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DISTRIBUTION OF BREAKING FORCES IN TWO-AXLE AGRICULTURAL TRAILERS

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Summary. The ways of detection of permissible values of the coefficient of linear distribution of braking forces in two-axle agriculture trailers according to the requirements of Regulation No. 13ECE are described in the paper. Criterion of calculation of the optimum distribution parameters which are helpful for the choice of the correctors of braking forces with linear characteristics is also presented. The example of the detection of the distribution boundary parameters for a trailer of loaded, unloaded and 4t capacity states is considered.

Key words: agricultural trailer, braking, requirements

INTRODUCTION

The regulations of agriculture vehicle homologation devoted to braking processes have improved since 2003 [Dyrektywa 2003/73/WE, Rozp. Min. Fin. Dz.U.04.5.31 2004]. So, the maximum permissible vehicle velocity was enlarged to 40 km/h, the value of minimum braking deceleration was enlarged to 4,5 m/s^2 and the requirements of usage of dual line coupling of tractor and trailer equipped in pneumatic brake system were also introduced. Since the following changes of regulations will be applied to agriculture trailers, at present, in the design process of trailers brake systems the requirements of Regulation No. 13 ECE are taken into account.

There are no concrete recommendations in the Regulation for the road set in which its each part could be regarded as an individual vehicle. To adjust the distribution of braking forces between the parts of the set, the compatibility band which presents acceptable range of changes of the braking rate of both tractor and trailer parts in function of air pressure in control line was defined.

When separating the set of vehicles composed of a tractor and two-axle trailer the forces in the coupler are ignored. So, ‘separated’ vehicles must meet the same requirements as the entire individual vehicle in a range of brake efficiency and forces distribution between the axles of a vehicle. The measure of the braking efficiency of a trailer is the braking rate z, expressed as the relation of the braking deceleration to the gravity acceleration. The minimum value of the braking rate of trailers z = 0.5 is correlated with the minimum required value of completely expanded deceleration of towed vehicles equal to 5 m/s^2. It seems the value of braking rate could be reduced to z = 0.45 for agricultural trailers towed by tractors.

In the process of the selection of braking forces distribution between trailer axles it is necessary to aim at an ideal distribution where indexes z_i of adhesion utilized by all axles are the same during the whole braking process, and therefore equal to the braking rate of the trailer z:

$$\frac{T_1}{R_1} = \frac{T_2}{R_2} = \ldots = \frac{T_i}{R_i} = z_i = z \tag{1}$$

where:

T_i – force exerted by the brakes on axle i,

R_i – normal reaction of road surface on axle i under braking.

Concerning the changeable degree of a trailer load, the obtaining of ideal distribution of braking forces is practically impossible, even if regulators of the braking forces are used. So, acceptable deviations of adhesion indexes of each axle from ideal distribution are presented in Regulation No. 13 ECE. The requirements to the trailers (categories O3, O4) for the detection of acceptable distribution of braking forces for agriculture trailers of categories R3, R4 and entire mass larger then 3.5 t are taken under consideration in the paper.

CACLULATION OF THE BASIC PARAMETERS OF THE DISTRIBUTION

Relative (concerning weight G of trailer) braking forces of front axle γ_1 and rear axle γ_2 are calculated from the dependence:

$$\gamma_1 = \frac{T_1}{G} = \frac{R_1 z_1}{G} = \left(\frac{b}{L} + \frac{h}{L} z\right) z_1 \qquad \gamma_2 = \frac{T_2}{G} = \frac{R_2 z_2}{G} = \left(1 - \frac{b}{L} - \frac{h}{L} z\right) z_2 \tag{2}$$

where:

T_1, T_2 – braking forces of front and rear axles,

R_1, R_2 – normal reaction of road surface on the front and rear axles of a vehicle:

$$R_1 = \frac{G}{L}\left(b + h \cdot z\right) \qquad R_1 = \frac{G}{L}\left(L - b - h \cdot z\right) \tag{3}$$

L – axel base of a trailer,

h – height of mass center location under the base,

b – distance of the mass center from the vertical plane which goes through the rear axle.

