Determining Maximum Acceleration Parameters for Vehicle – Trailer Combinations

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Abstract

The paper is devoted to the trailer combination starting, in particular to the method of determining the trailer acceleration while starting. The characteristics of the combination, in particular those related to the joint of a towing vehicle and a trailer affect the trailer combinations while starting. While starting, both vehicles start oscillating and the trailer acceleration can reach high values. We have determined the value of the first maximum acceleration of the towing vehicle and the trailer maximum acceleration both numerically and graphically. Moreover, the paper attempts to identify how the characteristics of both the combination and joint may influence the maximum acceleration rate of the trailer. Last but not least, the applied experimental method is explained.

Keywords: Acceleration. Centrifugal forces. Accelerating period. Adherence. Vehicle combination. Oscillation.

Introduction

When dealing with means of transport, it is required to identify the acceleration that can be reached by the vehicle in question. It is vital to know the acceleration development depending on time and its maximum rate in order to identify the inertial forces acting on the vehicle and its components while starting. The issue is tackled by the driving dynamics in motor vehicles from which it follows that the maximum acceleration of a motor vehicle must not exceed the limit value, which is the so - called adhesion condition [1] [3].

In road transportation, vehicle – trailer combinations comprising a towing vehicle and a towed vehicle, such as a trailer or semi – trailer have been of frequent use. Trailers are coupled with a towing vehicle's rear while semi - trailers are attached to a towing vehicle on their front so that some fraction of the weight of a semi - trailer is carried by the moving vehicle. Since an easy coupling and decoupling of both vehicles is a must, the joint has to be loose, i.e. there has to be some allowance ζ. Trailer combinations have the allowance ζ of 20 – 30 mm. In order to decrease the trailer acceleration rate induced by the towing vehicle, sprung joints are of frequent use in trailer combinations. Fig. 1 illustrates the hook arrangement as an instance of the sprung joint (spring mounting).

The defined allowance and spring mounting of the joint make possible the relative motion of both vehicles. Hence, the oscillation coming from the towing vehicle causes longitudinal oscillation of the vehicle - trailer combination. While oscillating, it is the joint that makes the trailer accelerate. In order to determine the maximum acceleration of the trailer, the adhesion condition cannot be applied. Generally, we shall suppose there may be higher acceleration rates of the trailer complying with the adhesion condition. Bearing in mind the aforementioned facts, the paper attempts to identify the methods to determine the maximum acceleration rate of the trailer when starting the vehicle – trailer combination.

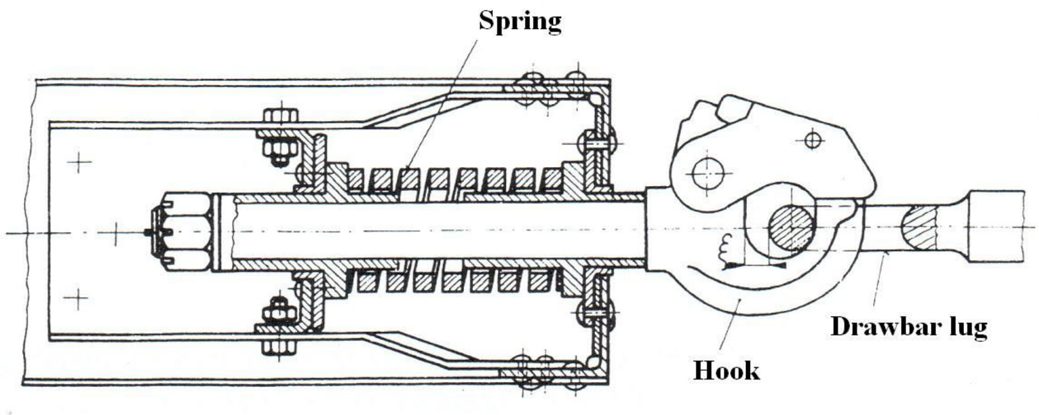

Fig. 1 Hook arrangement of the trailer and towing car coupling

When solving this task, it is necessary to take into consideration the forces acting on the vehicle trailer combination in the course of starting. The forces are shown in Figure 2 for the trailer acceleration periods.

