## A METHOD OF SELECTION OF BRAKING FORCES DISTRIBUTION IN A ONE UNIT VEHICLE

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### INTRODUCTION

In order to raise the quality and efficiency of transport in the agricultural sector an increase of automobile transportation and, at the same time, the limitation of agricultural tractors and trailers usage is needed. An interesting alternative to the traditional agricultural tractor-trailer set is a technology, widely applied in the USA. This is the technology of lightweight semi-trailers with bow curved shaft of 'gooseneck trailers' type coupled by ball catch with passenger-cargo automobiles of pickup type [1]. During the exploitation time of such cars, the values of axle loads and the location of the mass centre change largely depend on the quantity and the character of the load ( a car is empty, loaded, coupled with trailer). At the same time it is practically impossible to meet the requirements of braking stability and efficiency with the constant (linear) distribution of braking forces retained. The aim of the paper is to analyse the breaking process of the passenger-cargo automobile from the point of view of the selection of linear-broken characteristics of the devices for braking forces correction.

While selecting the distribution of braking forces, it is necessary to tend to the ideal distribution. Theoretically, it takes place when the adhesion utilisation coefficients  $z_i$ , i.e. the ratio of the braking forces  $T_i$  acting on the wheels axis and the vertical reaction of the base  $R_i$ , equal to  $G_i$  axle load, are the same for all the car axes for the whole breaking process [2]:

$$\frac{T_1}{R_1} = \frac{T_2}{R_2} = \dots = \frac{T_i}{R_i} = \frac{\sum T_j}{\sum R_j} = \frac{a}{g} = z_i$$
(1)

Such distribution of breaking forces is recognised as optimal, when it is possible for the homogeneous pavement to fully use the adhesion forces and achieve the highest intensity of vehicle braking:

$$\left(\frac{a}{g}\right)_{\max} = \frac{\sum R_i \mu_{rz}}{\sum R_i} = \mu_{rz}$$
(2)

where:

 $R_1, R_2, ..., R_i$  – are vertical reactions of the road pavement to the wheels of the correspondent axis (N),

a – is the delay of the vehicle during the breaking process (m/s<sup>2</sup>),

g-acceleration of gravity,

 $\mu_{rz}$  – is the coefficient of the length-wise rebate adhesion.

# THE FORCES ACTING UPON THE TWO-AXIS VEHICLE DURING THE PROCESS OF THE IDEAL BREAKING

On the horizontal road the vertical reactions of the pavement to the wheels of the two-axis vehicle (fig. 1):

$$R_{1} = \frac{G}{L} \left( b + h \frac{a}{g} \right) \qquad \qquad R_{1} = \frac{G}{L} \left( L - b - h \frac{a}{g} \right) \tag{3}$$

depend on the intensity of breaking a/g presented in the form:



Fig. 1. The scheme of the forces acting upon the vehicle during the breaking process (rectilinear movement)

During the process of ideal breaking the coefficients of adhesion utilisation are the same and equal to the intensity of breaking  $z_1 = z_2 = a/g$ ; in the extreme case (with the maximum efficiency of breaking) they reach the boundary value equal to the rebate adhesion coefficient  $z_{1gr} = z_{2gr} = \mu_{rz}$ . It is possible to present the specific braking forces  $T_1/G$  and  $T_2/G$  expanded on the wheels of both the axes in the form of the dependence:

$$\frac{T_1}{G} = \frac{R_1}{G} \frac{a}{g} = \left(\frac{b}{L} + \frac{h}{L}\frac{a}{g}\right)\frac{a}{g} \qquad \qquad \frac{T_2}{G} = \frac{R_2}{G}\frac{a}{g} = \left(1 - \frac{b}{L} - \frac{h}{L}\frac{a}{g}\right)\frac{a}{g} \qquad (5)$$

The dependence presented above shows that both the ratio of the braking forces on the vehicle axis and the ratio of their boundary values  $T_{1gr}$  and  $T_{2gr}$  during the ideal breaking are not constant and depend on the intensity a/g:

$$\frac{T_2}{T_1} = \frac{L - b - h\frac{a}{g}}{b + h\frac{a}{g}} \qquad \qquad \frac{T_{2gr}}{T_{1gr}} = \frac{L - b - h\mu_{rz}}{b + h\mu_{rz}} \tag{6}$$

The changes of the specific reactions  $R_1/G$  and  $R_2/G$  and the specific braking forces  $T_1/G$  and  $T_2/G$  are presented in Fig. 2a.



Fig. 2. The changes of the breaking forces during the process of synchronic braking of a two-axis car: a) the change of the axel load and the specific braking forces; b) the dependence of the specific braking forces of back and front wheels; the parameters of the vehicle are: G = 15107.4; L = 2.51 m; b = 1.17 m; h = 0.7 m

The curve of the distribution of the braking forces according to the dependence (6) for the ideal breaking is presented in Fig. 2b. It delimits the diagram of the specific braking forces on the area of the earlier blocking of the front axis wheels (lower curve) and the area of the earlier blocking of the back axis wheels (upper curve). The same figure shows the constant ratio of the braking forces (straight line 0-b-c), with which the asynchronic braking takes place. The front axis will be over-braked on the 0-b interval and the back one will be over-braked on the *b*-*c* interval.

