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PIOTR DOBRZANIECKI*

ACTIVE SYSTEM FOR CONTROL OF OPERATIONAL PARAMETERS OF MINE DIESEL LOCOMOTIVE DRIVE

AKTYWNY SYSTEM KONTROLI PARAMETRÓW PRACY UKŁADU NAPĘDOWEGO GÓRNICZEJ LOKOMOTYWY SPALINOWEJ

A b s t r a c t

Requirements for better reliability, durability and effectiveness of the suggested means of transportation make the need of using state-of-the-art control systems and the system managing the work of the various vehicle components, such as the engine, brakes, etc. ABS, ASR, ESP and other systems are well known and widely used in the automotive industry. The traction control systems, eliminating the negative phenomena in the transient operation of driving systems are also met in rail vehicles. As there are no such solutions for narrow-gauge railway vehicles, including those used in mining plants, the system for control of operational parameters of the driving system of a mine diesel locomotive is suggested. The method for measurements of vehicle speed is indicated and use of these data in an adaptive system which adapts the operation of the driving system to the current contact conditions between wheel and rail is indicated.

Keywords:diesel drive, mine rail locomotive, traction control system

S t r e s z c z e n i e

Rosnące wymagania odnośnie do niezawodności, trwałości i efektywności proponowanych środków transportowych powodują, że niezbędne jest stosowanie nowoczesnych systemów sterujących i zarządzających pracą poszczególnych układów pojazdu, takich jak silnik spalinowy, układ hamulcowy itp. Powszechnie znane i stosowane w motoryzacji są układy typu ABS, ASR, ESP i inne. Również w pojazdach szynowych spotyka się układy kontroli trakcji, zapobiegające niekorzystnym zjawiskom w stanach nieustalonych pracy układu napędowego. Wobec braku tego typu rozwiązań, przeznaczonych do wąskotorowych pojazdów szynowych, w tym tych stosowanych w zakładach górniczych, zaproponowano opracowanie systemu kontroli parametrów pracy układu napędowego, przeznaczonego dla górniczej lokomotywy spalinowej. Wskazano sposób realizacji pomiaru prędkości pojazdu i zaproponowano wykorzystanie tych danych w adaptacyjnym układzie dostosowującym pracę układu napędowego do aktualnych warunków współpracy koła z szyną.

Słowa kluczowe: górnictwo, napęd spalinowy, górnicza lokomotywa spalinowa, system kontroli trakcji

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* Ph.D.Piotr Dobrzaniecki, Division of Roadway Systems Institute of Mining Technology KOMAG, Gliwice, Poland.

1. Introduction

Active systems for controlling traction parameters are commonly used in transportation, especially in the mining industry. ABS, ASR, ESP and other systems are examples. These systems increase effectiveness of operation of drive transmission during both acceleration and braking. The traction control systems also enable limiting the overload of driving systems through active adaptation of applied torque to the momentary possibilities of its transmission to the carriageway. The ABS system can also be used in rail vehicles. However, so far such systems have not been used in driving the machines such as the narrow-gauge locomotives used in mining plants. Suggestions for solutions to an active system for the control of traction parameters on the example of a Lds-100 mine rail locomotive are given.

2. Systems for control of traction parameters of rail vehicles

Systems which increase the efficiency of transmission of traction torque and braking forces to the carriageway are commonly used in the automotive industry. Cars have advanced systems for control of transition parameters, which enable intervention regarding transmission of forces in the driving system. Advanced control systems enable selective control of operational parameters of each wheel (braking, reduction of applied torque), which improves significantly drive efficiency and safety. ABS (anti-lock braking system) or ASR (acceleration slip regulation) are examples. These systems (ASR acceleration slip regulation system and analogous TCS, ASC+T and other systems) maintain the neutral traction properties of the vehicle (especially steering ability) by intervention in a degree of transmission of driving force and braking force by each wheel (in the latest version of the systems). ABS, in cooperation with other systems enables control over the vehicle during manoeuvring on slippery surfaces and keeping the required track.