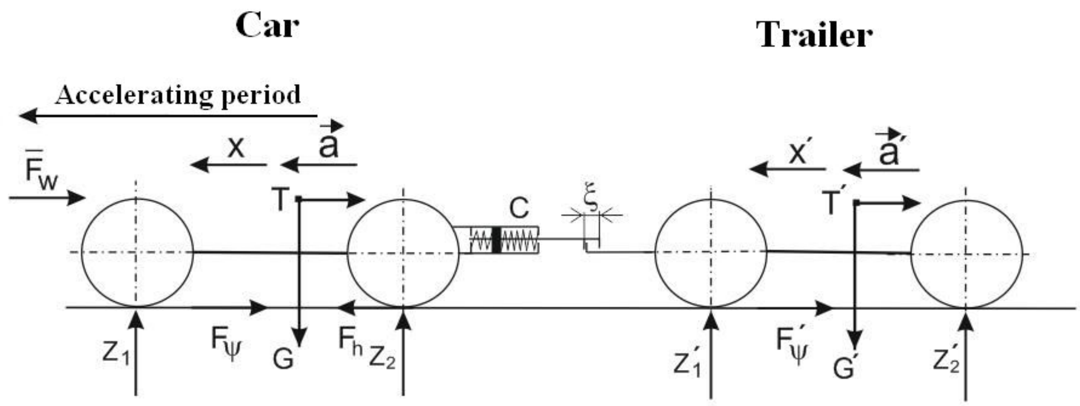

Fig. 2 Scheme of the vehicle trailer combination

where:

G	denotes the weight of a towing vehicle,
G'	denotes the weight of a trailer,
F_h	denotes the driving force of a towing vehicle,
F_S	denotes the inertial force of a towing vehicle,
F_S'	denotes the inertial force of a trailer,
F_Ψ	denotes the roadway resistance of a towing vehicle,
F_ψ'	denotes the roadway resistance of a trailer,
Z_1, Z_2, Z_1', Z_2'	denotes upright reactions in the area where wheels contact the roadway,
$\bar{F}_m$	denotes the air resistance of the vehicle combination,
c $\bar{x}$	denotes the force in the vehicle joint (c – spring firmness, $\bar{x}$ - spring deformation).

In line with [1], the driving force F_h can be expressed as follows

$$F_h = \frac{M_m i \eta_m}{R_d} \tag{1}$$

where:

M_m denotes the torque of a motor,
i denotes the gear ratio between a motor and a drive axle,
η_m denotes the mechanical efficiency,
R_d denotes the dynamic radius of a drive gear.

In starting, the torque value transmitted from the motor is conditioned by the way of the gradual clutch shot.

1. Sketching Graphs to Identify the Maximum Acceleration

a_{max} $a'_{\max}$

It becomes evident from previous analysis that the first maximum acceleration of a towing vehicle can be expressed by the relation (2) at t = t_ζ

$$a_{\max} = \overline{C} t_{\xi} - g\varphi \tag{2}$$

and the maximum trailer acceleration can be expressed by the relation whereas $\overline{x} = \overline{x}_{\max}$

