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RESEARCH IN SELF-BOOSTING DISC BRAKES FOR COMMERCIAL VEHICLES

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ABSTRACT - The current tendencies in automotive industry need intensive investigation in problems of interaction of active safety systems with brake system equipments. At the same time, the opportunity to decrease the power take-off of single components, for example such as brake system, is investigated. Authors propose a modification of disk brake structure with self-boosting characteristic for commercial vehicles. This brake gear due to original construction will allow decrease force required for its drive under the condition that brake gear will generate such brake torque as conventional disk brake.

The compilation and investigation on proposed brake gear model in AMESim software is supposed. The obtained results can find application during designing of new types of brake systems especially for heavy vehicles and buses.

TECHICAL PAPER - The first mention of disc brakes is dates the last century beginning. English doctor Lanchester patented the disc brake project in 1902. These brakes were installed on the same car Lanchester. Disc brakes began to apply on sports cars in 1952. The first disc brakes have appeared on serial car Citroen DS19 in 1958. The first European air mechanical disc brakes entered series production in 1989 on the Renault R420. These were of the Lucas D2 type. Their introduction was preceded by many years of painstaking development and the test work on vehicles test bench and dynamometer. The brakes on these vehicles have gained rapid acceptance in the field, and the market demand has risen rapidly since their introduction.
Meanwhile the development of the D2 concept has continued, with the considerable work taking place on features such as pad and disc size, easy of manual adjustment and the ability to install on both front and rear axles [1].
In floating caliper brakes, the braking moment production relies on the generation of a large clamping force between two or more brake pads, which then produce a frictional torque on the rotating assembly. It would clearly be of benefit that the force required from the brake actuator must be reduced for the declination of brake actuator weight and power consumption.

THE REVIEW OF DISC BRAKES WITH SELF-BOOSTING - Self-boosting is incorporated and the pneumatic drive is applied in one of the first designs of a disc brake for the heavy-duty trucks. Steel balls provide the self-boosting by the moving on inclined surfaces of deepenings at displacement of one disc concerning another, Figure 1, a.

In the middle of 1960th years the company Chrysler offered the design of disc wheel brake for the off-road truck. The brake mechanism was inside of the case, one of which half was the wheel hub. Discs with friction pads settled down between rubbing surfaces of the case and a case cover. The brake actuated by means of two working cylinders. During braking pistons are missed and discs are turned on some corner in the opposite sides. Thus balls, being rolled on inclined surfaces, moved apart discs and pressed them to brake drum walls, Figure 1, b.

a) b)

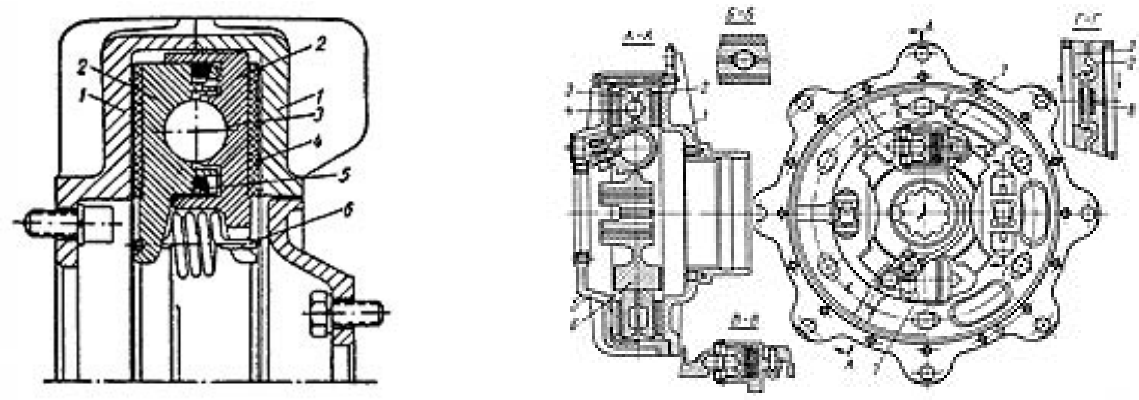


Figure 1: a) disc brake for the heavy-duty track: 1 – brake drum; 2 – brake discs; 3 – steel ball; 4 – brake pad; 5 – mating ring; 6 – compression spring; b) Chrysler disc brake with self-boosting

Designs of disc brakes with self-boosting presented in figure 1 have following disadvantages:

- Relative complexity of a design owing to presence of balls, inclined surfaces of flutes and coupling springs;
- The complicated removal of heat and wear products from rubbing surfaces because brake mechanisms settle down inside of brake drums. Such arrangement also negatively affects on operational qualities and maintainability of the given designs.

One of the most interesting examples of a disc brake design with self-boosting is the electronic wedge brake, which was described in [2-4]. It is based on an electric powered controlled friction brake with high self-reinforcement capability. The physical effects involved lead to a significant reduction of energy consumption of the brake actuator compared to "conventional" brake-by-wire systems, Figure 2.

a) b)

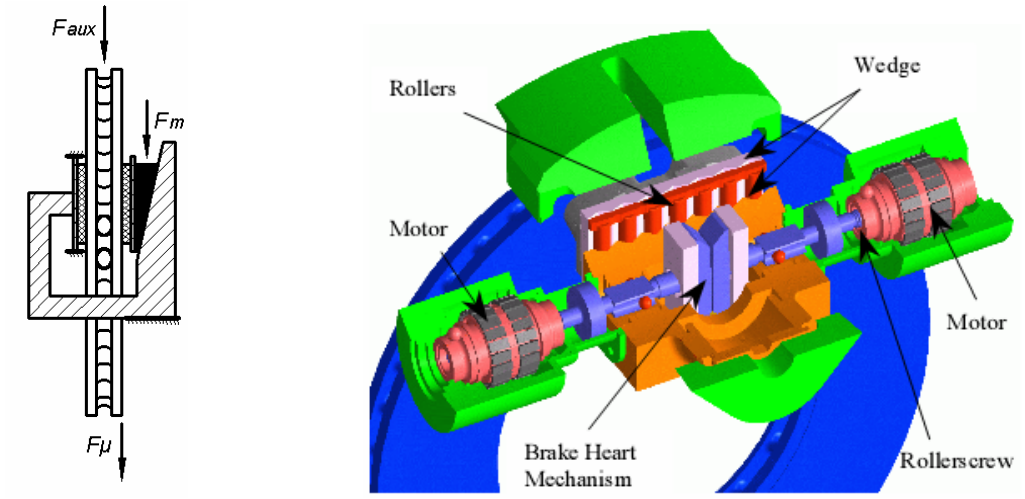


Figure 2: a) eBrake – electric powered controlled friction brake with mechanical self-reinforcement; b) cross section through prototype

Mathematically, the characteristic brake factor for a floating caliper brake actuated by this method is given by

$$C^* = \frac{Pad \quad Braking \quad Force}{Brake \quad Actuation \quad Force} = \frac{2\mu_B}{\tan\alpha - \mu_B}$$

From this equation, it can be seen that for low coefficients of friction, C* is positive, so a steady pushing force is required to maintain the braking force. When the coefficient of friction is greater than the tangent of the wedge angle, then a steady pulling force is required from the actuator to stop the wedge being pulled further in. Furthermore, when the coefficient of friction increases, the wedge position becomes unstable and needs to be controlled to stop the wheel jamming [3]. It is the biggest lack of this design. Because a brake pad friction coefficient varies in enough wide limits under influence of various operating factors, such as hit of moisture, dirt, and dust on rubbing surfaces of a brake. Therefore, unstable behavior probability of a brake is high enough in working conditions.

In both the automotive and aerospace industries today, there is a strong trend towards 'power-by-wire' technologies, aimed at replacing hydraulic or pneumatic systems with equivalent electrically powered ones. Accordingly, there has been interest for some years in electrically actuated brakes and several companies have designed and tested prototype systems.
The idea, however, to electromechanically actuate vehicle brakes goes back to the early days of automotive history when A. Stevens and W.-S. Penney first saw the simple and precise controllability of brakes powered by electric energy [5]. This property is one of the major motivations for the recently increasing research activities in the field of mechatronic brake systems.

Thus, lead the analysis allowed authors to formulate the primary goals of the given research:

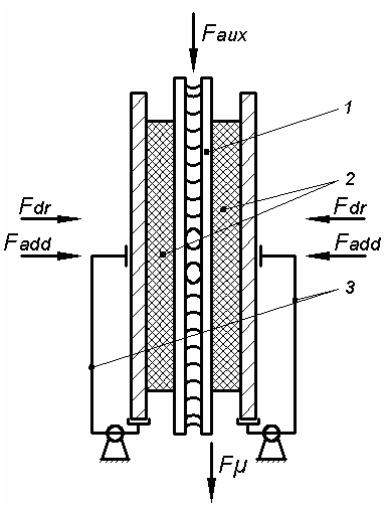
- To find the decision for realization of self-boosting in disc brake mechanism which can be distributed to different drives and types of vehicles;
- To estimate functional working capacity of disc brake with self-boosting by means of simulation in AMESim;
- To offer the imitating model for estimation of reliability and loading modes in ADAMS.

DISC BRAKE WITH SELF-BOOSTING - Proceeding from the above-stated research problems, authors offer an original design of the disc brake mechanism with self-boosting which is deprived the specified disadvantages. Besides, the mechanism design demands the minimal changes in comparison with a serial disc brake. It certainly concerns to advantages of the offered design.

The disc brake mechanism contains the brake disk 1; brake pads 2, which are located on both sides from the disc, the floating caliper 5, figure 3, b. The support 4 contains the intensifying plugs 3 connected with brake pads of the brake mechanism. Introduction of an intensifying plugs allow automatically increase value of brake force at braking.

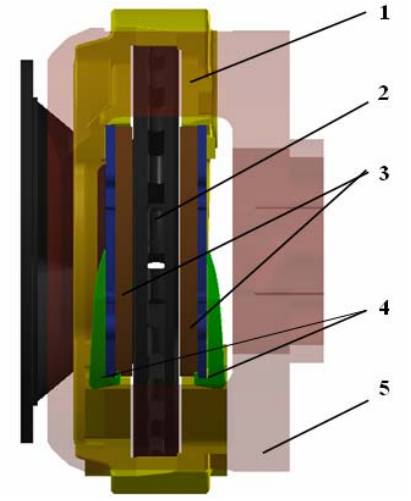
Work of the brake mechanism is based that there is a friction force in the contact zone which aspires to move pads in the direction of a brake disc rotation, figure 3, a. Then this effort is in addition applied to brake pads, that automatically increasing driving effort value.

a)



1 - brake disc; 2 - brake pads; 3 - intensifying plugs; F_{aux} - axial force; F_{dr} - driving effort; F_{add} - additional effort; F_{μ} - friction force

b)



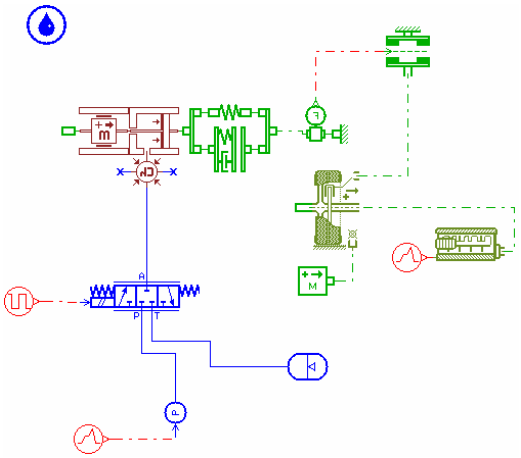
1 - support; 2 - brake disc; 3 – brake pads; 4 - intensifying plugs; 5 - floating caliper

Figure 3. Disc brake mechanism with self-boosting

SIMULATION OF THE DISC BRAKE WITH SELF-BOOSTING - AMESim has been used by authors for demonstration of the offered design efficiency. Tests of hydraulic brake system model with the serial brake mechanism and tests of the enhanced hydraulic brake system, in which the serial brake mechanism has been replaced by an offered design of the brake with self-boosting, have been performed.

The realized models of hydraulic brake system with the standard brake mechanism and enhanced hydraulic brake system are represented in figure 4. As the purpose of tests was demonstration of working capacity and efficiency of a disc brake with self-boosting, the subsystem of brake system has been realized in AMESim, in which following components were used: imitation of the driver's influence on a brake pedal; brake mechanism of the wheel; a wheel, with a part of vehicle weight, falling on it and the engine for the car runaway.

a)



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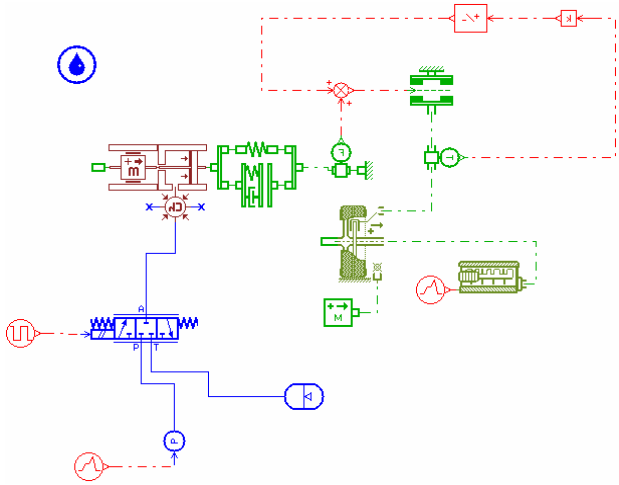

Figure 4: a) hydraulic brake system model with the standard brake mechanism; b) enhanced hydraulic brake system model

Basic data for simulation of both models:

- Part of vehicle weight, falling on braking wheel – 400 kg;
- Initial braking speed - 22 m/s;
- Maximal pressure in the brake gear - 120 bars;
- Time for which the maximal pressure is achieved - 2 s;
- Friction coefficient between brake disc and brake pads – 0,4;
- Brake disc diameter - 310 mm.

Basic simulation dependences are represented in figures 5 – 7, simulation results are shown in table 1. On the basis of the preformed tests in AMESim, a three-dimensional model of the disc brake with self-boosting in UNIGRAPHICS has been developed and the imitating model for carrying out of virtual tests of the brake in ADAMS is prepared. A mechanical systems simulation is used for the forecast of a full dynamic behavior of the complex brake unit system having a lot of cooperating with each other parts. The simulation model of the disc brake mechanism with self-boosting in ADAMS is represented in figure 8.

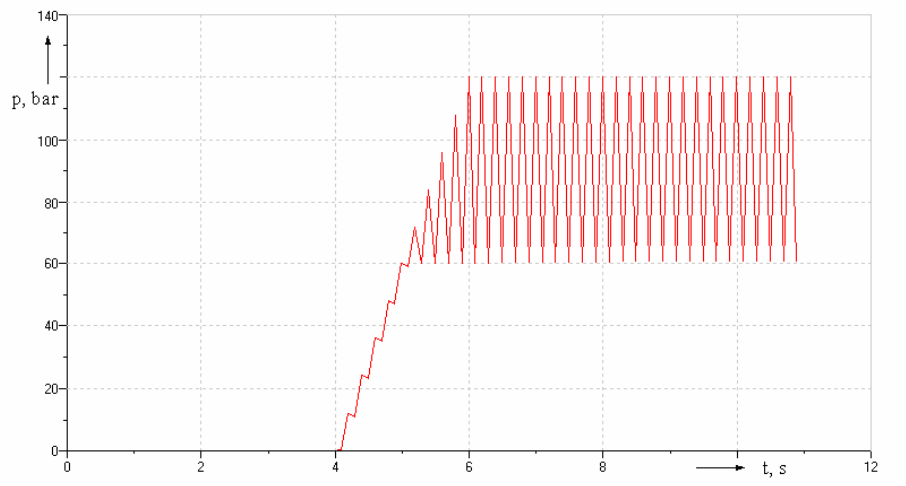

Figure 5. The pressure in brake system for both models

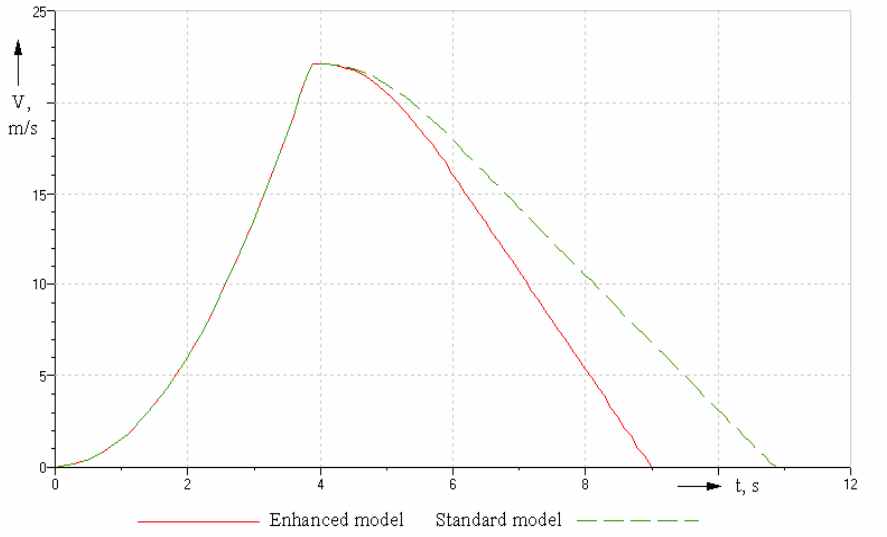

Figure 6. Car speed dependences on braking time

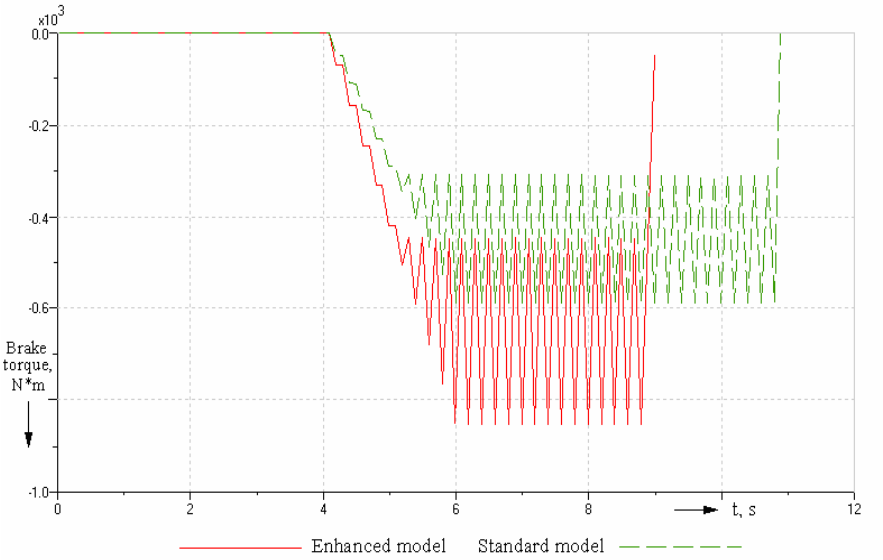

Figure 7. The brake moment dependence on braking time

Table 1. Basic simulation results

	The baking time, s	Maximal brake torque, Nm	The braking distance, m
Standard brake system model	10,9	589	84
Enhanced brake system model	9	855	64
Improvement of a parameter in comparison with standard model, %	17,4	45,1	23,8

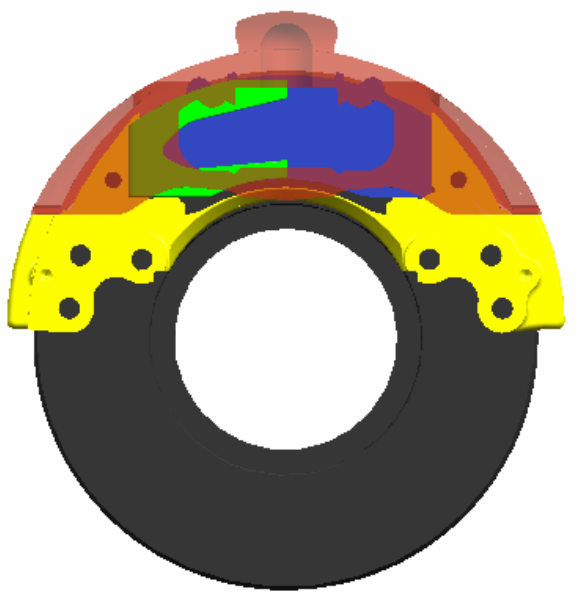

Figure 8. The simulation model of the disk brake mechanism with self-boosting in ADAMS

The purpose of 3D-simualtion of brake gear in ADAMS lies in the fact that nowadays the intensive investigations are carried out on problems of interaction of active safety systems with brake system equipments. The special place is occupied here with creation of new brake gear design which should possess except for reliability and durability such important for active safety systems properties as minimal hysteresis losses and the high response time, which are of importance for active safety systems. It is known that the hysteresis loop area is formed at brake release within full range of control effort changing.

As a result of the disc brake with self-boosting model simulation in ADAMS the hysteresis characteristic was received, figure 9. The characteristic represents dependence of the brake torque from the brake pressure.

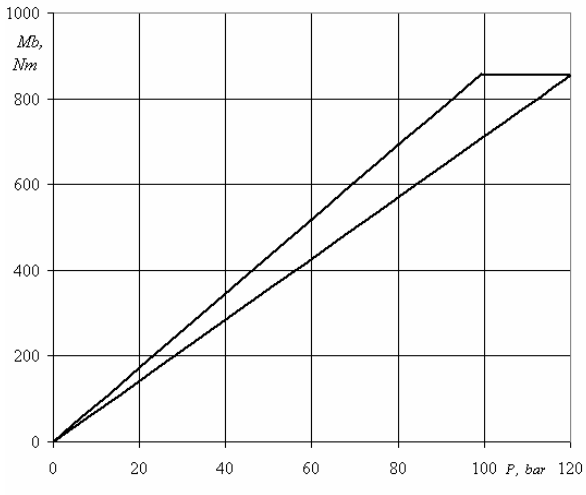

Figure. 9 Hysteresis loop of the disc brake mechanism with self-boosting

By means of hysteresis characteristic it has been adjusted, that the hysteresis looses does not exceed 18% in a disc brake with self-boosting.

The received hysteresis value lies in interval of average values for serial disc brake design [6]. Accordingly, it is possible to mention that the introduction in a serial disc brake design of an additional element, an intensifying plug, has not rendered essential influence on hysteresis losses value and, consequently, on response time of the disc brake mechanism.

CONCLUSIONS – The performed review and the analysis of brake designs allowed to develop the original disc brake mechanism with self-boosting. The offered brake favorably differs from the considered brake mechanisms with the minimal changes, which are necessary for bringing in serial brake mechanism design and also reliable working capacity in all range of friction coefficient between brake pads and brake disk during operation. Besides it, tests which were spent in AMESim showed advantages of the offered design in comparison with serial disc brake mechanism.

Thus, the offered design possesses the following basic advantages:

- The minimal changes of the serial brake design;
- Reliability in all working range;
- Maintenance of the best brake dynamics at identical parameters of the brake mechanism and equal driving effort;
- Decreased power-off from engine at braking.

The design of the disc brake mechanism with self-boosting offered by authors at present is developed as the pilot project for bus manufacture at the Minsk Automotive Plant.

REFERENCES

(1) Siigmar Micke, Richard E. Thompson, Bernd-Holger Roehling (1990). The Introduction of Air Disc Brakes for Trucks and Buses in Europe, SAE Technical Paper Series, paper No. 902203.

(2) Henry Hartmann, Martin Shautt, Antonio Pascucci, Bernd Gombert. “eBrake® - the mechatronic wedge brake”, SAE Technical Paper Series, paper No. 2002-01-2582, 6 pp, 2002.

(3) Richard Roberts, Martin Schautt, Henry Hartmann, Bernd Gombert. “Modeling and Validation of the Mechatronic Wedge Brake”, SAE Technical Paper Series, paper No. 2003-01-3331, 11 pp, 2003.

(4) Richard Roberts, Bernd Gombert, Henry Hartmann, Dittmar Lange, & Martin Schautt. “Testing the Mechatronic Wedge Brake”, SAE Technical Paper Series, paper No. 2004-01-2766, 9 pp, 2004.

(5) Stevens, A. and Penny, W. “Elektrische Bremse für Motorwagen”, Kaiserl. Patentamt 121043, 1899.

(6) Э-46-99. The investigation of disc brake mechanisms. – Minsk Automotive Plant, 1999. – 11p.

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