IDENTIFICATION OF STATIC CHARACTERISTICS
OF A PNEUMATIC REGULATOR
OF BRAKING FORCES IN VEHICLES

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Summary. A method of identification and determination of static characteristics of an automatic regulator of braking forces in a vehicle is presented in the paper. Theoretical and experimental static characteristics of a regulator were defined. The results of the experiment were presented in the form of the function of the control lever position of a regulator. Comparison and analysis of theoretical and experimental characteristics in braking-reverse-braking process were carried out.

Key words: pneumatic brake systems, regulator of braking forces in vehicles

INTRODUCTION

Pneumatic braking systems are mainly implemented in buses, trucks, truck-trailer and truck-semi-trailer vehicles. During exploitation period of such automobiles the values of pressure on the axles and location of mass center are changing widely. It is connected with the weight and character of load and with the intensity of vehicle braking. To obtain high efficiency of braking and retain stability of movement automatic regulators of brake forces are used.

6120 regulator produced in Polmo Prashka [1996] is an example of an automatic regulator of braking force, located in the circuit of truck back wheels (Fig.1). The regulator is controlled mechanically by lever 8. It is possible to change the angle of the lever position by fixing the lever end to the back axel of a vehicle, and regulator cover to vehicle chassis. So, the value of an angle of the lever position is the function of the vehicle load. The characteristics of this regulator (Fig.1c) is radial. For the defined position of lever 8 the relation of pressure in terminal 1 (pressure in the circuit of front wheels) and pressure in terminal 2 (pressure in the circuit of back wheels) is constant. The smaller the load of the back axle, the bigger the reduction of pressure [Biedrzycki 1995, Katalog 1996, Łomako *et al*. 2002].

The aim of the work is the theoretical and experimental determination of static characteristic of an automatic regulator of braking force and mathematical description of

the regulator. The availability of this characteristics is necessary for the choice of the proper regulator and determination of its location in any vehicle.
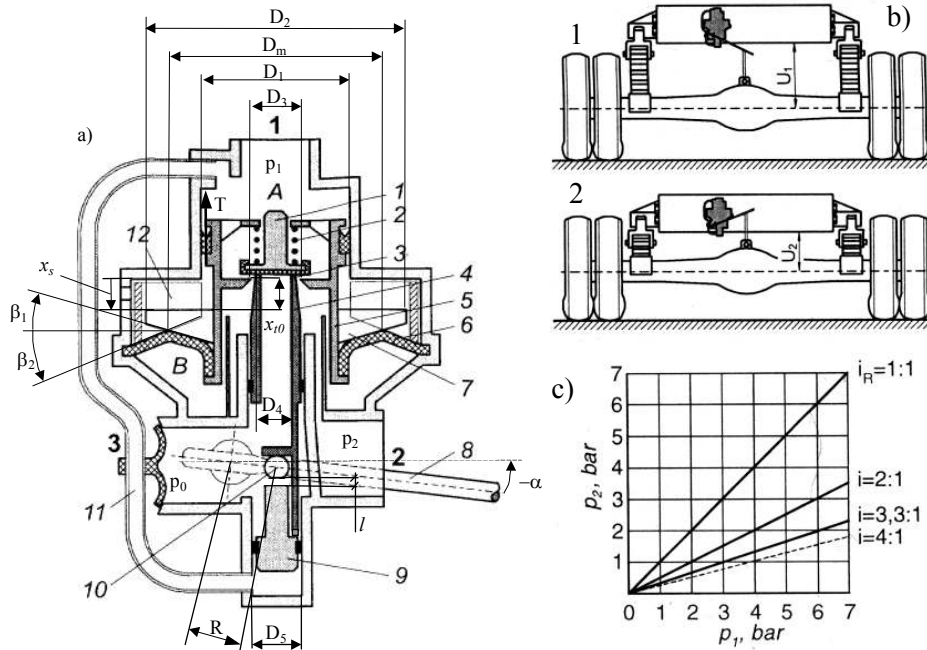