$$a'_{\max} = \frac{c}{m'} \overline{x}_{\max} - g\varphi \tag{3}$$

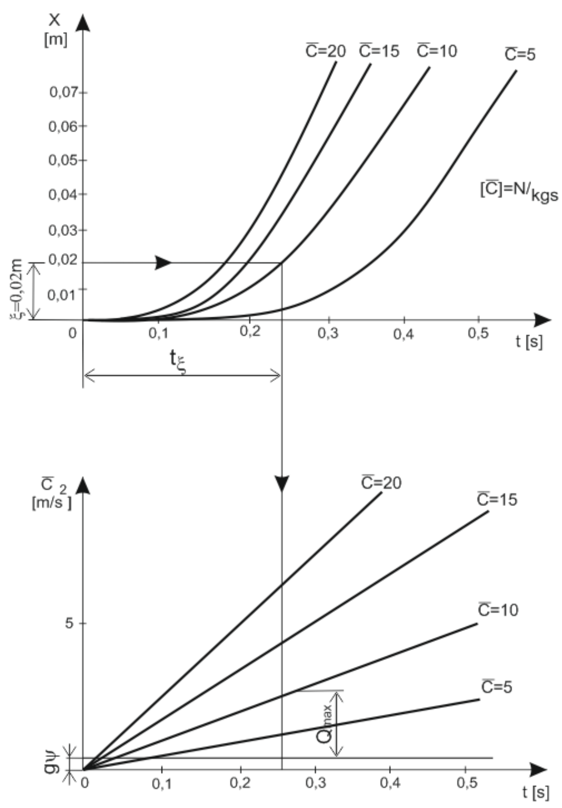

Fig. 3 Graphical determination of a_{max}

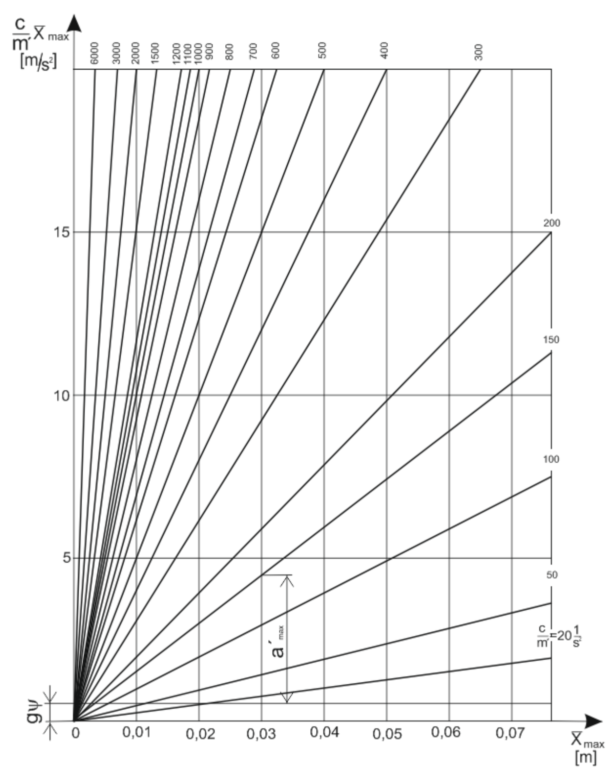

Fig. 4 Graphical determination of $a'_{\max}$

By equation (2), it is possible to sketch graphs shown in Fig. 3. The graphs illustrate the way to determine t_ζ and a_{max}. Similarly, by equation (3), we can sketch the graph shown in Fig. 4 and apply the indicated method in line with the given equation in order to obtain the value of $a'_{\max}$.

To determine the value, we need to know the values of firmness c and mass m' as well as the value of the maximum spring deformation $\bar{x}_{max}$. While testing various variants, the direct dependence of $\bar{x}_{max}$ on the $\bar{C}$ value was proved.

If having various ω_x values, we are dealing with a group of lines (Fig. 5) that are used as indicated to determine $\bar{x}_{max}$ at specific values $\bar{C}$ and ω_x. The problem is that it always applies for a specific value ζ and $\bar{x}_0$ (allowance in a joint and a spring preload). To utilize this phenomenon in a practical manner, it deems necessary to make a set of such graphs covering the allowance range ζ as well as the spring preload range. Thus, it would be possible to determine the interpolation for $\bar{x}_{max}$ in an acceptably precise manner.

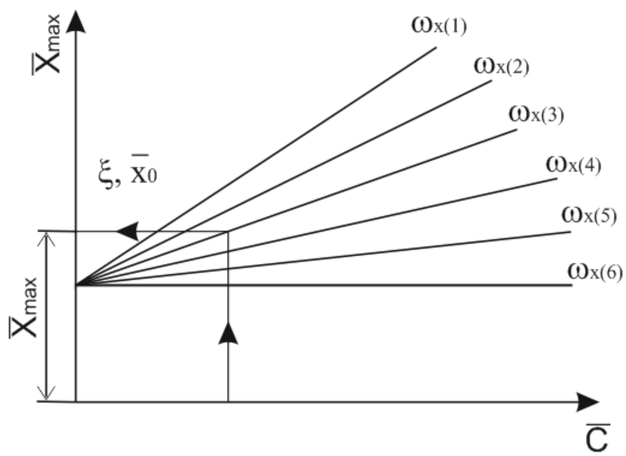

Fig. 5 Determination of x_{max}

2. *The Influence of the Trailer Combination Characteristics on the Trailer Acceleration Rate*

Following the explanations and relations given above, it is apparent that the trailer acceleration is affected by the characteristics of the vehicle – trailer combination joint, such as allowance ζ, spring firmness c and spring preload $\bar{x}_0$. In addition, the acceleration rate is influenced by some characteristics of the entire vehicle – trailer combination that can be summarized into two major characteristics, such as the trailer relative mass υ and the C value. The C value is the growing rate of the towing vehicle driving force with respect to the unit of its mass.