The problem of maintaining the vehicle on the route when its speed and load is within the limits does not apply to rail vehicles. However, in this case, some wheel slippage can occur during acceleration and wheels can be blocked with slippage during braking. When wheels are blocked during braking they can be locally worn out deforming the rings. As a consequence of frequent blockage of wheels earlier repairs of locomotive wheels are required.

Manufacturers of locomotives intended to be used on tracks of width S = 1435 mm offer advanced control and diagnostics systems in their new products. Such advanced systems enable full automation of the locomotive with keeping the speed set by the operator, as well as control of start-up, acceleration and braking operations through an anti-slippage system with individual action on each wheel and with adjustment of braking force. The GRIFFIN and DRAGON locomotives presented in Fig. 1 and 2 are examples.

In the GRIFFIN locomotive, the driving system with two two-axle carriages in Bo'Bo' arrangement is used. In the case of the DRAGON locomotive the driving system has two three-axle carriages in Co'Co' arrangement with an individual drive for each axle [1]. Analysis of the parameters of each motor's power supply as well as the individual character of the drive enable the state of each axle to be determined and, in connection with information about electric parameters, we are provided with complete data about the transmission of drive torque and braking force. Such a solution increases the effectiveness of machine operation

Fig. 1. GRIFFIN electric locomotive manufactured by NEWAG Group [1]

Fig. 2. DRAGON electric locomotive manufactured by NEWAG Group [1]

and also limits overloads and protects against excessive wear of the components which as a result increases the reliability and life of the entire system.

In locomotives used in the mining industry there are no solutions that would prevent against slippage during acceleration or braking. Only hydrostatic braking in the case of hydraulic motors and electrodynamic braking in electric motors are possible. Recovery of energy during braking is possible, when the motors operate in generator mode; however, slippage is still possible. In the case of a hydro-mechanical drive transmission, proper selection of diesel engine and hydrokinetic gear enable reducing the slippage during start-up, but cannot eliminate blocking of wheels during braking. Further in the paper, the drive of a mine diesel locomotive is presented, as well as the method of speed measurement, and new solutions increasing the efficiency of traction torque transmission are given.

3. Lds-100 locomotive driving system

The Lds-100 locomotive has a hydro-mechanical system for drive transmission which is presented in Fig. 3.

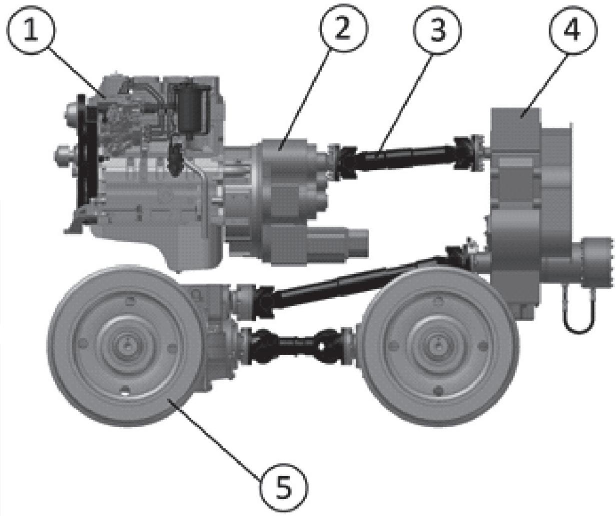

Fig. 3. Diagram of Lds-100K-EMA locomotive driving system [6]

where:
1 – Diesel engine
2 – Hydrokinetic gear
3 – Jointed shaft
4 – Reversible gear
5 – Wheel sets with a gear

