# Research in hydraulic brake components and operational factors influencing the hysteresis losses

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## Abstract

*Up-to-date automotive brake systems place stringent requirements upon the performance, reliability, and active safety. Such advanced systems as antilock braking systems (ABS), the electronic stability programme system, and the anti-slip control system assist a driver in ensuring driving safety under many conditions. The influence of the brake components on active safety systems is mainly determined through the hysteresis loop width. Among other negative outcomes, this parameter limits the possible frequency of cyclic braking during ABS operation. This paper presents an experimental analysis of the factors influencing the hysteresis pressure losses in a hydraulic brake system. The factors under investigations are the brake pedal stroke velocity, the gaps between the brake pads and the brake disc, and the configuration of the brake system. Experiments were carried out on the brake test equipment at the Automotive Engineering Department, Faculty for Mechanical Engineering, G.H. Raisoin Collage of Engineering Nagpur.*

**Keywords:** *hysteresis, hydraulic system, brake, AMESim*

## 1 INTRODUCTION

The stability of the static and dynamic characteristics of a brake system depends in many ways on the frictional forces arising in a master cylinder, valves, pipelines, and other brake elements. The wear, gaps, and slacks on the brake devices are also caused by these inner frictional forces. Traditionally, the internal friction is seldom considered in brake dynamics except for evaluating the brake torque oscillations. However, the most critical outcome of the above influence is connected with a hysteresis phenomenon. The hysteresis takes place by changing the sign of the frictional forces at the brake release mode and occurs because a pressing force on the friction surface of the brake pad is still retained by the time of the brake release. A literature survey has revealed that the problems of reduction in hysteresis losses in the brake system components have been actively investigated in many respects. The analysis performed shows that the hysteresis impacts in one way or another on the following: (a) the operation of the brake callipers and valves [1–3]; (b) the performance of the disc brakes, especially for heavy vehicles [4, 5]; (c) the response speed of anti-lock braking systems [6–8]. The presented paper describes the investigations of hydraulic brake system components from the point of view of the hysteresis losses and the operational factors having an influence on the hysteresis value. The research procedures consisted of the combined application of bench testing with the subsequent simulation. The detailed description of the test bench used during the investigations has been presented in reference [9]. For simulation purposes, the model of an automotive brake system was created using the AMESim software environment. The general approach to the model development was based on the methodologies discussed in references [10] to [13].

Table 1 Test bench data

| | |
|---|---|
| Test concept | Servo hydraulic |
| Pedal force domain | F 5 0–5000 N |
| Pedal velocity domain | v 5 0–1000 mm/s |
| Maximal frequency of sensor scanning | 6 kHz |
| Test modes | Force control, stroke control, ramp-shaped, oscillating control effort |
| Safety measures | Emergency switch; adjustable mechanical force limiter |

The general idea of the presented research lies in the definition of the share of hysteresis losses by the main components of a typical automotive brake system such as the master cylinder, brake gear, or booster. This approach allows weak points in a brake hydraulic chain to be found and recommendations are given for the development of an advanced brake system, in which the principal hysteresis-generating elements may be replaced by similar mechatronic devices.