# THE PRINCIPLES OF BRAKING FORCES DISTRIBUTION OF A ONE UNIT VEHICLE

For the selection of the optimal braking forces distribution the following two conditions must be observed:

- a high degree of efficiency a/g, which corresponds to the short way of braking;

- the retention of movement stability of the vehicle while braking, i.e. the condition  $z_1 > z_2$  observed.

In order to avoid the back axis blocking (over-braking) with different values of rebate adhesion coefficient  $\mu_{rz}$ , the limits of stability bounds (line I in Fig. 3) [3], determined according to the condition of the ideal distribution of the specific braking forces, should not be exceeded (5). The approach to the ideal proportion of braking forces can be achieved by the application of the distribution in the form of a broken line 0-*b*-*c* (Fig. 2b). The switch from one linear characteristic (0-*b*) onto another (*b*-*e*) in braking point *b* takes place because of the application of the automatic regulators which are controlled by the pressure in the braking servo-motors or by the delay or another quantity. The limit of the permissible deterioration of effectiveness of braking in the  $0.2 \le a/g \le 0.8$  range (line II, Fig. 3) is determined according to the dependencies that come from Regulations table 13 ECE (first solution, Fig. 6), i.e.:

$$\frac{T_1}{G} = \frac{R_1}{G} z_1 = \left(\frac{b}{L} + \frac{h}{L}\frac{a}{g}\right) \left(\frac{a/g + 0.07}{0.85}\right) \qquad \frac{T_2}{G} = \frac{a}{g} - \frac{T_1}{G}$$
(7)

The minimal coefficient  $z_1$  of the adhesion utilisation on the wheels of the front axis, which is expressed by the ratio of the circumferential force  $T_1$  to the axle load  $R_1$  is  $z_1 = (a/g+0.07)/0.85$ .



Fig. 3. The range of the permissible linear coefficients of braking forces distribution (the data of the vehicle from Fig. 2)

It comes from the dependence (7) that for a given range of the intensity of braking (a/g) the blocking of the wheels of the front axis takes place before the back axis wheels blocking, i.e.  $z_1 > a/g > z_2$ . With the constant distribution of braking forces being used, the distribution line must be situated between boundary curves I and II; moreover, it should tend to the upper curve.

In order to determine the broken-linear distribution of the braking forces it is necessary to determine the changes of the ideal distribution of the braking forces for both loaded and unloaded vehicle (Fig. 4) using the equations (5). It is also necessary to define the location of the points of the breaks of the characteristics and the directional equations of separate straight lines.



Fig. 4. The distribution of braking forces in the form of a continuous line (ideal distribution) and a linear broken approximation line (the data for the empty vehicle is on fig. 2; for the loaded vehicle: G = 21582 N, b = 1.2 m, h = 0.9 m)

The location of point *b* of the break of the characteristic for the loaded vehicle is searched for by the minimisation of the surface area between the curve of the ideal distribution and the broken line 0-*b*-*e* (Fig. 2). On the basis of the criterion it was found out that the intensity of breaking in point *b* is equal to half of the intensity of braking in point *d* of straight-line *b*-*e* intersection with the curve of the ideal distribution of the braking forces  $(a/g)_b = 0.5 (a/g)_d$ . The presented above solution has a simple geometric interpretation – the tangent to the curve of the ideal distribution of the braking forces in point *b* is parallel to the straight-line, which goes through points 0 and *d*.

After the assumption of the maximal intensity of braking  $(a/g)_{\text{max}}$  which corresponds to point *d* (Fig. 2) the intensity of braking  $(a/g)_b = 0.5(a/g)_{\text{max}}$  in point *b* of the break of the characteristic and the braking forces corresponding to the point are calculated:

$$T_{1b} = G\left[\frac{b}{L} + \frac{h}{L}(a / g)_b\right](a / g)_b \qquad T_{2b} = G\left[1 - \frac{b}{L} - \frac{h}{L}(a / g)_b\right](a / g)_b \quad (8)$$

On that base the directivity factor of line 0-*b* as equal to the braking forces distribution  $i_1 = T_{2b}/T_{1b} = tg\alpha_1$  is determined as follows:

$$i_{1} = \frac{T_{2b}}{T_{1b}} = \frac{(L-b) - h(a/g)_{b}}{b + h(a/g)_{b}}$$
(9)

Consequently, in the range of the changes of intensity  $0 \le (a/g)_{ob} \le (a/g)_b$  the breaking forces are calculated basing on the dependence



Fig. 5. The diagram of indexes of the intensity of axis braking with the linear-broken ratio of braking forces and the linear ratio for the loaded vehicle

