A PROTOTYPE ASR SYSTEM FOR VEHICLES WITH PNEUMATIC BRAKING SYSTEM

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Summary

The design basis, conceptual design, and a prototype construction of a new anti-slip regulation (ASR) system (also referred to as “traction control system”) have been presented. The operation of the proposed ASR system consists in the applying of the parking (emergency) brake, actuated by means of a two-state modulator controlled by an electronic control module. This principle differs from that employed in the current ASR systems, where the service brake system is used for ASR purposes. The construction of the system under consideration is based on the use of the piston-spring part of the spring brake actuator of the rear driving wheel brakes to apply a braking torque to appropriate wheels during system operation. The concept under consideration may be implemented in trucks, buses, or other vehicles provided with air brake systems.

The idea of system operation was verified by computer simulation tests, during which the system functioning parameters were optimised. On these grounds, a prototype version of the system was built and subjected to rig tests and then to road tests.

Keywords: motor vehicles, active safety, traction control systems ASR.

1. Introduction

When an automotive vehicle is starting or accelerating, the engine torque transmitted to individual driving wheels of the vehicle may become too high and produce on a specific wheel a circumferential force exceeding the maximum driving force obtainable in the current wheel-to-road adhesion conditions. If the circumferential force on the wheel exceeds the adhesion force available then an excessive longitudinal slip of this wheel will take place, which may ultimately reach a value of 100%. This is a very unfavourable phenomenon because it may make it difficult or even impossible for the vehicle to start, it may reduce the vehicle acceleration dynamics, and it may result in a loss of directional

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stability of vehicle motion. The use of a traction control system (anti-slip regulation system), commonly abbreviated to ASR) ensures that the circumferential force developed in the area of contact of the driving wheel with the road surface is kept within appropriate limits when a driving torque is applied to the wheel.

This paper covers the idea of operation and a proposal of engineering design of the ASR system, where the construction, functions, and operation of the air brake system have been made use of, with the engine control system having been employed as well.

The ASR system proposed may operate as an "overlay," i.e. it may even be applied to the vehicles with air brake systems that have already been in service; additionally, it may cooperate with the engine control system reducing the vehicle driving torque. According to the plans adopted, the system is to be based on standard components of the vehicles being currently in use.

The effects of this work include the making of a prototype system based on the engineering design prepared. The system presented was verified by computer simulation tests, rig tests, and road tests.

2. An idea of the system to control the slip of driving wheels

An important factor, which is critical for correct functioning of an ASR system, is the speed of system response to the occurrence of excessive slip of the driving wheel. If an excessive growth of the peripheral speed of the accelerating wheel is allowed, this will result in a significant drop in the adhesion coefficient and, in consequence, the vehicle driving force will further decrease. Moreover, an excessive delay in the applying of a braking torque to the accelerating wheel will cause high dynamic loads to occur in the power transmission system of the vehicle. In trucks, differential lock systems are even used because of insufficient speed of response, i.e. unsatisfactory effectiveness, of ASR systems. Therefore, the main goal of the ASR idea proposed is to raise the speed of system response as the basic parameter determining the system effectiveness. An additional important good point of the new design is the fact that the interference of the ASR system in the service brake system would be thus eliminated, which would undoubtedly improve the safety of vehicle braking.

In the existing ASR designs, the braking torque has been obtained by operating the diaphragm part of the spring brake actuator of the appropriate rear driving wheel brake. Conversely, the operation of the proposed ASR system consists in the applying of the parking (emergency) brake, actuated by means of a two-state modulator controlled by an electronic control module. The essence of the solution presented is the use of the piston-spring part of the spring brake chamber as an actuator in the anti-slip regulation system. This idea may be implemented in all the commercial and other vehicles provided with air brake systems.

The idea under consideration is different from that of the existing ASR systems, where the service brake system is used for the same purposes.
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Fig. 1. Schematic diagram of an air brake system with ABS, provided with the new ASR system.

Legend:

<table>
<thead>
<tr>
<th>Item</th>
<th>Q-ty</th>
<th>Description</th>
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<tr>
<td>1</td>
<td>1</td>
<td>Air compressor</td>
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<tr>
<td>2</td>
<td>1</td>
<td>Air dryer with pressure regulator</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>Pressure limiter, 0.8 MPa</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Four-circuit protection valve</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>Compressed air reservoir, 40 dm³, service brake, rear axle circuit</td>
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<tr>
<td>6</td>
<td>1</td>
<td>Compressed air reservoir, 40 dm³, service brake, front axle circuit</td>
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<tr>
<td>7</td>
<td>1</td>
<td>Compressed air reservoir, 20 dm³, secondary brake circuit</td>
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<td>8</td>
<td>1</td>
<td>Brake foot valve</td>
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<tr>
<td>9</td>
<td>2</td>
<td>Piston chamber</td>
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<td>10</td>
<td>2</td>
<td>Quick-release valve</td>
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<td>11</td>
<td>1</td>
<td>Parking brake hand control valve</td>
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<tr>
<td>12</td>
<td>1</td>
<td>Relay valve</td>
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<tr>
<td>13</td>
<td>2</td>
<td>Diaphragm-spring chamber</td>
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<td>14</td>
<td>3</td>
<td>ABS modulator</td>
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<tr>
<td>15</td>
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<td>Vehicle speed sensor</td>
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<td>ECU ABS</td>
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<td>17</td>
<td>1</td>
<td>Compressed air reservoir, 20 dm³, ASR system</td>
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<td>18</td>
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<td>20</td>
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<td>Two-way valve</td>
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<td>21</td>
<td>1</td>
<td>Control valve to operate the actuator of the injection pump control rack</td>
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<tr>
<td>22</td>
<td>1</td>
<td>Actuator of the injection pump control rack</td>
</tr>
<tr>
<td>23</td>
<td>1</td>
<td>Pressure limiter, 0.6 MPa</td>
</tr>
<tr>
<td>24</td>
<td>2</td>
<td>Relay-control valve</td>
</tr>
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</table>
A schematic diagram of the compressed-air brake system of a truck with an anti-lock brake system (ABS) and a traction control system (ASR) built to the new idea has been presented in Fig. 1.

The proposed ASR system includes the following major components:
- Compressed air reservoir of the ASR system (item 17);
- ASR modulator (item 19);
- Relay-control valve (item 24);
- Diaphragm-spring brake actuator (item 13);
- Pressure limiter (item 23);
- Electronic control unit (item 18).

The ASR system operates the spring part of the rear wheel brake actuator, which normally (without the intervention of the ASR system) performs the functions of a parking or emergency brake. When the ASR system is active, the spring part of the brake actuator is operated as follows. Based on the logics of the control algorithm, the electric signal generated by the electronic control unit of the ASR system (18) turns on the two-state ASR modulator (19), which is supplied from a compressed air reservoir (17). In result of this, a pneumatic signal is generated at the modulator outlet and fed to the control port of the relay-control valve (24), which causes de-aeration of the piston-spring part of the brake actuator (13). In result of expansion of the actuator spring, a force is generated in the piston rod, which causes a braking torque to be applied to the appropriate driving wheel. This in turn reduces the slip and improves the traction properties of the driving wheels. When the control signal disappears then the ASR modulator (19) returns to the normally-closed state, the pneumatic signal controlling the relay-control valve (24) disappears, compressed air is fed again through this valve to the chamber of the piston-spring part of the brake actuator (13), the actuator spring is compressed back, and the wheel brake is released.

3. Testing of a prototype ASR system

To verify the correctness of the engineering solution presented, the following tests were carried out:
- Simulation tests;
- Rig tests;
- Road tests.

3.1. Simulation tests

For the purposes of these tests, the vehicle was represented by a model consisting of a set of rigid solids, for which standard simplifying assumptions were made.

Moreover, an algorithm of the functioning of the prototype ASR system was worked out.

The simulation tests of the movement of a vehicle provided with the prototype ASR system
were carried out to obtain time histories of the values of the following quantities:

- Vehicle speed;
- Peripheral speed of the driving wheels;
- Pressure in the brake chamber;
- Slip of the driving wheels;
- Pulses controlling the operation of the ASR valves.

The optimising calculations carried out have shown that the compressed air held in the piston-spring part of the brake actuator does not have to be fully released to the atmosphere during operation of the ASR system. It has been found sufficient to reduce the air pressure to a level of about 0.37 MPa so that an adequate braking torque is achieved for satisfactory operation of the ASR system. This is a favourable finding because the energy demand may be thus reduced and the speed of operation of the ASR system may be increased as well.

Based on the simulation tests carried out and the test results obtained, the parameters related to the process of functioning of the prototype system were optimised. An example of the simulation curves obtained for the optimised system parameters has been presented in Fig. 2.

![Simulation curve](image)

**Fig. 2. Simulation of a start of a vehicle with the ASR system, in second gear, on a “μ-split” road surface, at an adhesion coefficient of \( \mu = 0.2/0.6 \).**
3.2. Rig tests

Based on the simulation tests carried out, a prototype version of the ASR system was built, which had to be first subjected to rig tests. Therefore, a test method was prepared and the tests were carried out on a stationary test rig, with using a facility that had already been in service and was designed and made at the Department of Vehicles and Fundamentals of Machine Design of the Technical University of Lodz.

Examples of time histories of the quantities measured during the rig tests of the prototype ASR system have been shown in Fig. 3.

![Fig. 3. Time histories of pressures in the piston-spring part of the brake actuator and of control signals for the relay-control valve 4311, measured at control signal frequencies of 0.5 and 1 Hz and at a mark-space ratio of 0.5.]

3.3. Road tests

Satisfactory results obtained from the simulation tests and rig tests made it possible to implement a prototype ASR system in a Jelcz 317 W truck-tractor belonging to the Department of Vehicles and Fundamentals of Machine Design of the Technical University of Lodz.

The road tests were carried out on a test track with a surface of $\mu_s=0.2/0.6$ adhesion coefficient, with the use of the vehicle as mentioned above.

During test drives, time histories of the following quantities were recorded by the measuring apparatus installed in the test vehicle:
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- Linear velocity of the vehicle centre of mass;
- Peripheral speed of the left and right wheels of the live axle;
- Pressure in the piston-spring chambers of the live axle brake actuators;
- ASR valve control signals.

Examples of time histories of the quantities measured and recorded during the road tests have been shown in Figs. 4 and 5.

The test results showed that the functioning of the ASR system in the conditions of a homogenous road surface with a low adhesion coefficient reduced the average value of the driving wheel slip, defined as the ratio of the difference between the peripheral wheel speed and the vehicle speed to the peripheral wheel speed, by about 20% in relation to that obtained by the vehicle without ASR. When the ASR system was used during vehicle acceleration on a road with "μ-split" surface then the average value of slip of the driving wheel moving on the road part with a longitudinal adhesion coefficient of μ=0.2 was reduced by about 40%, thanks to which the vehicle acceleration was significantly increased.

![Fig. 4. Vehicle acceleration on a road surface with a low adhesion coefficient (μ=0.2), with an ASR system (regulation by applying brakes)](image1)

![Fig. 5. Vehicle acceleration on a "μ-split" road surface (μ=0.2/0.6), with an ASR system (regulation by applying brakes)](image2)
4. Conclusions

The presented stages of work on the new ASR concept provided grounds to formulate conclusions as given below.

1. The simulation tests and the optimisation that followed confirmed both the model developed and the algorithm of the proposed system design to be correct.

2. Thanks to the simulation test results, a prototype ASR system could be made with the application of standard components of compressed-air brake systems.

3. The rig test results met the requirements of UN ECE Regulation No. 13.

4. The road tests confirmed the prototype ASR system to function correctly.

5. The road tests showed that the prototype ASR system functioned properly as an "overlay" added to an air brake system and that it was additionally capable to cooperate with the engine control system in reducing the vehicle driving torque.

The work results obtained and the experience simultaneously acquired have enabled the authors to formulate the following recommendations and guidelines for the future.

1. It is recommendable to search for electrically controlled pneumatic system components of a new generation with shorter delay and higher operation speed.

2. Work should be carried out to optimise the locations of relay and control components of the vehicle pneumatic system in order to improve the effectiveness of operation of the ASR system.

3. Further work on the presented concept of the ASR system should include studies on the impact of diameters and lengths of the pneumatic control pipes on the quality of system operation.

4. The influence of a quick-release valve cooperating with the relay-control valve should be tested to answer a question whether the system operation speed might be raised by modifications introduced in this field.

5. Research work should be carried out to optimise the pressure operating the relay-control valve.

6. Work should also be carried out to extend the range of application of the new ASR concept to other vehicles and machinery provided with compressed-air brake systems.
References