Driving torque in the diesel engine is transmitted by jointed shafts through a hydrokinetic gear, reversible gear and intersecting axis gear of wheel sets. There is no differential gear in wheels (pos. 5) what means that all wheels have the same rotational speed. The linear speed of the locomotive is determined using an inductive sensor installed on the reversible gear's body. A special disk, revolutions of which are recorded by a sensor, is installed on the shaft flange. Information about the revolutions is transmitted to the locomotive control system and, after taking the velocity ratio for the place of the sensor installation into account, it is displayed on the operator's control panel as the locomotive speed. This information is also sent to the control system. Control only of rotational speed does not give the full information required to determine the condition of the system. In the case of slippage, which is controlled by the operator in a limited way, there are dynamic overloads to the drive system and that speeds up wear of its components (shafts, gears) and reduces the efficiency of driving system. In this case, much depends on how the vehicle is run by the operator. The efficiency of using operational parameters of the machine depends on the driver's strategy. Slippage during vehicle start up also overloads the hydrokinetic element and increases the temperature of the working medium, which reduces its efficiency. Increase in the temperature of the working medium in the hydrokinetic gear has a negative impact on its lifespan. The adaptability of a system equipped with traction control parameters and active mechanisms supporting the operator would increase the safety and reliability of the machine. Due to the fact that there are no practical solutions of the systems for identification of operational parameters, the paper presents a suggested system, which, by comparison of two independently determined vehicle speeds, would identify frictional coupling between wheels and rail and would control the actuating components of the driving system to adapt operational parameters (engine rotational speed, braking force) to the actual conditions.

4. System for control of traction parameters of mine diesel locomotive

The suggested active system for the control of traction parameters is based on the comparison of two vehicle speeds determined in relation to two reference systems. A schematic diagram of the system is presented in Fig. 4. The suggested method is a universal one and after some adaptation, it can be applied in vehicles with different driving systems.

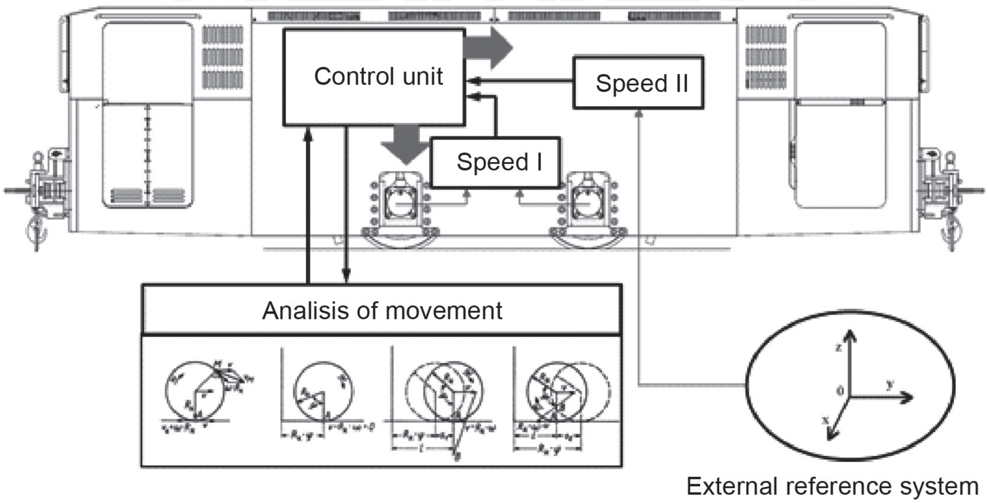

Fig. 4. Schematic diagram of the system for control of traction parameters

The principle of its operation is based on the simultaneous measurement of rotational speed in the selected place of the driving system as well as the linear speed of the vehicle in relation to the reference systems (objects on the carriageway on which the vehicle moves). Transformation of rotational speed in the driving system to the linear speed of the vehicle (using the right gear ratio) and its comparison with the linear speed measured in relation to the reference systems enable identifying movement condition according to the following criteria:

- $[n_1 \Rightarrow v_1] > v_2$ – slippage of driving wheels,
- $[n_1 \Rightarrow v_1] = v_2$ – stable operation,
- $[n_1 \Rightarrow v_1] < v_2$ – slippage of driving wheels,

where:
n_1 – rotational speed in the driving system,
v_1 – linear speed of the vehicle, determined from the rotational speed in the driving system,
v_2 – linear speed of the vehicle measured directly.

Identification of the real condition of the driving system is the input information to be used in controlling the traction parameters by actuating systems, responsible for engine operational parameters (rotational speed) and braking parameters.

In Fig. 5 the concept of the model system for the analysis of an active system for control of traction parameters is given.