The type of dependence of the trailer highest acceleration rate a'_{max} on the five characteristics given (cf. Fig. 6 – 10) is presented in graphs.

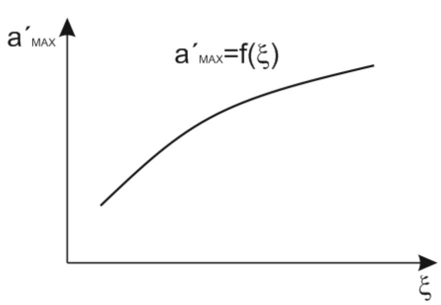

Fig. 6 Dependence $a'_{max} = f(\xi)$

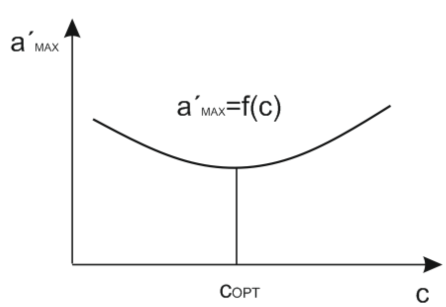

Fig. 7 Dependence $a'_{max} = f(c)$

The following conclusions can be drawn from the dependences illustrated:

a) The growing allowance ζ raises quite significantly the rate of the trailer maximum acceleration $a'_{\max}$. To avoid too high trailer acceleration rates and subsequent fairly significant inertial force rates of the trailer components under stress, it is advisable to have the lowest possible allowance.

b) While the spring firmness c in the joint increases, the rate of $a'_{\max}$ decreases initially and increases afterwards. It follows that the dependence is $a'_{\max} = f(c)$ minimum. When considering the joint type, it is possible to find the optimum firmness c_{opt}, providing thus the conditions for the least trailer acceleration rate as well as for the minimum stress of the trailer components.

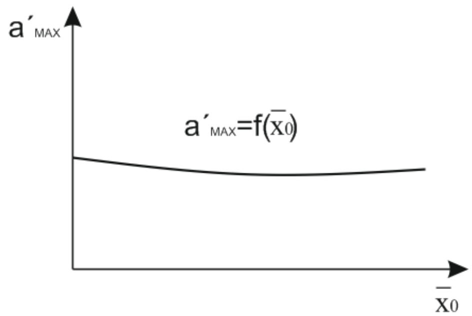

Fig. 8 Dependence $a'_{\max} = f(x_0)$

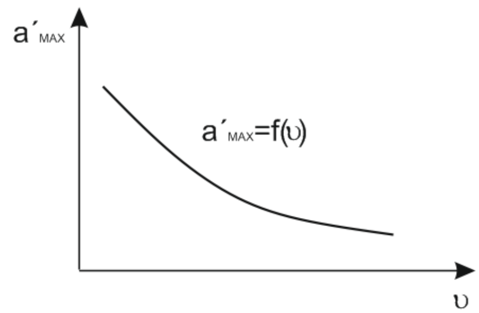

Fig. 9 Dependence $a'_{\max} = f(\nu)$

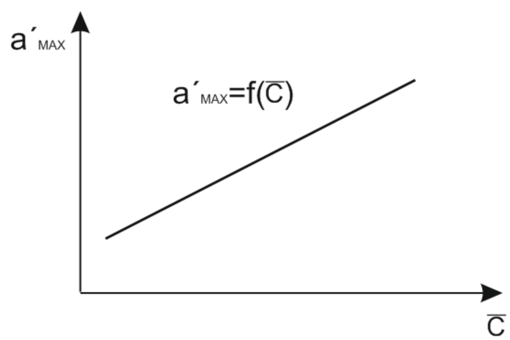

Fig. 10 Dependence $a'_{\max} = f(\xi)$

c) An array of variants has been tested to identify the influence of the spring preload $\overline{x}_0$ in the range $\overline{x}_0 = 0 \div 0{,}01$ m. In the range given, the growing spring preload resulted in a moderate $a'_{\max}$ decrease, however the effect of $\overline{x}_0$ was not of a profound significance.

