the cargo may be wider) and that the loading platform should be no less than 7 m long, and should be as low as possible (the distance of the platform's loading surface from the road surface). A semi-trailer with such parameters will be able to transport almost any agricultural and construction machinery (including haulers, also articulated ones, with a capacity of about 40 tons), military vehicles and most transportable industrial devices and steel structures.

Taking into account its intended use and trying to attain the highest possible versatility of the semi-trailer designed, the authors of the design concluded that the cargo bed should consist of two load-bearing beams, the spacing between which can be adjusted from a position in which the beams are side by side (in which case they would form a sort of a central frame) to a position where the beams are fully extended from side to side (thus creating a classic frame structure). The configuration with the central frame would enable the transport of vehicles whose chassis would be resting on the frame of the trailer with wheels or tracks hanging on both sides of the frame. This method of transport reduces the height of the trailer with cargo, and in many cases, it is indispensable to allow the trailer to pass under low bridges. The configuration with beams spaced laterally facilitates the transport of yachts and drums as well as other elements of circular or similar cross section. In addition, it should be possible to obtain a flat load platform and to adjust the length of the bed. The design of the semi-trailer should also facilitate the entry of self-propelled vehicles onto the load platform.

It was also assumed that one version of the semi-trailer should meet the requirements for standard vehicles, which is extremely important for the carrier who is not required to obtain a permit for passage when the trailer does not carry oversize cargo (this allows one to avoid the sometimes time-consuming administrative procedures and reduce the costs of transport activity).

To meet these requirements, the semi-trailer should have a modular structure and possess five axles with the load capacity of 12 tonnes each. It was decided that the trailer should consist of the following modules: the gooseneck, the load platform, a two-axle bogie and a three-axle bogie. The individual modules can be combined, producing different configurations of the trailer and adapting it to the specific load (Fig. 1).

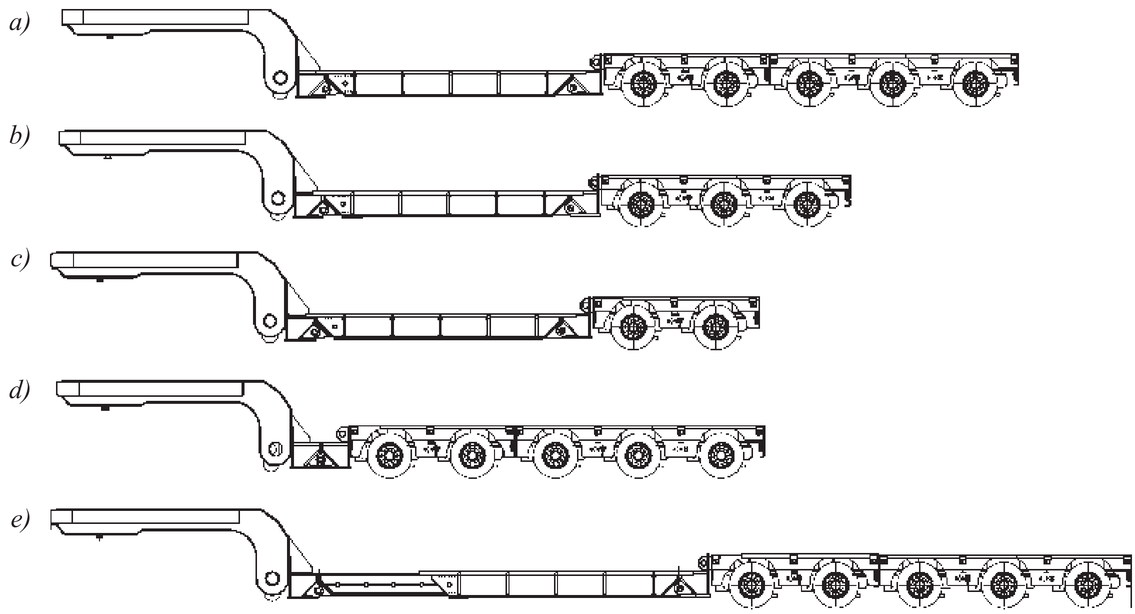

Fig. 1. Possible configurations of the semi-trailer; the bed can be extended, as shown in Figure e (not applicable to the configuration shown in Figure d, in which there is no bed)

Gross vehicle masses in different trailer configurations should equal:

– 2-axle 48 tonnes, i.e. 24 tonnes supported by the fifth wheel coupling and 24 tonnes resting on the axles,
– 3-axle 60 tonnes, i.e. 24 tonnes supported by the fifth wheel coupling and 36 tonnes resting on the axles,
– 5-axle 84 tonnes, i.e. 24 tonnes supported by the fifth wheel coupling and 56 tonnes resting on the axles,

The dimensions of the trailer in a 2-axle and a 5-axle configuration without the bed (Fig. 1c and 1d) should allow the vehicle to meet the requirements for a standard vehicle. The design of the trailer should make it possible to couple it to a ballast tractor unit with a maximum number of axles of 4 and the typical height of the fifth wheel coupling in this type of vehicles, i.e. 1300 mm.

3. Development of the design of the semi-trailer chassis

A computer program was developed to study the impact of various geometric parameters of the tractor-trailer combination (length and width of the combination, number of axles and the distance between the axles) on the manoeuvrability of the whole combination. The mathematical model implemented in the program uses the appropriate geometrical relationships, with the assumption that trailer wheels roll without skidding (Fig. 2). In the program, displacement trajectories are calculated for each trailer wheel during a turn; also are determined the changes in the steer angle of the wheels, as well as the off-tracking of the trailer and its corner cutting (Fig. 3). A detailed description of the model and the research are given in [3]. The results showed that in order to satisfy both the generally applicable requirements for standard vehicles [4] as well as the requirements for oversize vehicles being in force in Germany, specified in TUV recommendations [5], the wheels of all trailer's axles need to be steerable and with forced steering.

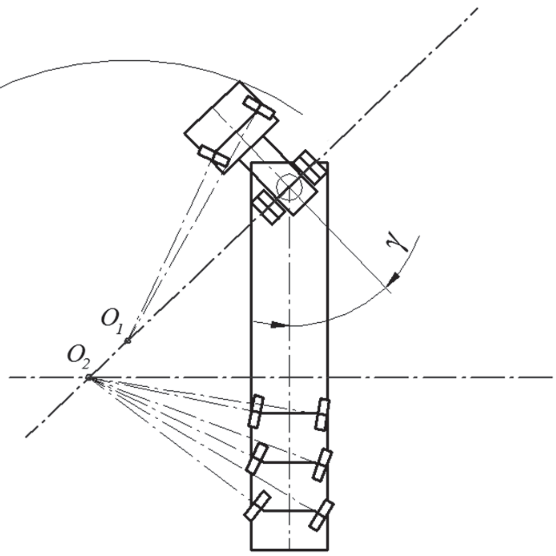

Fig. 2. The correct settings for the wheels of the tractor and the trailer during a turn

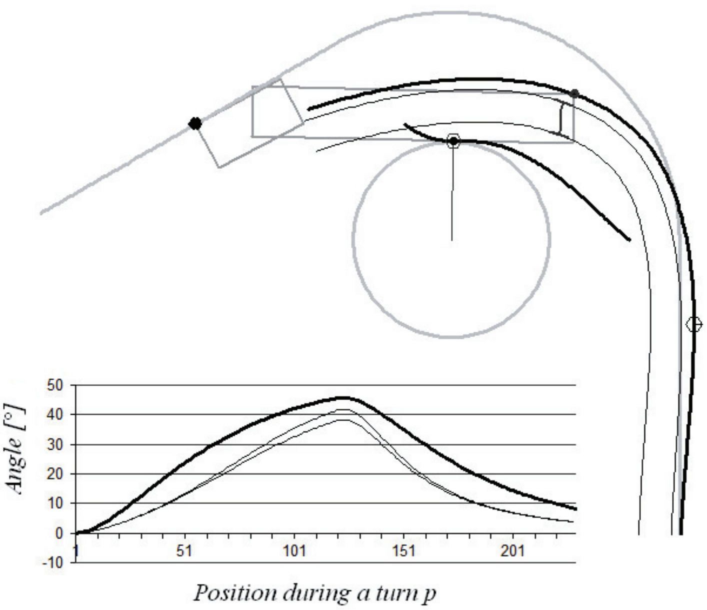

Fig.3. Displacement trajectory of the right rear corner of the trailer, the point on the trailer which is closest to the centre of the bend, and the wheels of the last axle of the trailer, as well as the articulation angle between trailer and tractor and trailer's rearmost wheels determined by the program testing the manoeuvrability of the semi-trailer

Given the legal and technological considerations, the distance between the axles of the semi-trailer was determined, and then the requirements concerning maximum steering angles of particular axles were specified. Additionally, it was decided that the vehicle will be equipped with axles with wheels with a radius of 17.5" and the lowest possible driving height (that ensures the lowest height of the bogies' load platform), and that the trailer will use pneumatic suspension.

In response to a request from Wielton Company, SAF Company prepared forced steer axles with a ride height of 255 mm, which were adapted to the design requirements of the proposed semi-trailer. Four different types of axles were prepared, with different maximum steering angle and spacing of the front and rear suspension mounting brackets. It was decided that axles with different maximum steering angles should be used, as this is very beneficial to the stability of the vehicle – axles with greater steering angles have narrower spacing between suspension brackets than axles with smaller permissible steering angles (the required maximum steering angle is the greater, the farther the position of the axle from the kingpin).

The development of a detailed design and manufacture of a hydraulic steering system using six-part steering linkages was entrusted to Tridec Company, specializing in the design and production of steering system components for special-purpose vehicles. Designs of all steering components were developed, including the coupling mechanism along with a system of wheel-turning actuators, steering rods, connectors, etc. (Fig. 4). This system allows correct operation of the semi-trailer in all its possible configurations.

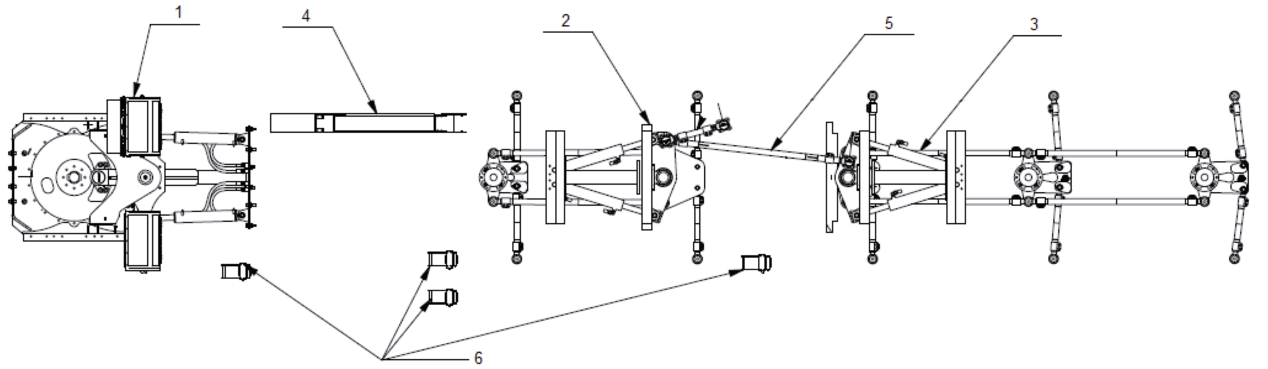

Fig. 4. Steering components of the semi-trailer: 1 – elements integrated with the coupling plate, 2 – components built-in in the 2-axle bogie, 3 – components built-in in the 3-axle bogie, 4 – hoses, 5 – rod connecting the steering columns of the 2- and 3-axle bogies (only used in the five-axle configuration with a loading bed), 6 – hydraulic couplers (Multifasters)

The pneumatic and braking systems adapted for operation in a semi-trailer of a non-standard length and modular design were supplied by Wabco. The braking system was equipped with ABS and EBS E with an additional signal separation using CAN-Router that enables collaboration of two separate systems located in the different bogies.

4. Development of the design of the semi-trailer support frame

In the first stage of the design work, different variants of the technical solutions for connecting semi-trailer gooseneck with the loading bed were analysed. Taking into account the functional, technological and strength-related aspects, it was specified that the gooseneck and the loading bed will be connected with mating hitches positioned on the front of the bed, and hydraulic actuators placed in the gooseneck of the trailer will maintain the vertical position of the bed. This solution ensures easy adjustment of the front of the bed and its lowering onto the ground. After lowering the bed onto the ground, it will be easy to decouple the gooseneck from the bed. After the disconnection, the tractor can leave with the gooseneck (which will be held by an additional supporting actuator in order to keep it from falling to the ground) to facilitate the loading, including the entry of self-propelled vehicles onto the load platform from the front side of the trailer.