Fig. 1. Automatic regulator of brake force: a) the construction: 1 – valve; 2 – spring; 3 – passage; 4 – pusher; 5 – piston; 6 – membrane; 7 – ribs of piston 5; 8 – lever; 9 – piston; 10 – ball pin; 11 – tube; 12 – insert with inner ribs; b) deflexion of suspension for: 1 – unloaded truck; 2 – loaded truck; c) characteristics of regulator for different angles of lever position: p_1 – pressure in input terminal, p_2 – pressure in output terminal [Łomako *et al.* 2002]

METHOD OF RESEARCH

Exploration of the regulator was performed for different angle positions of lever 8 (Fig.1) ($\alpha = 0$ – horizontal position of lever). 6 repetition of measuring were carried out in each position. Runs of pressures p_1 and p_2 in receivers 5 and 7 were registered by standard programs of recorder MC201A.

The example registered run $p_2 = f(p_1)$ is presented in Figure 3. It is composed of three parts: I – filling of 5 and 7 receivers (Fig.2) (process of vehicle braking), and II,III – vacation of receivers (reverse-braking process). It was observed, that for $\alpha < 170$, registered runs have the character presented in Figure 3 and differ only by the degree of pressure p_2 reduction, and therefore by inclination angle of lines I and III. In case of $\alpha < 170$ angles the lines I and III are crossed and $p_1 = p_2$ for the whole run. It indicates that the regulator valve is completely opened.
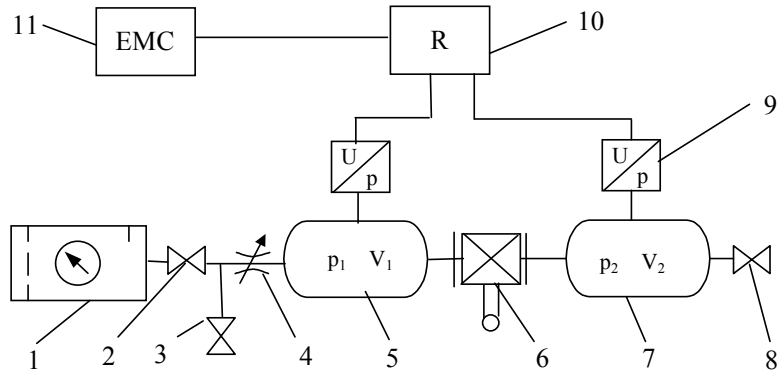
Fig. 2. Scheme of the testing stand: 1 – air preparation station; 2,3,8 – separating ball valve QH/4,
5,7 – air receivers; 4 – throttle, 6 – regulator 6120, 9 – pressure converter P15RV1/10B,
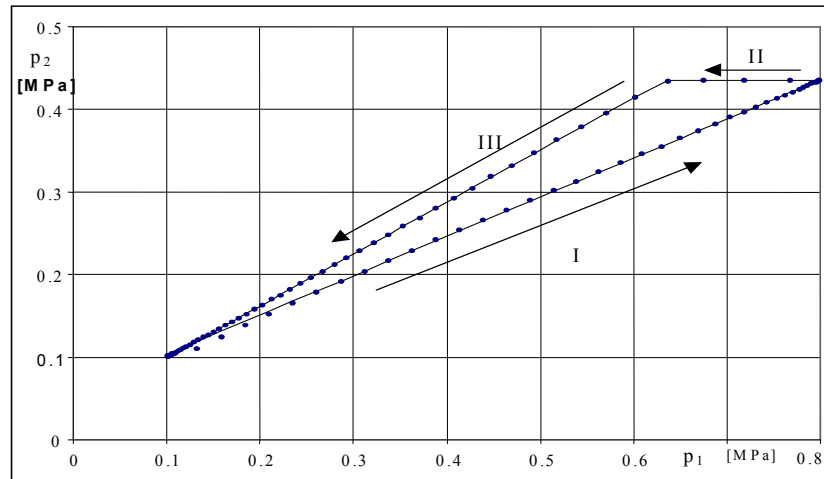10 – recorder MC201A, 11 – computer

Fig. 3. Registered experimental pressure run and approximated run for lever position $\alpha = 0$
(each 20th point is presented)

It is possible to approximate the presented run by the following lines:

$$I - p_2 = A\, p_1 + B$$
$$II - p_2 = C \tag{1}$$
$$III - p_2 = D\, p_1 + E.$$

The equations coefficients $A..E$ depend on an angle position α of the regulator lever, and therefore on the vehicle load. Average values of the obtained coefficients for each angle positions of the lever are presented in Table 1.