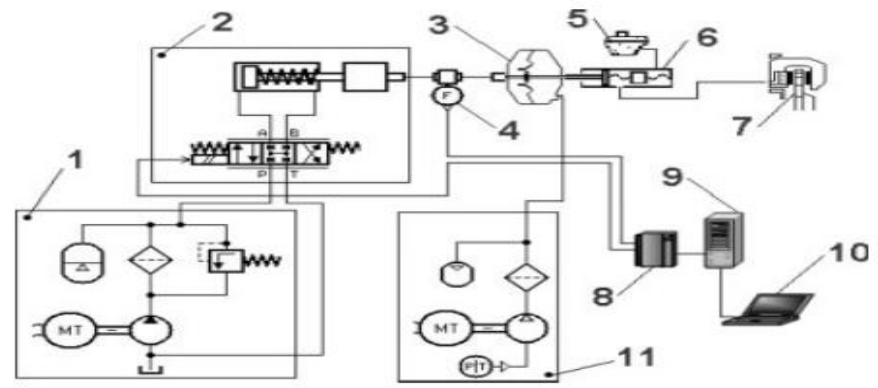


Fig. 1 Structure of the component test bench for braking systems

1, hydraulic unit; 2, brake robot actuator; 3, vacuum booster; 4, force and displacement sensors; 5, overflow tank; 6, brake master cylinder; 7, wheel brake with disc; 8, signal converter; 9, real-time computer; 10, laptop with suitable software; 11, vacuum unit

## 2 TEST PROCEDURES

The experimental investigations of hydraulic brake components were performed on the special test bench configuration with a 'brake robot', allowing the dynamic and precise reconstruction of the brake pedal action. Table 1 shows the main data of the test stand. The following brake system components and equipment were used for experiments: brake robot actuator, brake master cylinder, vacuum booster, wheel brake, signal converter, real-time computer, laptop with controlling software, force and pressure sensors, hydraulic and vacuum pump, hydraulic and vacuum tank, charging unit, storage batteries, overflow tank, and hydraulic and air pipes (Figs 1 and 2). The research work consists of several stages. 1. The influence of the brake pedal stroke velocity on hysteresis value is estimated; next the operating modes were chosen: (a) steady state braking; (b) service braking; (c) emergency braking. None of these braking modes has exact limits on the brake pedal stroke velocity. From statistical and practical data, the following intervals of brake pedal stroke velocity were taken: steady state braking, 5– 15 mm/s; service braking, 50–200 mm/s; emergency braking, 1000–1300 mm/s [14]. Each of the velocity intervals was divided into several parts during experiments to obtain hysteresis characteristics for all subintervals.

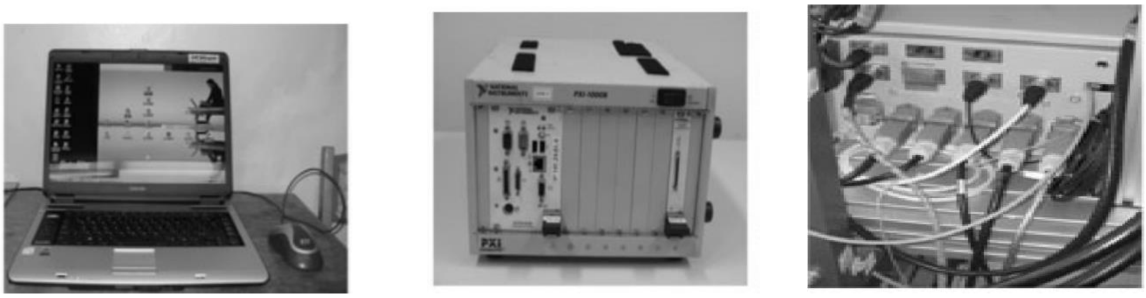

**Fig. 2 Measurement system**: (a) laptop with suitable software; (b) real-time computer; (c) signal converter

The simulation of the brake pedal action in the considered brake system configurations was realized using a special actuator allowing control of the rod velocity and displacement. The actuator rod is directly connected to the rod of the brake master cylinder or booster rod. Taking into consideration the pedal ratio Uped, calculated on the basis of geometric parameters (Fig. 3), the values of the rod velocities for brake pedal stroke velocity during the emergency, service, and steady state braking were obtained (Table 2).

