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ELEMENTS OF PNEUMATIC SUSPENSION SYSTEM OF RAIL-BUS

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Summary: *The present paper considers the elements of pneumatic suspension system of rail-vehicle as a part of rail-bus pneumatic system. The paper presents a mathematical model of a part of pneumatic suspension system. The dynamic properties of the model are analyzed to make the right selection of control parameters. The experimental results are also given for the double non-return valve due to its strongly non-linear properties.*

Introduction

In this work there have been considered elements of auto-rail vehicle pneumatic suspension system as a part of auto-rail vehicle pneumatic installation system (rail bus) - Fig.1

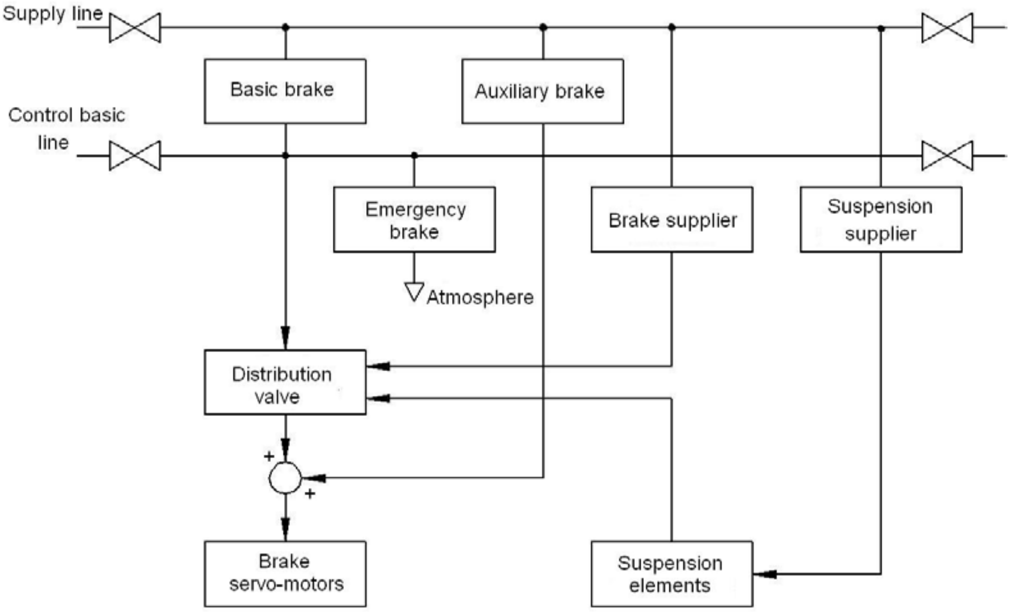

Fig. 1. Basic elements of pneumatic installation

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A theoretical description of pneumatic characteristics poses many calculation problems. The complexity of the mathematical model mainly concerns the flexible and non-linear control elements. The problem areas cover:

- considerable deformation and translocation of the working element of pneumatic spring,
- load asymmetry,
- very diverse external temperature conditions,
- undetermined conditions of flow between the tanks.

The construction of adequate mathematical models is to allow for the right selection of the construction parameters of the system and for defining their effect on the following pneumatic suspension system properties:

- damping properties of the suspension,
- dynamic action of the system (evaluation of smoothness of operation),
- vehicle stability,
- potential active control of selected parameters of the pneumatic system (pressure and air flows through selected elements).

The system diagram presented in Fig. 2 shows that the module is a pneumatic cascade which consists of flexible chamber (semitoroidal) and rigid chamber. The system involves two such modules joined with a double non-return valve. The signal from the rigid chamber of higher pressure is transferred to the braking system. The signal is the information on the vehicle load in the place of the axis investigated. Both branches are supplied from the pneumatic system with two inlet control valves.

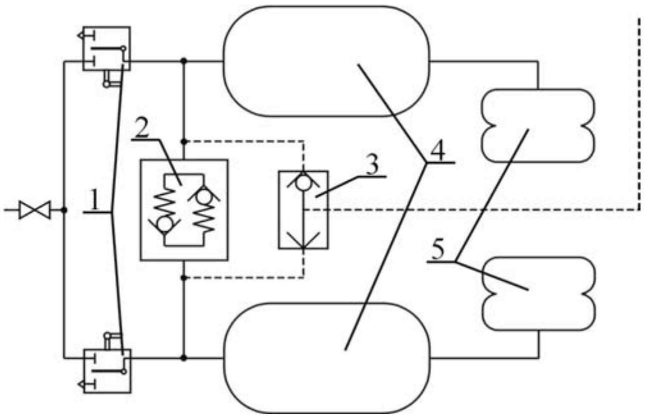

Fig. 2. Elements of pneumatic suspension system of the truck: 1 – inlet control valve, 2 – double non-return valve, 3 – logic OR valve, 4 - rigid chamber, 5 – flexible chamber

