Measurement 106 (2017) 173–178

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

# Measurement and evaluation of the quality of static characteristics of brake valves for agricultural trailers ☆

Zbigniew Kamiński, Krzysztof Kulikowski *

*Bialystok University of Technology, Faculty of Mechanical Engineering, ul. Wiejska 45C, 15-351 Bialystok, Poland*

ARTICLE INFO

*Article history:*
Received 28 August 2016
Received in revised form 26 April 2017
Accepted 29 April 2017
Available online 2 May 2017

*Keywords:*
Tractor trailer
The braking system
Relay emergency valve
The static characteristics
Measurement

ABSTRACT

Braking systems of vehicles are subject to very high demands in terms of the dynamic properties (speed and synchrony of action) and static properties. The quality of the static characteristic has a significant impact on the operation of the brake system follow-up operation. This paper describes the test apparatus and the methodology for measuring the static characteristics of the air brake valves for agricultural trailers. The paper presents formulated numerical indicators of the evaluation of quality of static characteristics and provides examples of the results of the static characteristics of the trailer brake valve with a predominance device. The developed methodology for measuring and assessing the quality of static characteristics of the trailer emergency valve can also be used to study other agricultural vehicles brake valves, and commercial vehicles.



## 1. Introduction

Towed agricultural machines and trailers often use air braking systems, which are controlled and powered from the tractor brake system [1]. The braking systems of agricultural vehicles are subjected to very high requirements for their dynamic and static properties.

Rapid braking requires high speed operation (reaction time should not exceed 0.6 s) while slow braking requires follow-up action (tracking) [2–4]. The follow-up action in brake systems of trailers understood as the ability to maintain, under steady state conditions, proportional dependence between the change in pressure in the brake cylinders (output signal) and the change in pressure in the control line (input signal) is achieved thanks to the negative feedback inside the brake valves of trailers [5,6]. Increasing the speed in the transition process is achieved through a fast, full opening of the control valve and keeping it in the open state for some time, after which the valve works in the follow-up mode [6]. In addition, changes in pressure in the brake cylinders of the tractor-trailer unit should be synchronized to ensure compatibility of tractor and trailer braking [2,7].

The accuracy in the steady state is of particular significance in follow-up systems that can operate with an input signal changing at a different speed and should ensure a steady work at possibly low or zero offsets. Therefore, static characteristic of brake valves of trailer should have tracking and as much as possible straight line form. In addition, the preset maximum control pressure should correspond to the maximum braking performance of the vehicle [6].

Analytical and experimental methods are used to determine the static characteristics of brake valves. The analytical method is based on the determination of the relationship between input and output signal, using the mathematical description of the physical processes taking place in the valve [8,9]. This method is mainly used at the stage of design calculations (synthesis) and verification (analysis) of brake valves [6,10]. The experimental method involves the introduction of subsequent steady state values of the input signal (the control), into the actual brake, and measuring the corresponding output value. Then, the approximation of experimental data is carried out to determine the coefficients of the regression line.

Analytical method for assessing the accuracy of follow-up operation of brake valves in steady states entails greater error than the experimental method, because of the need to adopt various simplifying assumptions in the process of creating a calculation model of valve [4]. Therefore, the static characteristics of brake valves are typically determined in an experimental way [11]. The test apparatus described in the paper is used to measure the static characteristics of agricultural vehicles brake valves controlled by pressure

☆ Studies have been carried out in the framework of the work No W/WM/8/2015 and financed from the funds for science of MSaHE.

* Corresponding author.
*E-mail addresses:* z.kaminski@pb.edu.pl (Z. Kamiński), k.kulikowski@doktoranci.pb.edu.pl (K. Kulikowski).

http://dx.doi.org/10.1016/j.measurement.2017.04.044
0263-2241/

signal. A procedure for measuring static characteristics, the identification of its parameters and defining indicators for assessing the quality were described on the example of the Wabcos's trailer relay emergency valve.

## 2. The description of test apparatus

The test apparatus for the experimental determination of static characteristics of commercially available trailer brake valves controlled by pressure is shown in Fig. 1.

Pneumatic diagram of the test apparatus along with the block diagram of the test valve actuating the brakes of the trailer is shown in Fig. 2. The test apparatus is powered from the compressed air source 1 after opening the shut-off valve 2. Reduction valve sets and maintains a constant air pressure (approx. 8 bar) in the supply circuit 3. Compressed air from the reservoir 4 flows through the tested brake valve 5 (chamber B) to the reservoir 6 connected to the supply chamber C of brake valve. The valve 5 is triggered in the braking mode as soon as the voltage of 24 V is applied to the coil of the normally closed three-way two-position valve 7 (the valves VY43ELMNC response time – 19 ms [12]). The compressed air flows through adjustable throttle valve 8 to the reservoir 9 and then to the control chamber A of the valve 5. The pressure increase in this chamber causes the displacement of control piston of brake valve 5 and the flow of compressed air from the reservoir 6 to output chamber E of the valve, and then to the reservoir 10 imitating the working chamber of the brake cylinder. The interruption of power supply to the solenoid valve 7 is followed by emptying the reservoir 9 and the brake valve 5 is overdriven into brake releasing mode, which causes the flow of air from the reservoir 10 to the atmosphere. The task of the throttle valves 8 and 11 is to determine the speed of the filling and venting of control bus of test valve (reservoir 9) to obtain a quasi-static pressure changes in the reservoirs 9 and 10.