Various solutions to change the length and width of the load platform were also analysed and it was decided that the best solution would be to use a double support frame of a closed box-profile, in which the change in length will be implemented by sliding out the front, internal part of the frame, from the rear external one. Moreover, it was decided that additional intermediate items, named adapters, will be placed between the load-bearing elements of the bed and the trailer's front module as well as the rear module, i.e. the bogie. Adapters will be connected to the bed by means of bolts.

A spreadsheet enabling the determination of the forces acting on key nodes of the semi-trailer depending on its load, and the key, essential dimensions (eg. the distance between the resistance surfaces and axes of the bolts, and the dimensions resulting from the placement of actuators; Fig. 5) was developed. Analyses of the possible forces and accelerations acting on the trailer frame during its operation under different conditions were also performed and on this basis the load values for strength calculations were determined.

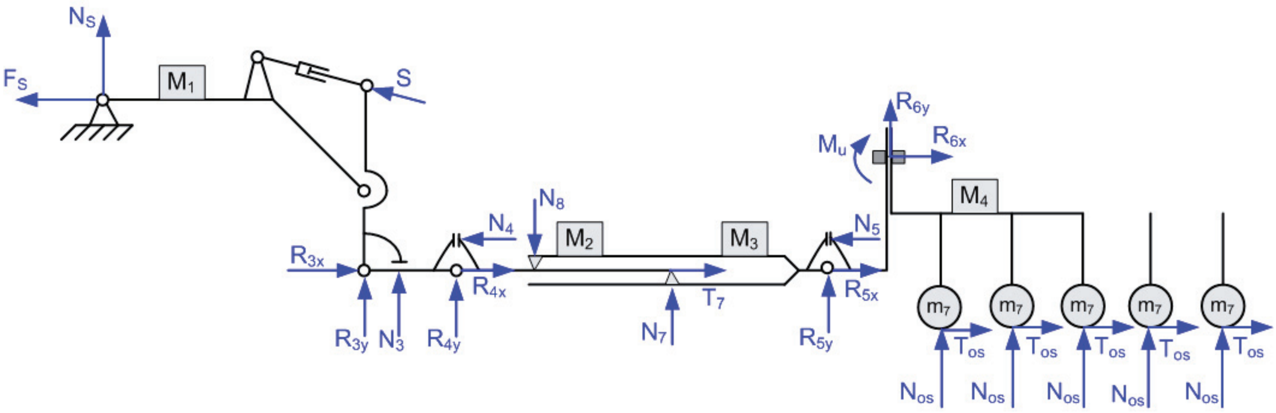

Fig. 5. Diagram of forces determined in the model of the load of the trailer's structural nodes

The initial design of the supporting structure of individual modules and then their discrete models were prepared (Fig. 6) and strength calculations by the finite element method (FEM) using the Abacus\Standard software were carried out (a method of FEM analysis is given in [1]). The preliminary designs of the supporting elements of individual modules were modified to maximize their strength and minimize weight. As a result of this work, the design of the support structure was prepared (Fig. 7), as a basis for the development of a detailed semi-trailer design (other structural components and vehicle equipment are attached to the elements forming the support structure).

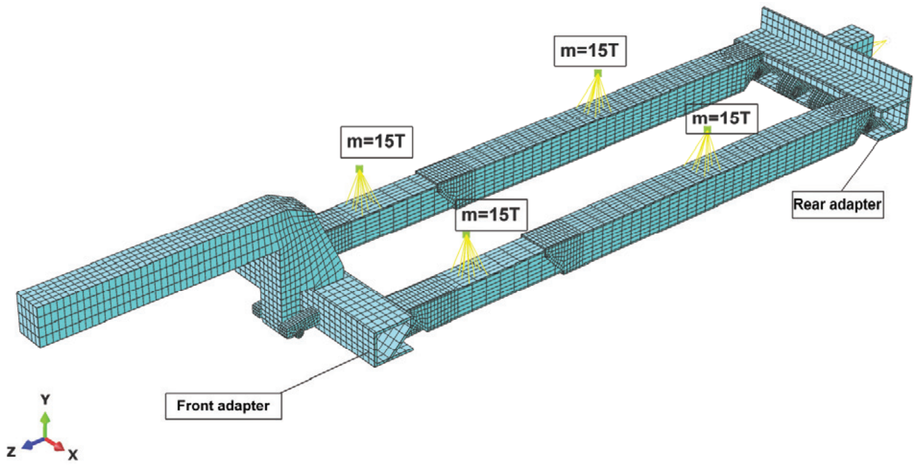

Fig. 6. Discrete model of the extendable frame with sample load

Designs of the following elements were developed:

- connections between the individual modules and the connections of the rear, external and front, internal elements of the beams of the loading bed, enabling the adjustment of the length of the bed, as well as the system preventing the falling of the gooseneck during the disconnection of the tractor from the trailer,
- swivel brackets for widening the loading platform, and extendable beams which allow to increase the width of the platform of the bogies,
- fold-up front ramps allowing machines to enter the loading platform and portable ramps allowing access from the lowered platform to bogie platform,
- decks, including removable bridges which, together with bed beams, form the flat deck of the loading platform; sides of the balcony; aluminum tool box; spare wheel mount,
- cargo fastening clamps [2] as well as supports and other elements that enable mounting of all the semi-trailer's systems, including the suspension and the steering system, the hydraulic and pneumatic systems, etc.

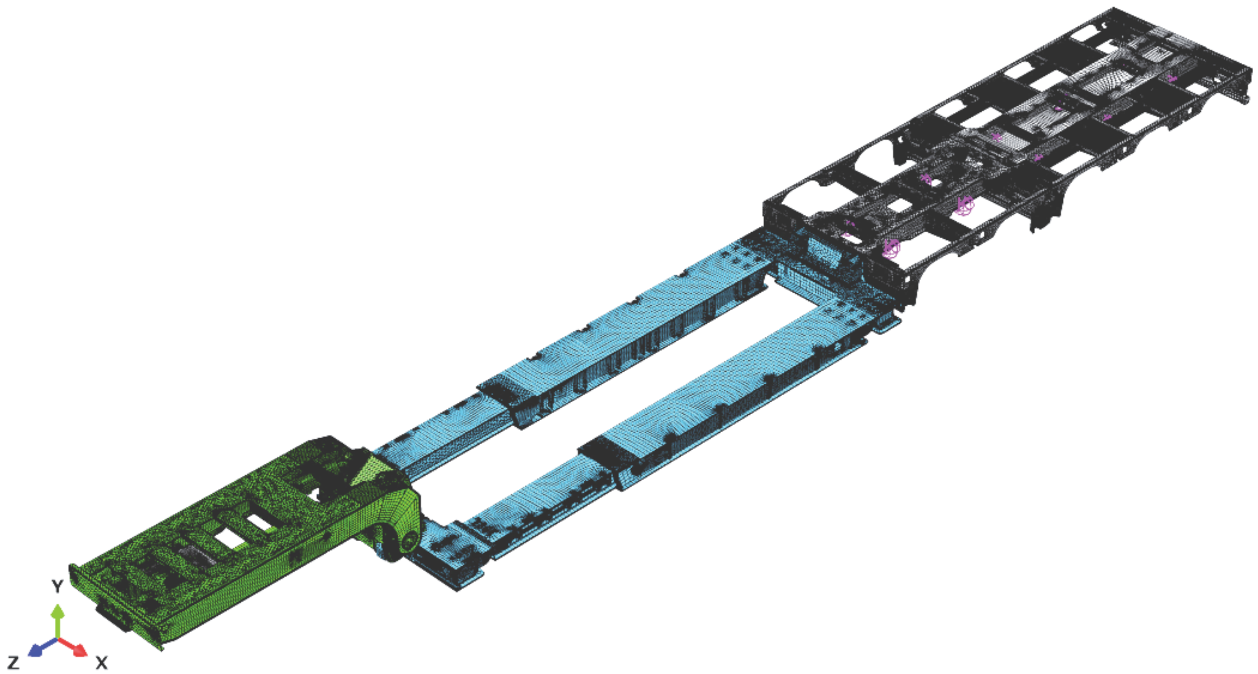

Fig. 7. Numerical model of the semi-trailer's support structure

Considering the large impact of structural details on stresses occurring in the components, the structural models of the individual modules of the semi-trailer were subjected to FEM analysis following their preparation (Fig. 8).