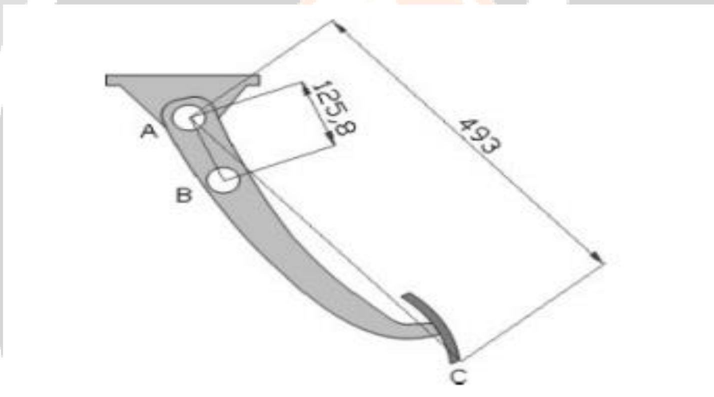


Fig. 3 Geometric parameters of the brake pedal in millimetres

2. To estimate the influence of different brake system components (vacuum booster, disc brake, brake master cylinder, and pipelines) on the value of the hysteresis losses, the sequential exclusion of these components from the hydraulic system configuration with one disc brake was carried out with subsequent repetition of all experiments: stage 1: full brake system (Fig. 4); stage 2: configuration from stage 1 without the brake booster (Fig. 5)

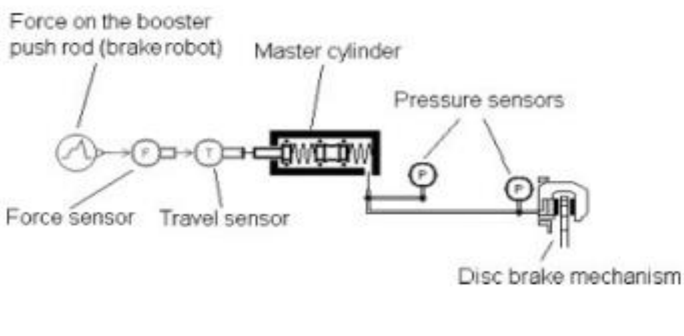


Fig. 5 The brake system configuration at stage 2

**3** ANALYSIS OF EXPERIMENTAL RESULTS The hysteresis, as applied to the performed brake testing procedures, is derived from the dependence

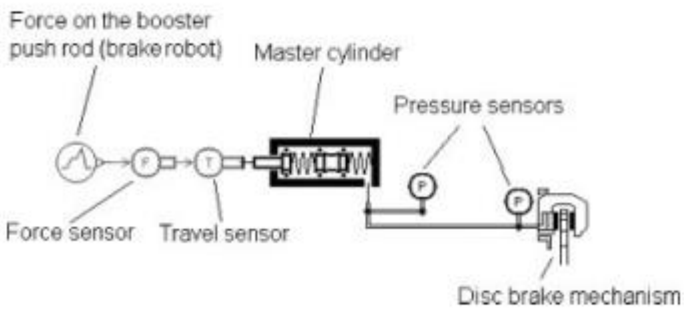


Fig. 6 The brake system configuration at stage 3

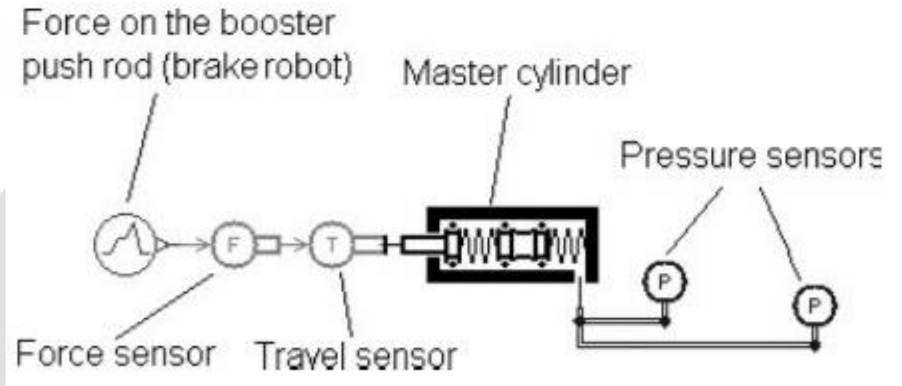


Fig. 7 The brake system configuration at stage 4

Between the pressure actuating on the brake gear and the brake pedal (actuator rod) displacement. Because of the strong non-linearity of this phenomenon, the method of areas limited by the hysteresis characteristic curves during the braking and brake release and abscissa axis is used for calculation of the hysteresis losses.