Elements of the measurement system were marked in gray in Fig. 2. During braking and releasing, the pressure in the reservoirs 6, 9 and 10 is measured by means of pressure transducers 13DB

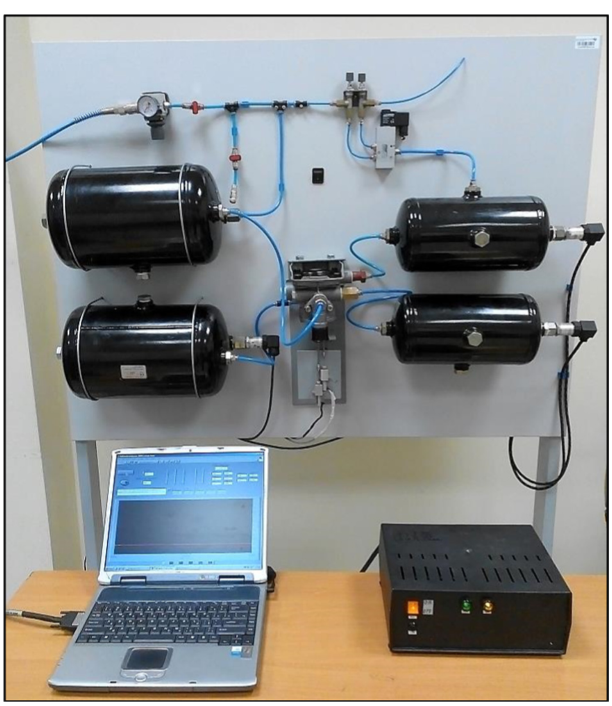

Fig. 1. The test apparatus for determination of static characteristics of brake valves.

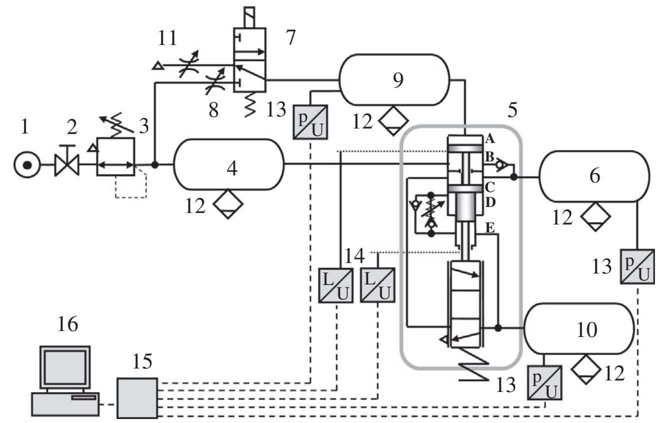


Fig. 2. Simplified diagram of the test apparatus: 1 – compressed air source, 2 – shut-off valve, 3 – reducing valve, 4, 6, 9, 10 – air reservoir, 5 – trailer emergency valve WABCO 971 002 300 05 7 – solenoid valve 3/2, 8, 11 – throttle valve, 12 – drain valve, 13 – pressure transducer DB sensor DMP 331, 14 – displacement sensor Penny & Giles D.15734/4 with an amplifier, 15 – input - output adapter, 16 – computer with measuring card DAQCard-6024.

Sensor DMP 331 (range: 0–10 bar, output signal range: 0–5 V, accuracy: 0.25%). The displacement of the piston of control valve 5 and the displacement of the poppet of the valve are measured using inductive sensors 14 D type 15734 14/4 Penny & Giles (measuring range: ±6.35 mm, the range of the output signal from the amplifier: 0–5 V, sensitivity: 78, 74 mV/V/mm, linearity: ±0.3% of measurement range), from which the measurement signal is converted into voltage by the amplifier CL104M ZEPWN. The output voltage signals from pressure and displacement transducers are collected from the adapter 15 using the measurement card DAQCard-6024 (resolution 12 bit) and then directly processed to pressure and displacement data with the integrated software installed in the computer 16.

A computer program prepared in LabView environment was developed for recording the measurements. The program has on/off function for recording of the course of measured values, setting the resolution of the sampling and contains calibration equations for processing the output measurement data. Additionally, the program allows for visualization of measurement process of the brake valve under test in real time.

## 3. Indicators of evaluation of the quality of static characteristics of brake valves

The most important, generally known indicators to assess static characteristics quality of brake valves usually include: linearity (nonlinearity), initial dead band and hysteresis [6]. Using the definitions (concepts) used in the theory of error of transducers and measurement devices [13–15], such as the static sensitivity, absolute offset or processing ambiguity, other indicators to assess the static characteristics of valves can be determined.

Designating, in accordance with the recommendations of ISO 6786 [16], input pressure (control) as $p_4$ and $p_2$ as the output pressure, the features of static characteristic $p_2 = f(p_4)$ can be evaluated using the following numerical indicators:

- **amplification coefficient $k_P$** (equivalent of static sensitivity of measuring devices), understood as limit of the quotient of growth of the output pressure $p_2$ to increase of input pressure (control) triggering this change $p_4$, designated by characteristic linearization $p_2 = k_P \cdot p_4 + k_0$ by linear regression,
- **absolute nonlinearity $\Delta p_2$** (referred to output) understood as the maximum difference between real and ideal static characteristic: