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Method of determination of safety factor on example of selected structure

Maciej Szulc[a],*, Ireneusz Malujda[a], Krzysztof Talaśka[a]

[a]Chair of Basics of Machine Design, Poznań University of Technology, Street Piotrowo 3, 60-965 Poznań, Poland

Abstract

The article shows a method of determining safety factors of a frame steel structure of the dump body in a vehicle used in the agricultural transport. The focus is on the method of use of the machine along with indicating the situations where a load-bearing structure is particularly exposed to damage. The determined values of safety coefficients are confirmed with the data obtained from long-term operation of machines manufactured based on the same technology. Long-term operation has not shown any cases of damage to the structure due to an overload.

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Keywords: universal tandem axle trailer; dump body; cantilever

1. Introduction

Design – is a selection of material and geometrical characteristics of machine elements. The level of risk of failure or damage to the structure is defined by the safety coefficient and proper selection thereof is one of the basic issues in the design of machines and devices [1]. A modern design is aimed at very precise determination of the safety coefficient due to economic reasons. Defining the situations where a structure is most exposed to damage, and determining a proper value of safety coefficient based thereon ensures long life of the machine. The new calculation methods enable fast analysis of results, which in turn allows to choose the most effective solution for a given structure [2]. Machines for transport in agriculture are designed with consideration that they operate in close contact with a human.

* Corresponding author. Tel.: +48 501932121.
E-mail address: szulc.maciej@wp.pl

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2. Structural characteristics of analysed object

The universal tandem axle trailers (Fig. 1) are a group of structures where the vehicle deadweight is proportionally distributed into driving axles and a drawbar. This makes that a portion of trailer mass is distributed on the drawing vehicle, which facilitates the movement of a unit of vehicles on a demanding ground. The position of the wheels and suspension system 1 (Fig. 1) against the centre of gravity of the trailer 3 is very important, since the distribution of masses on both the axles and coupling 2 is closely defined by the traffic regulations.

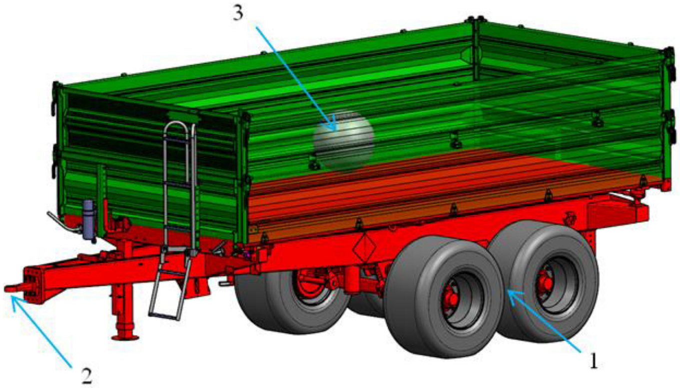

Fig. 1. Tandem universal trailer: 1 – wheel and suspension system, 2 – coupling, 3 – vehicle gravity centre [3].

The trailer's superstructure (Fig. 2) is a platform along with sides 1 in various combinations depending on vehicle use. The total height of sides can be 1 800 mm. The platform is mounted on frame 2 in four pivoting points 3 and two support points 4. In order to determine the direction of vehicle self-dumping, two support points need to be blocked with the central interlock system 5. This allows dumping to the right, left or backwards. In the central frame position is a hydraulic telescoping dump actuator 6, whose force of action is 77 kN and arises from pressure of 20 MPa. The total deadweight of a vehicle with standard equipment is 2 800 kg and a total allowable deadweight is 14 000 kg.

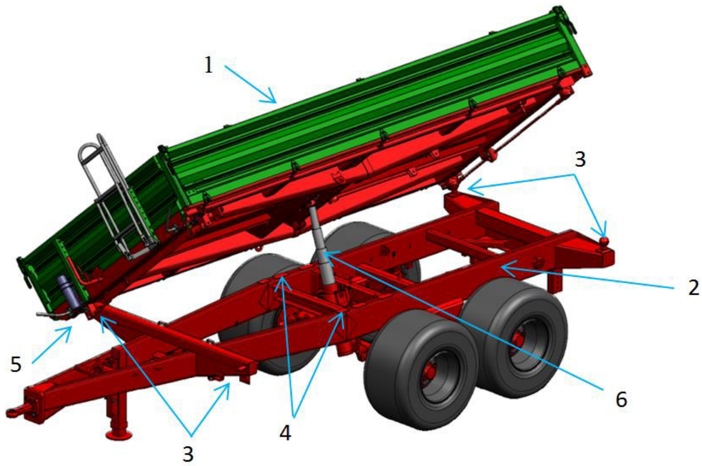

Fig. 2. Trailer structure diagram: 1 – superstructure, 2 – frame, 3 – rotation-supporting points, 4 – supporting points, 5 – central locking system, 6 – telescopic hydraulic actuator [3].

3. Conditions of use

The universal agricultural trailers serve for self-damping and are found in agricultural transport. Their universality allows for transportation of multiple various products both bulk and solid materials. For bulk materials, the basis for maintaining a load is an open-load carrying body whose loading weight is distributed evenly, which in turn provides a relatively even distribution of load on individual structural elements. In the case of transportation of other loads the side walls of an open-load carrying body needs to be opened for, the position of the centre of gravity depends on the user who should follow the requirement of as even distribution of load-bearing structure as possible. While determining the safety factor a situation of improper load distribution needs to be considered.

The grounds the units composed of a drawing vehicle and a trailer move on are various roads and arable lands with peat lands, waterlogged areas and waste land. These areas are often characterized by irregular surface structure and low compaction. This contributes to vehicle tipping (Fig. 3) and to shifting the centre of gravity of the load. This as a consequence changes the load distribution in a vehicle. The discharge backwards on an unstable ground may lead to overturning of a vehicle. In this case the joints connecting a frame with an open-load carrying body are extremely overloaded, which should also be considered when determining the safety factor. The situation shown in Fig. 3 shows an attempt to bring stability back to the trailer by applying a force opposite to the direction of vehicle dump. The point where this force is applied has not been planned structurally, and so its effects can be irreversible. This situation, considering the vehicle universality is probable and so it is reasonable to determine the points at which a specific force can be applied.

Fig. 3. Example of untypical situation during use [3].

4. Safety factor for static load

The safety factor for static load is divided into components in order to describe the known factors affecting structural strength [4]. The product of these components gives a final value:

$$x_w = x_1 x_2 x_3 \tag{1}$$

x_w – safety factor
x_1 – design accuracy 1÷1.15
x_2 – non-typical overload 1.1÷1.18
x_3 – overload factor 1.1÷1.2

The first component x_1 allows for size deviations of individual frame elements, from a deviation related to thickness of a metal sheet, to dimensional tolerances of all sections made by cutting sheets in the process of edge bending. The primary supporting beams of the frame structure are made of two towbars connected with each other. It is important that geometrical dimensions of the cross-section are within the field of dimensional tolerance. Also, a careless design of welds connecting structural elements is considered. The interval of value of this factor depends on the tolerance of shape and position as specified in technical documentation. For the frame in question, the value of a component safety factor is determined based on technical documentation, manufacture technology and training level of the crew, and it is 1.05.

The second component x_2 allows for the factors that occur very rarely. It relates to, i.e. dump of trailer with load (Fig. 4) during self-dumping, which causes the centre of gravity of a vehicle to shift and as a result affects the distribution of stress in a load-bearing structure. Higher load may result in irreversible changes in directly exposed elements. Therefore, it is important to localize the points where short-term, hazardous stresses occur and these need to be given the structural characteristics that will provide a required strength. Since the universal agricultural trailer can be self-dumped in three directions, there are several points exposed to a short-term considerably higher load. Identification of the real characteristics of machine operation makes it possible to determine the points of action of these forces and the overload simulations with finite elements approach indicate precisely the points of overload. The value of this partial factor is determined based on long-term observations of operated machines and it is 1.16.

The final partial factor x_3 assumes a probability of failure to follow the vehicle operation manual. The purpose of a universal trailer with a specific load volume allows transportation of a load with various own mass such as, i.e. grains of cereals, bulky feeds and other. Therefore, to base any decision on the load volume is wrong. On the other hand, no presence of any devices that would indicate the current load makes room for overload. Perhaps it would be reasonable to develop the load level indicators or protections that would prevent a vehicle use when its total allowable mass is exceeded. Because of the difficulties in determination of this factor, its value is highest considering the available range. For the trailer in question the factor x_3 is 1.15.