The hysteresis values were calculated from the area inside the build-up and release curves. First, the polynomials of quintic orders describing the experimental curves have been formed using special statistical software. Then the above-mentioned polynomials have been integrated.

The pressure in the brake gear can be successfully converted to the braking force via a reduced coefficient of conversion. The force integral over the displacement gives the work done by the brake gear to create the braking pressure; the hysteresis losses are equivalent to the parasitic work of the brake gear. In addition, the pressure integral over the displacement gives the hysteresis work reduced to the pressure (specific pressure hysteresis).

**3.1**

Influence of the braking pressure velocity on the hysteresis value It may be deduced from analysis of the obtained experimental data that the character of the influence of the actuator rod velocity on the value of the hysteresis losses in the hydraulic brake system is the same during all experimental stages. The diagram (Figs 8 to 13) and numerical values below Fig. 6 The brake system configuration at stage 3 Fig. 7 The brake system configuration at stage 4 Fig. 8 Influence of the braking velocity on the hysteresis characteristic without gaps between the brake pads and disc during emergency braking at stage 1

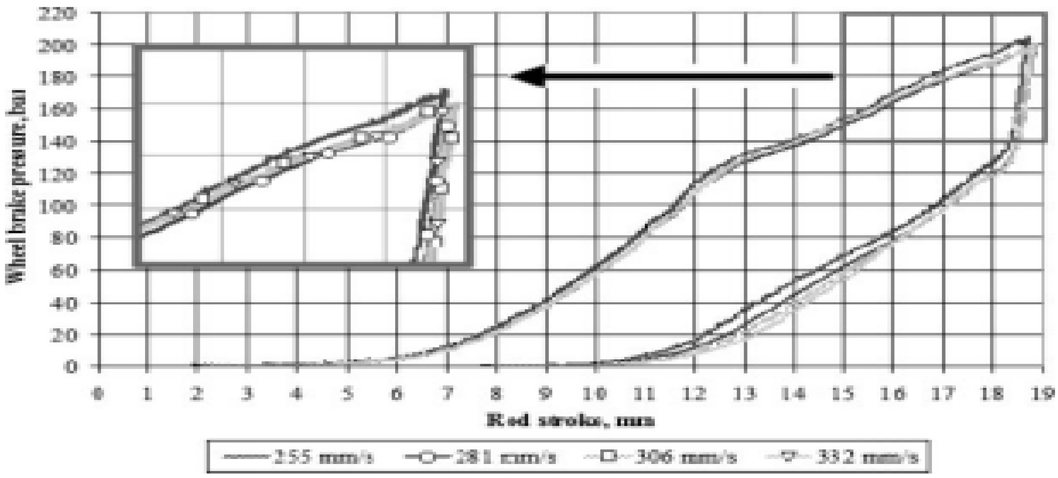


Fig. 8 Influence of the braking velocity on the hysteresis characteristic without gaps between the brake pads and disc during emergency braking at stage 1

## 4 CONCLUSIONS

From the test results it can be deduced that the component test bench for brake systems allows the efficient estimation of parameters and working capacity both for the full-length hydraulic brake system and for its single components. The original test procedure was developed for the component test bench for brake systems. To calculate the hysteresis losses, the method of areas limited by the hysteresis characteristic curves of the brake pressure build-up and release and by the abscissa axis was used in this work. The first investigated problem (stage 1) was the influence of the brake pedal stroke velocity (actuator rod velocity) on the hysteresis value. Regarding the analysis of the experimental data obtained, it was found that, when the actuator rod velocity increases during both the service and emergency braking, the hysteresis value increases nearly in proportion to this velocity growth (Tables 3 to 5).

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