The obtained results were used for the determination of general dependencies $A(\alpha)...E(\alpha)$ as the function of the angle position of the regulator lever. In the case of functions $B(\alpha)$ and $A(\alpha)$ the polynomial of third degree was accepted, which resulted in the following functions and correlation coefficients R^2:

$$B(\alpha) = 1.762 \cdot 10^{-6} \alpha^3 - 3.898 \cdot 10^{-5} \alpha^2 - 1.762 \cdot 10^{-3} \alpha + 5.646 \cdot 10^{-2} \qquad R^2 = 0.98$$
$$E(\alpha) = 9.349 \cdot 10^{-7} \alpha^3 - 5.815 \cdot 10^{-6} \alpha^2 - 1.812 \cdot 10^{-3} \alpha + 3.312 \cdot 10^{-2} \qquad R^2 = 0.99$$
(2)

Table 1. Average values of coefficients of functions which describe the static characteristics in different angle positions of control lever

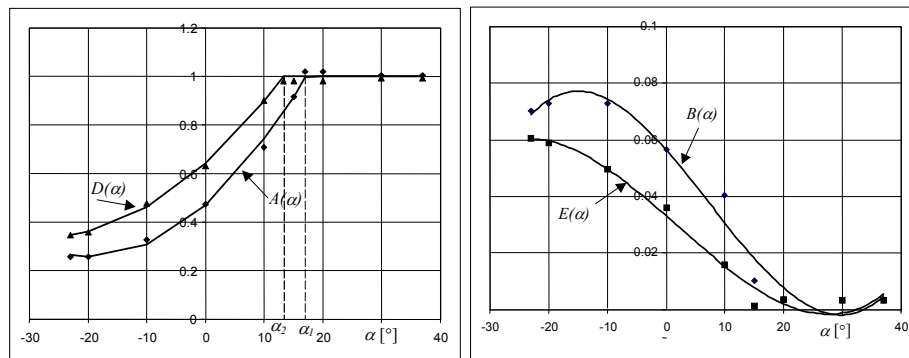| α [°]	A [°]	B	C	D	E
-23	0.2574	0.07009	0.2754	0.3469	0.06062
-20	0.2581	0.07289	0.2779	0.3567	0.05888
-10	0.3280	0.07280	0.3243	0.4762	0.04949
0	0.4741	0.05672	0.4276	0.6291	0.03599
10	0.7064	0.04024	0.5711	0.9011	0.01574
15	0.9135	0.01035	0.6973	1.0132	0.001366
20	1.0182	0.003661	0.4581	0.9814	0.003661
30	1.0056	0.003198	0.5749	0.9916	0.003198
37	1.0056	0.003210	0.4218	0.9918	0.003210

Fig. 4. The runs of functions $A(\alpha)$, $B(\alpha)$, $D(\alpha)$, $E(\alpha)$ and experimental points (Tab.1)

Functions $A(\alpha)$ and $D(\alpha)$ are described by complex functions consisting of polynomial of second degree and constant value, obtaining the following dependences:

$$A(\alpha) = \begin{cases} 5{,}498 \cdot 10^{-4} \, \alpha^2 + 2{,}155 \cdot 10^{-2} \, \alpha + 4{,}700 \cdot 10^{-1} & \text{for} \quad -23° \leq \alpha < \alpha_1 \\ 1.0 & \text{for} \quad \alpha_1 \leq \alpha \leq 37° \end{cases} \quad R^2 = 0.99 \qquad (3)$$

$$D(\alpha) = \begin{cases} 3{,}840 \cdot 10^{-4} \, \alpha^2 + 2{,}168 \cdot 10^{-2} \, \alpha + 6{,}418 \cdot 10^{-1} & \text{for} \quad -23° \leq \alpha < \alpha_2 \\ 1.0 & \text{for} \quad \alpha_2 \leq \alpha \leq 37° \end{cases} \quad R^2 = 0.99$$

where:

α_1 and α_2 are values of angle position of the lever, for which the character of functions $A(\alpha)$ and $D(\alpha)$ changes.