The breaking forces  $T_{1d}$  and  $T_{2d}$  in point *d* are calculated on the basis of the equation (5) of the ideal distribution of breaking forces for the intensity of breaking equal to  $(a/g) = (a/g)_{a} = (a/g)_{max}$ :

$$T_{1d} = G \left[ \frac{b}{L} + \frac{h}{L} (a/g)_{\max} \right] (a/g)_{\max}$$

$$T_{2d} = G \left[ 1 - \frac{b}{L} - \frac{h}{L} (a/g)_{\max} \right] (a/g)_{\max}$$
(11)

On segment *b*-*d* the breaking forces  $T_{1bd}$  and  $T_{2bd}$  are determined by the dependencies:

$$T_{1bd} = G\left(\frac{a}{g}\right)_{bd} \frac{1}{1+i_2} \quad T_{2bd} = G\left(\frac{a}{g}\right)_{bd} \frac{i_2}{1+i_2}$$
(12)

where the intensity of breaking  $(a/g)_b \le (a/g)_{bd} \le (a/g)_d$  and the value of the coefficient  $i_2$  of the distribution of the breaking forces is calculated basing on the example:

$$i_2 = \operatorname{tg} \alpha_2 = \frac{T_{2d} - T_{2b}}{T_{1d} - T_{1b}} = \frac{0.5(L - b) - 0.75h(a / g)_{\max}}{0.5b + 0.75h(a / g)_{\max}}$$
(13)

achieved after the assumption  $(a/g)_b = 0.5(a/g)_d = 0.5(a/g)_{max}$ .

For the verification of the parameters of the linear-broken characteristic for the unloaded vehicle the identical values of coefficients  $i_1$  and  $i_2$  are accepted. It is also accepted that point d' of the intersection point of straight line b'-e' with the curve of the ideal distribution corresponds to the same maximal intensity of breaking as in the case of the loaded vehicle. At the same time, it determines the location of straight-line b'-e' in the system of coordinates and allows finding point b' of the break of the characteristic for an empty vehicle as the point of intersection of straight-line 0-b' with straight-line b'-e'.

The selected linear-broken distribution of breaking forces should be checked in accordance with the requirements of Regulation Table 13 ECE. According to the second solution for the personal-cargo cars (group N1) the coefficients of adhesion utilisation of the wheels of the front axis  $z_1$  and the back axis  $z_2$  in the range of the breaking intensity  $0.15 \le a/g \le 0.5$  must be located in a certain segment (Fig. 6):

$$z_1 \ge \frac{a}{g} - 0.08 \qquad z_2 \le \frac{a}{g} + 0.08 \tag{14}$$

For intensity  $a/g \ge 0.5$  the following condition is valid (Fig. 4):



$$z \le 2\frac{a}{g} - 0.42 \tag{15}$$

Fig.6. The boundary values of adhesion utilisation according to Regulation table 13 ECE

For the verification of the requirements (14) and (15) it is necessary to calculate the breaking forces  $T_1$  and  $T_2$  for the selected proportions  $i_1$  and  $i_2$  in the function of intensity a/g according to the dependencies (10) and (12). Next, the dependencies  $z_1$  and  $z_2$  are determined on the basis of expression (3):

$$z_{1} = \frac{T_{1}}{R_{1}} = \frac{a/g}{\left(\frac{b}{L} + \frac{h}{L}\frac{a}{g}\right)(1+i)} \qquad z_{2} = \frac{T_{2}}{R_{2}} = \frac{a/g}{\left(1 - \frac{b}{L} - \frac{h}{L}\frac{a}{g}\right)(1+i)}$$
(16)

The diagrams of the coefficients  $z_1 = f_1(a/g)$  and  $z_2 = f_2(a/g)$  of adhesion utilisation achieved for the loaded vehicle as well as for the empty vehicle are not to over-cross the boundary lines shown in Fig. 4.

Figures 5 and 6 show the results of the calculations of the selection of breaking forces distribution according to the linear and linear-broken characteristics for the personal-cargo car. Basing on Figure 5, it can be assumed that for the linear breaking forces distribution lines  $z_1$  and  $z_2$  for the loaded vehicle exceed the permissible limit (the dot line). It means that for a given car the stable breaking forces distribution between the front and the back axis cannot be applied. The application of the linear-broken distribution (the full line and the dashed line) makes it possible to achieve the higher intensity of breaking meeting at the same time the requirements of Regulation table 13 ECE.

### CONCLUSION

The analysis of the ideal breaking forces distribution of the two-axis car proved that in most cases the selection of the linear breaking forces distribution, which meets the requirements of Regulation table 13 ECE, is impossible. The linearbroken distribution of the breaking forces can meet the requirements; in its turn, it requires the application of the automatic regulators of the breaking forces in the breaking systems. The method of the selection of the optimal breaking forces distribution presented in the article was used for the determination of the linear-broken characteristic of the corrector for the personal-cargo car of the pick-up type.

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#### SUMMARY

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The article presents an analysis of the ideal breaking forces distribution of a one-unit tractor. A method of the selection of the linear-broken distribution of the breaking forces is described. There are also the results of the calculations of the parameters of the breaking forces distribution for the personal-cargo cars of the pick-up type, which are used in agriculture.