d) The decreasing trailer relative mass υ makes the trailer maximum acceleration rate $a'_{\max}$ increase relatively. The fact shall be taken into account while comparing partially or fully loaded means of transport.

e) The increasing quantity $\overline{C}$ which depends on the towing vehicle characteristics and actions performed by a driver makes the rate of the maximum trailer acceleration go up.

3. Experimental Determination of the Acceleration Rate for the Vehicle – Trailer Combinations

To verify the method, we have used sensors arranged as illustrated in Fig. 11a. The sensors are composed of a ring with four tensometers – 1, a weight – 2 and a main circuit board – 3. Tensometers are linked to form bridges (Fig. 11b). When weights – 2 are acting on the ring with tensile force, the internal tensometers are under stress during the ring deformation which is caused by the tensile force. The external tensometers are under stress during the ring deformation which is caused by pressure. When weights are acting on the ring by exerting pressure, tensometers are under stress reversely.

When a tensometer is placed on the vehicle, then inertial force is exerted by the ring on the weight. The inertial force is the product of the weight mass and vehicle acceleration.

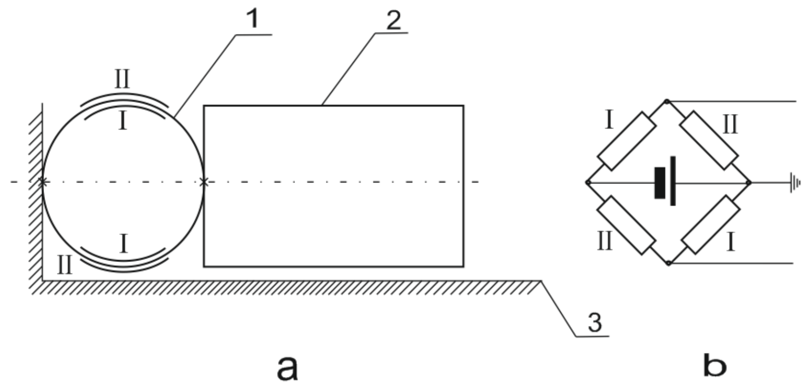

Fig. 11 Scheme of a sensor to measure acceleration

Deformation of tensometers causes the bridge balance to be disturbed. The voltage on the bridge output is proportional to the acting inertial force and thus proportional to the acting acceleration. The voltage is being first transferred to the amplifier and then to the loop of the loop oscillograph which is used to register the acceleration development depending on time.

The sensors have been used to measure acceleration in both real combinations and models allowing to make simple changes of the joint characteristics. The measurements confirmed the applicability of the theoretical relations and dependencies mentioned previously. Table 1 lists the values a_{max} and a'_{max} being compared and measured in a model combination and calculated for several variants.

Table 1 The values a_{max} and a'_{max}

Variant	a_{max} $[m/s^2]$		Error Δa_{max} [%]	a'_{max} $[m/s^2]$		Error $\Delta a'_{max}$ [%]
	Measured	Calculated		Measured	Calculated	
A	13,56	13,19	2,73	23,45	23,21	1,02
B	10,18	10,08	0,982	17,85	17,31	3,2
C	17,7	16,61	6,15	16,6	28,81	8,3
D	10,75	9,69	9,85	15,13	15,41	1,85
E	7,22	7,52	4,15	13,81	12,91	6,51

Summary

We have presented the method to tackle the issue of the trailer combination starting and procedures to determine the trailer maximum acceleration. When compared to lengthy and time - consuming calculations, the presented graphical method is profoundly advantageous as it is fast. For the joint types, the dependences a'_{max} on the vehicle – trailer combination characteristics are of importance. We can follow from the facts stated previously that a certain combination of characteristics, in particular unsprung or partially sprung joints as well as higher allowances ζ, can lead to higher acceleration rates of the trailer than those rates given by the adhesion condition. Hence, the condition is not sufficient to calculate the acceleration rates and the method presented in the paper should be applied.

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