The values of the angles for runs described by equations (3) are $\alpha_1 = 17.1°$ and $\alpha_2 = 13.5°$ correspondingly.

DESCRIPTION OF STATIC CHARACTERISTICS OF A REGULATOR

The obtained runs of static characteristics (Fig. 3) and parameters runs (Fig. 4), which describe the change of the characteristics depending on lever angle position, are closely connected with the regulator construction and its geometric parameters. To determine theoretical runs of static characteristics it is necessary to analyse the work of the regulator in the case of filling and vacation of receivers 5 and 7 (Fig. 2).

In the case of filling, the airflow goes from terminal 1 through compartment A, next through passage 3 to compartment B, and afterwards to output 2 and receiver 7. The flow through the regulator takes place till the pressures on input p_1 and output p_2 reach such values at which terminal 3 closes. The values of the pressures depend closely on the diameter D_m of the membrane adhesion and therefore on the angle position of lever 8 and vehicle load. In the case of pressure falling on input 1, piston 5 displaces up and there appears a passage from compartment B to atmosphere through pin 4, with simultaneous close of the passage between compartments A and B. Such valve construction allows quick exhaust of the cylinders of the back lever of a vehicle.

It is possible to define the theoretical static characteristics of the regulator tested on the basis of an equation of the balance of forces which act on piston 5 while braking (pressure p_1 increases $\dfrac{dp_1}{dt} > 0$):

$$p_a(S_{m1} - S_1) - T - F_{S0} + p_1(S_1 - S_3) - p_2(S_{m1} - S_3) = 0 \qquad (4)$$

and for reversal braking (pressure p_1 decreases $\dfrac{dp_1}{dt} < 0$)

$$p_a(S_{m2} - S_1) + T + p_1 S_1 - p_2(S_{m2} - S_4) - p_a S_4 = 0 \qquad (5)$$

where:

S_1, S_2, S_3, S_4 – squares of the surfaces regulator elements with diameters $D_1, D_2, D_3, D_4,$

T – friction force which acts on piston 5,

p_a – atmospheric pressure,

F_{s0} – initial pressure of spring 2 ,
S_{m1}, S_{m2} – working field of membrane surface and piston for braking and reverse braking, correspondingly.

The change of the size of the working surface of the regulator membrane during the change of airflow direction is connected with the size of clearance between pusher 4, piston 9 and ball pin 10. After equations (4) and (5) are transformed we have:

$$p_2 = \frac{S_1 - S_3}{S_{m1} - S_3} p_1 + \frac{1}{S_{m1} - S_3} (p_a(S_{m1} - S_1) - T - F_{S0}) = 0 \qquad \text{dla} \qquad \frac{dp_1}{dt} > 0 \qquad (6)$$

$$p_2 = \frac{S_1}{S_{m2} - S_4} p_1 + \frac{1}{S_{m2} - S_4} (p_a(S_{m2} - S_1 - S_4) + T) = 0 \qquad \text{dla} \qquad \frac{dp_1}{dt} < 0 \qquad (7)$$

It is possible to define the value of active diameter of membrane in the cases of braking and reverse braking by the following expressions:

$$D_{m1} = D_1 + \frac{2x_{s1}}{\tan(\beta_1) + \tan(\beta_2)} \qquad\qquad D_{m2} = D_1 + \frac{2x_{s2}}{\tan(\beta_1) + \tan(\beta_2)} \qquad (8)$$

where:
β_1, β_2 – inclination angle of piston wings and ribs of insert,
x_{s1}, x_{s2} – piston position (Fig. 1).

The following dependencies define piston 5 position taking into account the angle position of lever 8 and clearance value l:

$$x_{s1} = R\sin(\alpha_1) - R\sin(\alpha) \qquad\qquad \text{dla} \qquad \frac{dp_1}{dt} > 0$$
$$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (9)$$
$$x_{s2} = R\sin(\alpha_1) - l + R\sin(\alpha) \qquad\qquad \text{dla} \qquad \frac{dp_1}{dt} < 0$$

where:
α_1 – value of angle position of the lever at which complete opening of a regulator occurs (Fig. 4).