For ideal conditions of braking the adhesion utilized by both front and rear axles are the same and equal to braking intensity $z_1 = z_2 = z$, and the distribution of braking forces is defined by the following parametric equation:

$$\gamma_1 = \left(\frac{b}{L} + \frac{h}{L} z\right) z \qquad \gamma_2 = \left(1 - \frac{b}{L} - \frac{h}{L} z\right) z \tag{4}$$

The correctors of braking forces distributions with linear characteristic are used in pneumatic brake systems of trailers. The characteristic is described by the equation of the line which goes through the origin of coordinates and another point in the diagram of relative braking forces $\gamma_2 = f(\gamma_1)$. For instance, for straight line O-K which goes through point K$z_{K,}$ the intensity of braking (Fig. 1d), directional index is equal to:

$$i_K = \frac{\gamma_{2K}}{\gamma_{1K}} = \frac{1 - b/L - z_K \cdot h/L}{b/L + z_K \cdot h/L} \tag{5}$$

Using the dependence $\gamma = \gamma_1 + \gamma_2$, it is possible to describe for line O-K the distributions of relative braking forces for each axle with the help of the following parametric equation:

$$\gamma_1 = z \frac{1}{1 + i_K} \qquad \gamma_2 = z \frac{i_K}{1 + i_K} \tag{6}$$

for which quality coefficient z is the parameter. The index of adhesion utilized by axles on line O-K of the braking forces distribution is calculated form the formula:

$$z_1 = \frac{T_1}{R_1} = \frac{z}{\left(\frac{b}{L} + z\frac{h}{L}\right)(1 + i_K)} \qquad z_2 = \frac{T_2}{R_2} = \frac{i_K \cdot z}{\left(1 - \frac{b}{L} - z\frac{h}{L}\right)(1 + i_K)} \tag{7}$$

Since the straight line of constant distribution of braking forces goes through the origin of coordinates $\gamma_2 = f(\gamma_1)$, its directional index is calculated in each case from the relation of ordinate to abscissa of the present characteristic point.

THE REQUIREMENTS OF THE DISTRIBUTIONS OF BRAKING FORCES FOR TRAILERS OF R3 AND R4 CATEGORIES

The usage of two variants of the requirements for trailers of entire mass larger than 3.5 t is allowed by Regulation No. 13 ECE.

Solution 1. In the first solution the space limitations of relative braking forces are defined from both the condition of definition of required braking efficiency (braking rate):

$$z \geq 0{,}85 \cdot z_{1,2} - 0{,}07 \quad \text{dla} \quad z_{1,2} = 0{,}2 \div 0{,}8 \quad (z = 0{,}1 \div 0{,}61) \tag{8}$$

and the condition of directive efficiency maintenance, i.e. earlier blocking of the front axle wheels of trailer:

$$z_1 > z > z_2 \quad \text{dla} \quad z = 0{,}15 \div 0{,}30 \tag{9}$$

Graphic interpretation of the described recommendations is depicted by the lines AB and CD in Fig. 1a and Fig. 2a. Correspondent limitations of braking forces in the coordinates system γ_1-0-γ_2 for casually chosen trailer in its **unloaded** and loaded states are presented in Fig. 1b and Fig. 2b. Boundary curves are calculated by putting the adhesion indexes z_1, z_2 defined from conditions (8), (9) to the dependence (2). Coordinates of characteristic points and the equations of each curve in the system γ_1-O-γ_2 are described in detail in [Kamiński and Miatluk 2004].

Solution 2. In accordance with the second solution the indexes of adhesion utilized by axles must belong to the defined interval for z = 0,15÷0,30:

$$z - 0{,}08 \le z_1 \le z + 0{,}08 \qquad z_2 \le z + 0{,}08 \tag{10}$$

Besides, for z ≥ 0,3 the following condition must come true:

$$z \ge 0{,}3 + 0{,}74\left(z_{1,2} - 0{,}38\right) \tag{11}$$

The limits of the allowed range of adhesion indexes are delineated by lines MN and JKL in Fig. 1c and Fig. 2c. Correspondent ranges of relative braking forces concerning the second solution are shown in Fig. 1d for an unloaded trailer, and in Fig. 2d for a loaded one. Concerning the restrictive character of condition (11) for upper bound K'L' in diagram γ_2 = f(γ_1), the range of its validation to the interval z = 0,3÷0,61 is restricted, similarly as in [Syta 1979].

SELECTION OF THE PARAMETERS OF LINEAR DISTRIBUTION

The permissible range of change of directional coefficient $i = T_2/T_1$ of straight lines which form the constant distribution of braking forces is defined on the basis of space limits in the system γ_1-O-γ_2. It is necessary to define the parameters of braking forces distribution for both a loaded and unloaded vehicle.

In the first solution the range of permissible distribution of braking forces is marked from the top by OB' line which is in contact with boundary curve D'B' in point B', and from the bottom by line OS tangent to boundary line AB in point S (Fig. 1b, Fig. 2b). For other technical parameters of the trailer the point which defines the maximum value of directional coefficient of the line of constant distribution of the braking forces may be also point D.

If we use the second solution, the lower limit of permissible space is marked by the line tangent in point T to curve JK (Fig. 2d). If the tangent point T is placed out of segment JK of the boundary curve, then directional coefficient of the boundary line is defined from the coordinates of point K (Fig. 1d). The upper limit of the distribution of braking forces is marked by the line which goes through the point L' (Fig. 1d, Fig. 2d). For some vehicles it can be also point N.

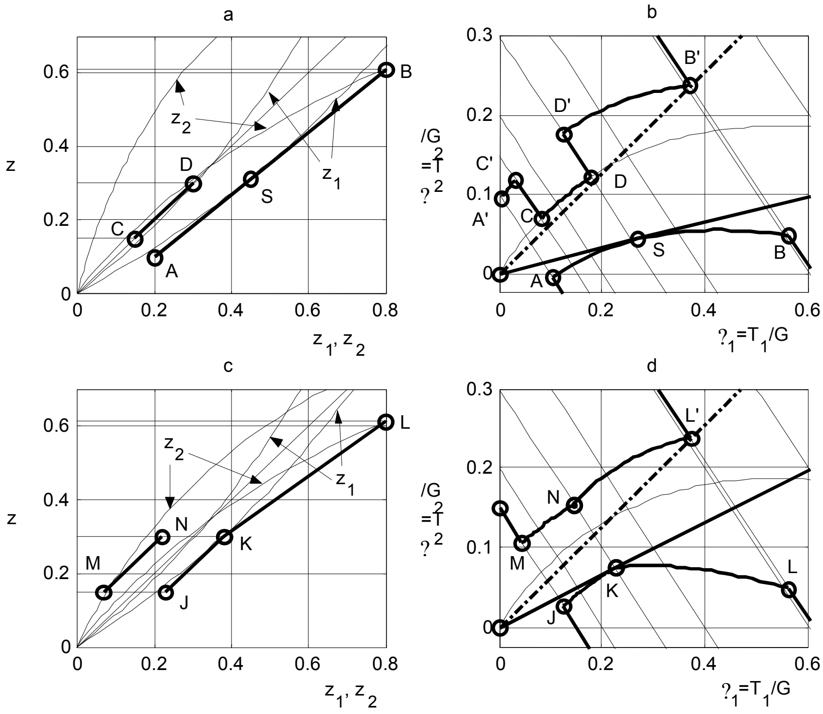

Fig.1. Determination of parameters of constant distribution of braking forces for an unloaded trailer of 1430 kg mass: a, c – runs of indexes of adhesion utilized by axles z_1, z_2; b – boundary values of the distribution coefficient according to solution 1; d – boundary values of the distribution coefficient according to solution 2; L = 2.35 m; b = 1.15 m; h = 0.82 m

Indexes of adhesion z_1, z_2 utilized by axles for boundary line of constant distribution of braking forces are calculated from the dependence (7) by putting in it the correspondent value of directional index and value of braking index for a given characteristic point. The runs of indexes for equations 1 and 2 are marked in Fig. 1, 2a, c.

Choosing the real distribution of braking forces $i = T_2/T_1$ it is necessary to aim at approaching the upper boundary line, that allow for a shorter stopping distance with simultaneous danger of earlier blocking of rear wheels in the range of intensity bigger than braking index value at intersection point of ideal distribution curve (4) and line of constant distribution.

In the process of searching the optimum value of directional coefficient of the line of breaking forces constant distribution, the criterion of maximization of average value of adhesion utilization coefficient $\zeta(\mu)$ on the defined interval of changes of adhesion coefficient between tyre and road (μ_1, μ_2) is used [Gredeskul *et al.* 1975]:

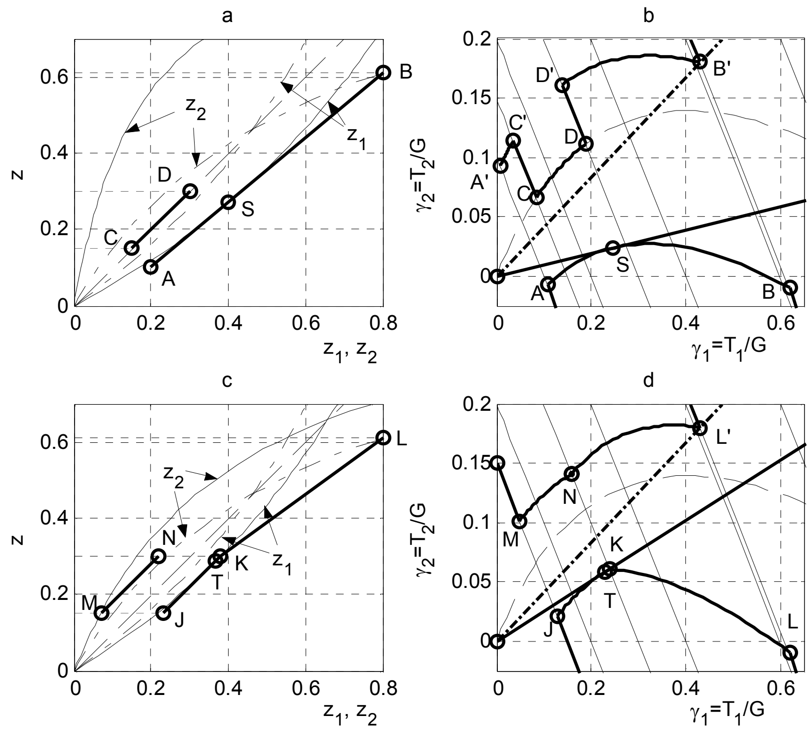

Fig. 2. Determination of parameters of constant distribution of braking forces for a loaded trailer of 5430 kg mass: a, c – runs of indexes of adhesion utilized by axles z_1, z_2; b – boundary values of the distribution coefficient according to solution 1; d – boundary values (limits) of the distribution coefficient according to solution 2; L = 2,35 m; b = 1,15m; h = 1,1 m

$$\zeta_{sr} = \frac{1}{\mu_2 - \mu_1} \int_{\mu_1}^{\mu_2} \zeta(\mu) d\mu \tag{12}$$

The optimum value of adhesion coefficient for this criterion is equal to:

$$\mu_{op} = \mu_1 + \frac{b}{L}(\mu_2 - \mu_1) \tag{13}$$

On this basis, it is easy to define the optimum value of the directional coefficient of braking forces constant distribution for both a loaded and unloaded trailer:

$$i_{op} = \frac{1 - b/L - \mu_{op} \cdot h/L}{b/L + \mu_{op} \cdot h/L} \tag{14}$$

by changing the values b/L and h/L correspondingly. It is possible to accept μ_1 = 0.2 and μ_2 = 0.45÷0.5 in the calculations for agricultural trailers. Obviously, the optimum line of constant distribution of braking forces must be in permissible area, marked by the boundary lines.

CONCLUSION

It is necessary to analyze the braking forces distribution of trailer for its different loaded states while selecting and forming the static characteristics of the devices which regulate and correct the braking forces distribution between the trailer axles.

The method of determination of permissible linear distribution of braking forces according to the requirements of Regulation No. 13 ECE and given criteria of optimum distribution, the searching described in the paper could be used for the design of pneumatic braking systems of trailers with braking forces correctors with linear characteristics. The adaptation of the same requirements of braking efficiency and stability to the agricultural trailers as to the automobile trailers will increase the safety of movement conditions of the truck-trailer road sets.

The application of the second variant of the requirements of Regulation No. 13 ECE for a given two-axle trailer results in fitting more efficiently the ideal characteristic, particularly for the axle adhesion index z_2.

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