The construction of the mathematical spring model is based on introducing the term of the so-called pneumatic capacity C as an equivalent of capacitance. The numerical value of the pneumatic capacity C acts as a factor of proportionality between the mass flow rate Q_m and the rate of pressure changes $\mathrm{d}p/\mathrm{d}t$ in the suspension cushion chamber (Fig. 2).

$$Q_m = C\frac{\mathrm{d}p}{\mathrm{d}t} \tag{1}$$

The pneumatic capacity during work can be treated as the sum of two capacities: constant and changeable.

$$C = C_0 + \Delta C \tag{2}$$

The constant part is closely connected to the gas equation of state while assuming polytropic gas compression

$$C_0 = \frac{V}{nR_p\Theta} \tag{3}$$

The changeable part is defined using the following formula:

$$\Delta C = \frac{A^2 \rho}{c} - f(F_{zew}), \tag{4}$$

where: A working area of the flexible chamber bottom, c chamber rigidity, ρ air density, $f(F_{zew})$ component incorporating the outflow of external forces.

Flow through the double non-return valve

Another difficulty is defining the model of air flow through pneumatic valves and between tanks. The flow through the inlet control valve can be of special importance as it is a slide valve, its characteristics are strongly non-linear and the mathematical model adopted must be confirmed by experiments. The present paper offers a preliminary linearised model of flow and inlet control valve as well as the characteristics of double non-return valve.

Air balance in the double tank system with a valve

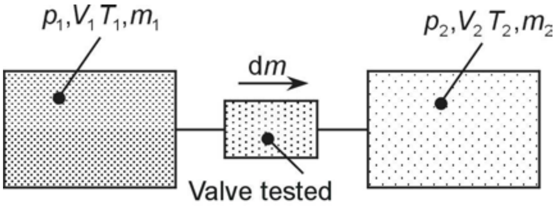

Fig. 3. Working diagram for theoretical analysis

The theoretical analysis of the system tested is based on the assumption that during examinations the system is hermetic and so the mass of the air contained in both pressure tanks, connecting pipes, and the valve is constant, which can be expressed with the following equation:

$$m_1 + m_2 = const \tag{5}$$

where: m_1 – the total mass of the air in the left tank together with the accessories, m_2 – the total mass of the air in the right tank together with the accessories,

which after differentiating of both equation sides, becomes

$$\mathrm{d}m_1 + \mathrm{d}m_2 = 0 \tag{6}$$

Equation (6) is, in fact, the law of conservation of mass in differential form, concerning the system examined.

Mass of the air $m_i \quad i = 1,2$, in the tanks is defined with the Clapeyron equation

$$p_i V_i = m_i R_i' T_i \quad i = 1,2 \tag{7}$$

where: $p\,[\mathrm{Pa}]$ – pressure in the tank, $V\,[\mathrm{m}^3]$ – tank volume, $T\,[\mathrm{K}]$ temperature in the tank, $R' = 287\ \mathrm{J/(kg \cdot K)}$ air gas constant.

In further analysis a simplified assumption was made that the values of thermodynamic properties V_i, R_i', T_i in both tanks are constant.

Hence

$$\mathrm{d}m_i = \frac{V_i}{R_i T_i} \mathrm{d}p_i \quad i = 1,2 \tag{8}$$

After substituting equation (8) into equation (6), we obtain

$$\frac{V_1}{R_1 T_1} \mathrm{d}p_1 = -\frac{V_2}{R_2 T_2} \mathrm{d}p_2 \tag{9}$$

Equation (9) proves that ha pressure changes in respective tanks are symmetrical.

If we consider time interval $\langle t_i, t_{i+1} \rangle$, then the ratio mass change Δm in a tank to time interval Δt_i gives the spot flow rate Q_m:

$$Q_m = \frac{m_{i+1} - m_i}{t_{i+1} - t_i} \tag{10}$$

The tank air mass is defined with

$$m = \frac{V}{R'T} (p_i + p_{atm}) \tag{11}$$

With the spreadsheet it is possible to define the characteristics in question.

Research stand

The research stand was developed based on two air tanks between which the component examined was placed. Each tank can be supplied with compressed air.

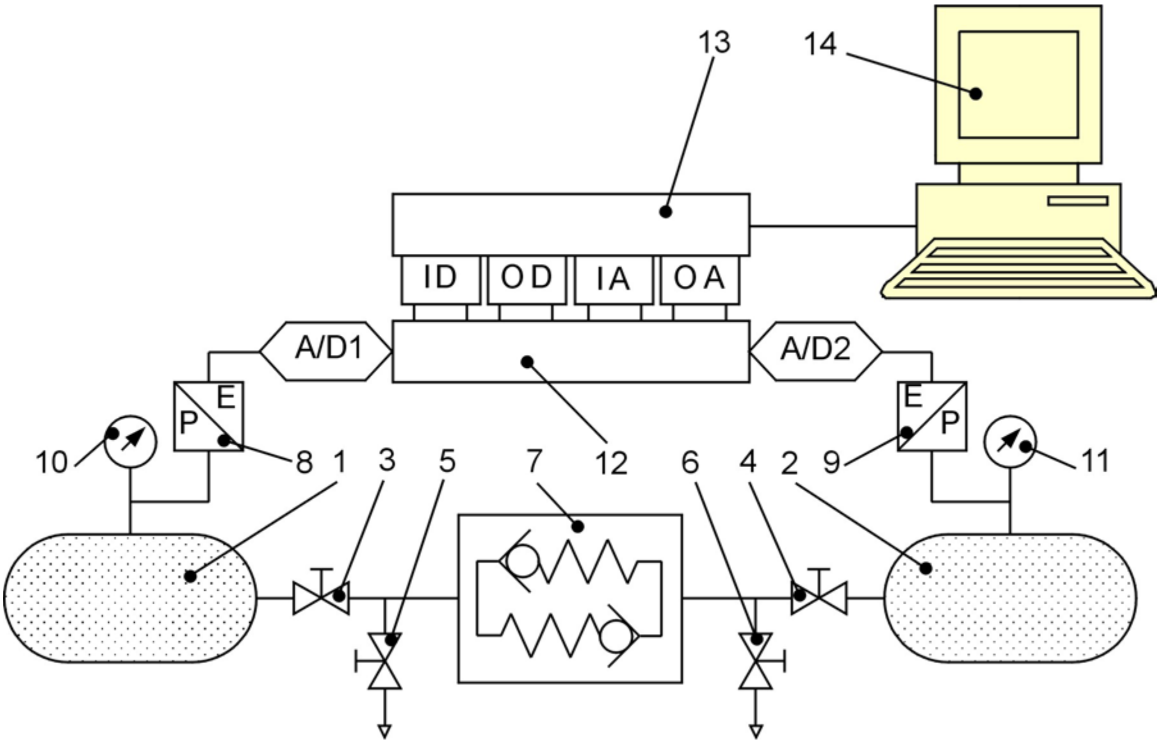

Fig. 4. Research stand diagram

1, 2 – pressure tank, $0{,}24\ \mathrm{m}^3$ each,
3, 4 – cut-off valve,
5, 6 – release valve,
7 – component examined, here double non-return valve,
8, 9 – pressure converter
10, 11 – precise measurement manometer,
Data acquisition equipment
12 – PCLD – 87 10 Terminal Wiring Board by Advantech

13 – PCI –1710 series 12/16 Multifunction CARD
14 – Personal computer with software Geni DAQ and Excel spreadsheet
ID - digital input, OD – digital output, IA – analogue input, OA – analogue output

Measurements results

The research concerned the double non-return valve given in Fig. 2, item 2, since the properties of rail-bus moving along the curved railway track and in case of uneven distribution of load depend on the valve parameters.

The pressure drops were measured in tanks for the flow from tank no 1 to tank no 2 (left chart in Fig, 5) and from 2 to 1 (right chart in Fig. 5).

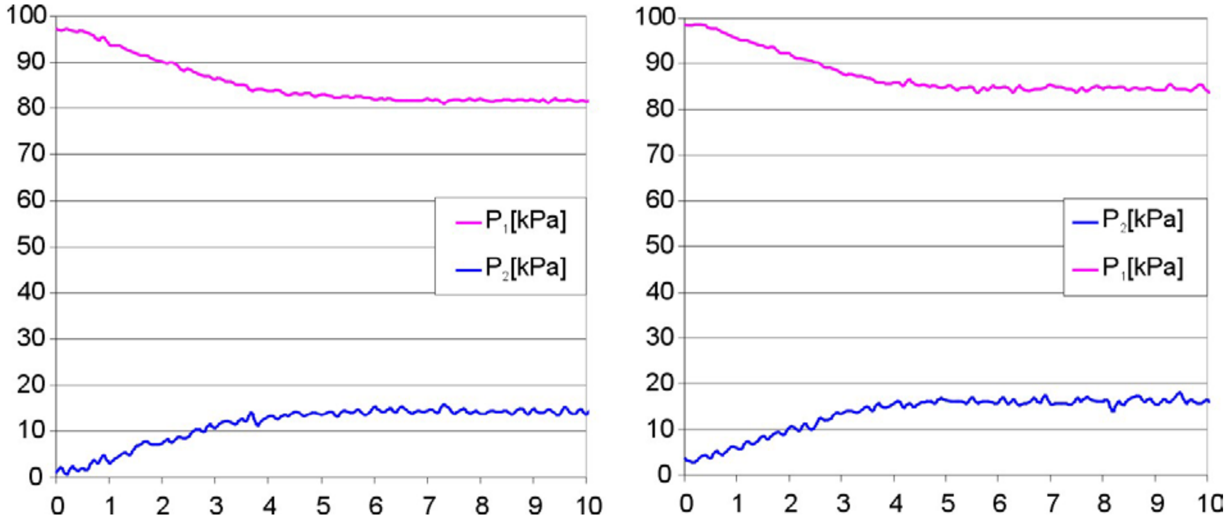

Fig. 5. Between-tanks air flow measurements: left chart – from 1 to 2; right chart from 2 to 1

The results indicate that the equipment measured shows a considerable symmetry, although as compared to the flow lock-pressure expected ($p_{lock} = 0{,}69\ \text{kPa}$) it is too low, as it is about $p_{lock1} = 0{,}65\ \text{kPa}$ for the flow $1 \rightarrow 2$, and $p_{lock1} = 0{,}67\ \text{kPa}$ for the flow $2 \rightarrow 1$.

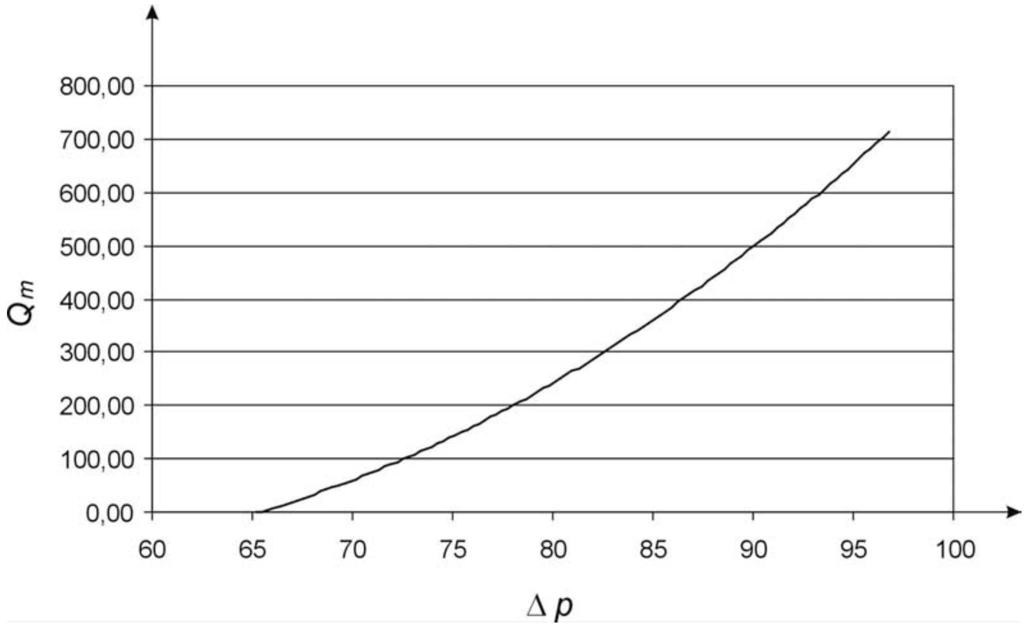

Fig. 6. Valve flow characteristic calculated based on the results given in Fig. 5

Conclusions

The research stand developed allows for measuring flow characteristics for valves of different types. Thanks to the use of multifunction card software, the results can be transferred to spreadsheet where they can be further processed. It is especially useful when verifying the mathematical model of the element researched, as it makes it possible to present both the experimental results and the model characteristics and their comparison using a single chart.

The most important advantage of the research stand is the possibility of indirect determining flow characteristics $Q_m = f(\Delta p)$ only with the pressures-in-tanks measurement and recording in time. All that allows for avoiding designs of complicated flow rate measurement systems (e.g. orifice design).

The measurement results confirm the equation developed earlier, showing that as for pressure and flow assumed, the changes in pressure can be treated as symmetrical.

At the further research stage one shall define the characteristics of the research stand to be factored in during the analysis of the component tested.

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References

Ogata K. (1999) Modern Control Engineering, *Prentice–Hall Intern., Inc,* (third edition).

Chorowski B., Werszko M. (1974) Mechaniczne urządzenia sterujące, *PWN, Warszawa – Wrocław*

Grajnert J. (1999) Pneumatyczne zawieszenia pojazdów szynowych, *Quarterly Pojazdy szynowe 1 and 2, part 1 & 2, Poznań*