Working diameters D_{m1} and D_{m2} of the membrane are defined by expressions (8) and (9) and are restricted by the conditions which result from the construction of a regulator:

$$D_1 < D_{m1} < D_2 \qquad\qquad D_1 < D_{m2} < D_2 \qquad (10)$$

Theoretical values of coefficients appearing in equation (1) were defined on the basis of the dependencies (6) and (7):

$$A_t(\alpha) = \frac{S_1 - S_3}{S_{m1} - S_3} \qquad\qquad B_t(\alpha) = \frac{1}{S_{m1} - S_3} (p_0(S_{m1} - S_1) - T - F_{S0}) \qquad (11)$$

$$D_t(\alpha) = = \frac{S_1}{S_{m2} - S_4} \qquad E_t(\alpha) = \frac{1}{S_{m2} - S_4}(p_0(S_{m2} - S_1 - S_4) + T) = 0 \qquad (12)$$

Experimentally determined (Tab.1) values of coefficients $A_t(\alpha)$ and $D_t(\alpha)$ and their theoretical runs are presented in Figure 5. Calculations were made for the following values: $D_1 = 47$ mm, $D_2 = 87$ mm, $D_3 = 16$ mm, $D_4 = 12$ mm, $D_5 = 15$ mm, $R = 11$ mm, $l = 1.2$ mm, $\beta_1 = 11.6°$, $\beta_2 = 7.7°$, $F_{S0} = 8.2$ N, $T = 2.7$ N.

A high model accordance in case $\dfrac{dp_1}{dt} > 0$ (vehicle braking) was observed. In the case of $\dfrac{dp_1}{dt} < 0$ the accordance is lower, particularly in the range of angles $00 < \alpha < 100$. It is connected with a partial displacement of pusher 4, and therefore incomplete using of clearance value l.
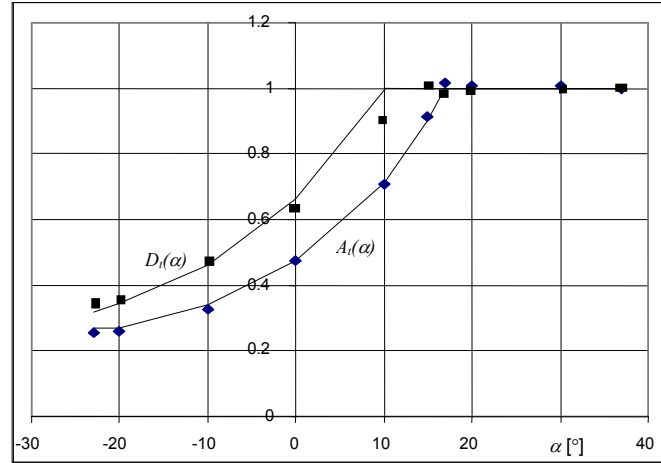

Fig. 5. Runs of theoretical functions $A_t(\alpha)$ and $D_t(\alpha)$ of coefficients of static characteristics and experimental points (Tab. 1)

CONCLUSION

Insensitivity area of an automatic regulator of braking forces plays an important role in general static characteristics of a braking system in two-direction process of brak-ing-reverse-braking. Static characteristics of a regulator which appear in publications do not contain hysteresis and refer only to the braking process. It makes it impossible to define the exact static characteristics of the whole braking system of a vehicle during braking-reverse-braking process. The results of the research permit, however, to analyse the process as a whole and define the optimum parameters of a braking system regulator in different types of vehicles (trucks, truck-trailers and truck-semi-trailers). While choos-ing this regulator it is also necessary to take into account its flow capacity, which affects

dynamic characteristic of the braking circuit and therefore the speed of braking system work.

The mathematical model of static characteristics presented in the paper permits to analyze the regulator with real constructive parameters, and also allows the choice of optimum values in the case of constructing a new type of a regulator for a braking system of a particular vehicle.

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