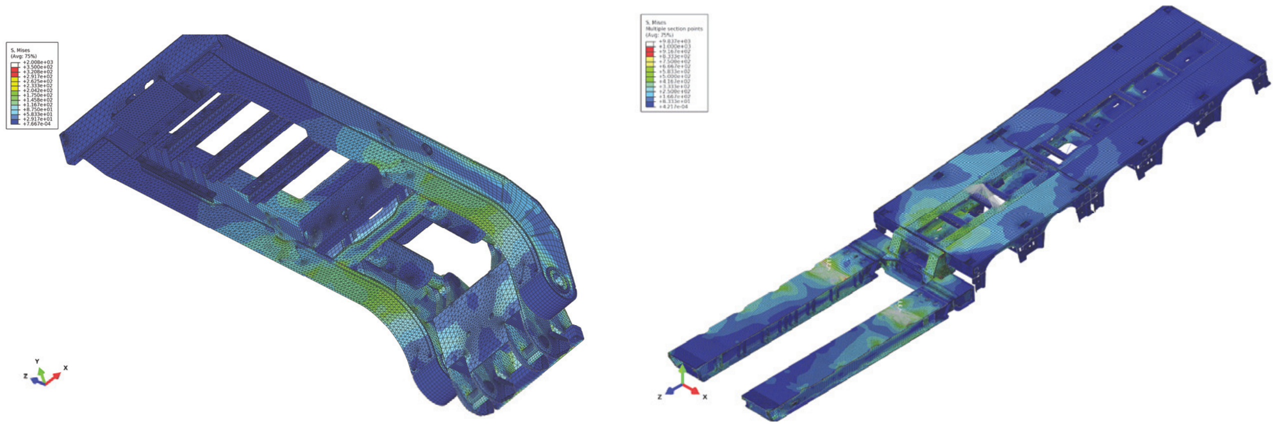

Fig. 8. Distribution of H-M-H stress in the components of the gooseneck and the rear part of the trailer

5. Prototype of the semi-trailer

Design and technological documentation of the prototype was developed and a prototypical, fully functional modular semi-trailer was built (Fig. 9).

Tests of the handling and functionality of the prototype confirmed the high quality of design solutions, ensuring excellent traction and functional properties.

6. Summary

This article describes the work carried out by the Lublin University of Technology and Wielton SA as a project aimed at developing the design and preparing the production of a semi-trailer for the transport of oversize cargo, in particular, heavy construction, agricultural and military vehicles,

Fig. 9. Prototype of the semi-trailer coupled to a three-axle tractor unit

steel structures, tanks, containers, and other oversized machinery and structures. The scope of work included the full range of design work, from marketing research and the formulation of functional assumptions and design, through the review of existing solutions, to the development of the design, and the construction of a prototype and its testing.

As a result of the project, a design was developed and a prototype of a modern modular low-bed semi-trailer for the transport of loads up to 65 tons was built and tested. The trailer can carry loads which are heavier than standard ones, owing to the use of a larger number of axles; the loads can also be oversized owing to the possibility of its extension and expansion. The advantage of the vehicle is its modular design, which allows the vehicle to adjust its configuration to the transported cargo. Four configurations of the semi-trailer were assumed, differing in the number of axles, length, and gross vehicle mass from 48 t to 84 t. Furthermore, in each of these configurations the semi-trailer can be adjusted to a user's needs, such as changing the length or width of the platform. The big advantage is that in the "smallest" configuration, the trailer meets the requirements for standard vehicles, and so it can be driven on roads without special permits. The semi-trailer meets all technical requirements being in force in the European Union and concerning this class of vehicles.

References

[1] Dębski, H., Koszałka, G., Ferdynus, M., *Application of FEM in the Analysis of the Structure of a Trailer Supporting Frame with Variable Operation Parameters*, Eksploatacja i Niezawodność – Maintenance and Reliability, Vol. 14, No. 2, pp. 107-114, 2012.

[2] Stokłosa, J., Koszałka, G., Gil, L., *Analysis of Forces in Elements Used for Fastening Loads on Road Vehicles*, Advances in Science and Technology, Vol. 12, pp. 94-100, 2012.

[3] Zniszczyński, A., Koszałka, G., *Badania symulacyjne zwrotności wielkogabarytowej naczepy*, Proceedings of the XXVI Scientific Conference. Problemy Rozwoju Maszyn Roboczych, Zakopane 2013.

[4] Commission Directive 2003/19/EC of 21 March 2003 amending, for the purposes of adapting to technical progress, Directive 97/27/EC of the European Parliament and of the Council relating to the masses and dimensions of certain categories of motor vehicles and their trailers.

[5] TUV Guidelines for the granting of exemptions to §70 StVZO for certain vehicles and certain other types of vehicles.