For static load, the product of safety factor components in the described frame structure of a universal trailer is 1.4. In order to verify whether the above factors are correctly determined, the analysis of the physical object is necessary. Such analysis has been made on a structurally similar, newly-designed trailer. The analysis has been conducted in three phases with variable load and vehicle dump angle. Fig. 4 shows the third phase of analysis wherein the total allowable load weight is increased by 25% and the vehicle dump angle is 30° in lateral direction.

Fig. 4. Simulation of extreme static load for newly-designed trailer [3].

The maximum load the trailer structural elements in this case were exposed to reported no damage and the vehicle did not lose its stability. The results of this experiment allowed to use the prototype for further fatigue tests.

5. Safety factor for fatigue load

In addition to the static load, the frame of a transport trailer is subjected to dynamic load which affect fatigue strength thereof. A difference between the static and fatigue calculations is due to the considered load duration and its nature described by individual factors. A key matter is to properly determine the case when dynamic load occurs.

The frame in question is subjected to external load that forces the occurrence of variable non-symmetric stress whose minimum value is higher than zero. It is the case, i.e. when driving at certain speed and with maximum trailer load or on crevices or raised parts of the road surface. Both the speed of driving and the vertical acceleration when driving over such an obstacle was determined based on real conditions of use. For approach of the calculations considering the fatigue of material, it is necessary to know the values of stresses corresponding to the fatigue strength Z_G. Fatigue strength Z_G is known as a maximum stress σ_{max} for a given stress cycle which when exceeded after the conventional number of stress cycles is achieved, causes a permanent damage to the element. The value of the required fatigue safety factor δ_w depending on the accuracy of calculations and knowledge of experimental data characterising this load is:

1.3 ÷ 1.4 – with very accurate calculations, uniform material, precise design;
1.4 ÷ 1.7 – for average work conditions;
1.7 ÷ 3.0 – for unfavourable work conditions, responsible structures.

The value of required safety factor δ_w = 1.35 was adopted as a mean value from the range of factors for very accurate calculations, uniform material and fine design [5]. Very accurate simulated calculations of these frames with finite elements method have been conducted for several years. This allowed for huge experience which translates into the quality of calculations. The results of calculations are verified experimentally on stationary test facilities or test tracks. The structural elements of this type of frames require the use of metal sheets made of only one type of steel with certain controlled chemical composition and specific mechanical properties. Also, the proper construction documentation, high level of technology and workshop equipment, and well-prepared and trained crew are all important factors. Moreover, the manufactured products should be subjected to partial and final inspection with a specific high standard of quality.

For non-symmetrical cycles, safety factor is as follows:

$$\delta = \frac{Z_G}{\sigma_m + \beta\gamma\sigma_a} \geq \delta_w, \tag{2}$$

where δ – real fatigue safety coefficient, Z_G – fatigue strength, σ_m – mean stress, β – stress concentration factor, γ – object size factor, σ_a – nominal stress amplitude, δ_w – required safety factor.

Value of mean stress is assumed as σ_m = 100 MPa with nominal stress amplitude assumed as σ_a = 70 MPa. The stress concentration factor has been determined whose value is 1.1 and the value of object size factor is 1 [6]. Following the substitution of the values of individual factors and physical quantities to the formula (2) for real safety factor, a fatigue real safety factor of δ = 1.38 was obtained. In order to verify whether the adopted assumptions are proper, the tests on the test track (Fig. 5) were conducted. After a certain number of load cycles, the trailer structural elements showed no signs of fatigue. The additional tests made under 50% trailer overload led to fractures of welds in points of stress concentrations revealed by MES simulation.

Fig. 5. Simulation of fatigue load on test track of newly-designed trailer [3].

6. Conclusion

Identifying the conditions of machine operation allows to minimize the value of the safety factor. For static load of the analysed trailer, a value of the safety factor can be 1.4 and for fatigue load – 1.38. The numerical verifying calculations performed with finite elements method and the test for static and fatigue load, show that the values of factors are appropriate and the structure is safe. Low values of safety factors contribute to low manufacturing costs. The process of determination of factors as described in this article, is based on analysis of results of calculations by MES of trailer frame that has been manufactured for 10 years. No damage to the structure that would occur under proper operation was determined.

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