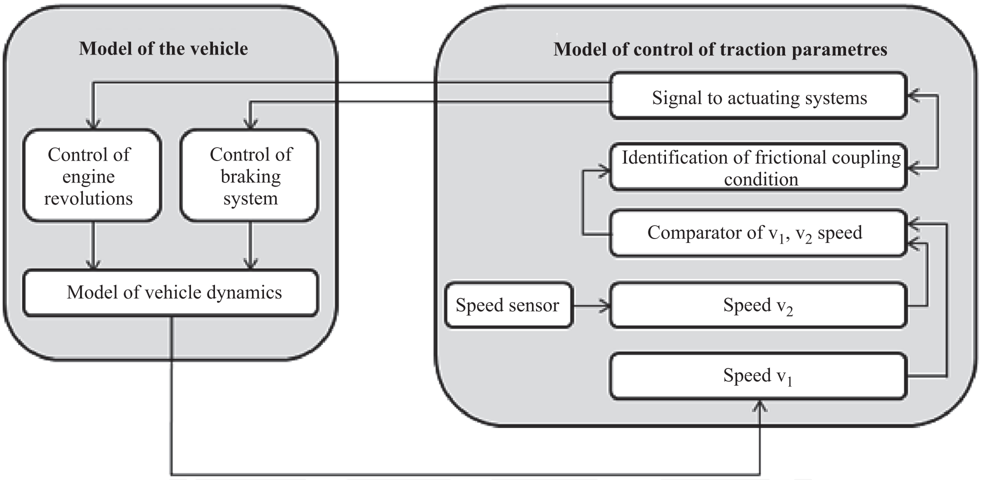

Fig. 5. Model of the system for control of traction parameters cooperating with a rail vehicle

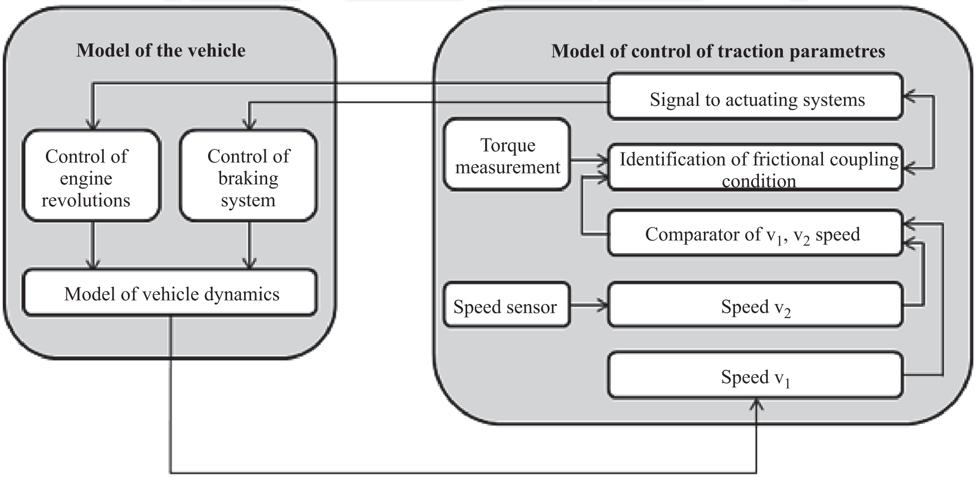

Fig. 6. Model of the system for control of traction parameters cooperating with a rail vehicle. Version with a torque sensor

The suggested model of the system for control of traction parameters can also be connected with a torque sensor installed in the vehicle driving system that enables better analysis of the drive transmission system. A schematic diagram of the model system is given in Fig. 6.

The manner of using the torque sensor in the locomotive driving system is explained in [4].

The system can be developed by use of special software e.g.:

- MATLAB/Simulink,
- packet ANSYS,
- MSC ADAMS.

Tests of each solution of the control system will be carried out using the model system. It will enable the required corrections to be made, system tuning and optimization as regards its required parameters considering limitations resulting from features of the vehicle, actuating components, controlled objects and control-and-measuring instruments.

5. Method of additional speed measurements

An optical sensor placed over the rail head is planned to be used to determine v_2 speed (as in Fig. 5 and 6). The suggested method of speed measurement is used among others to determine the movement of rolled metal sheets. A simplified method of the optical sensor operation is shown in Fig. 7.

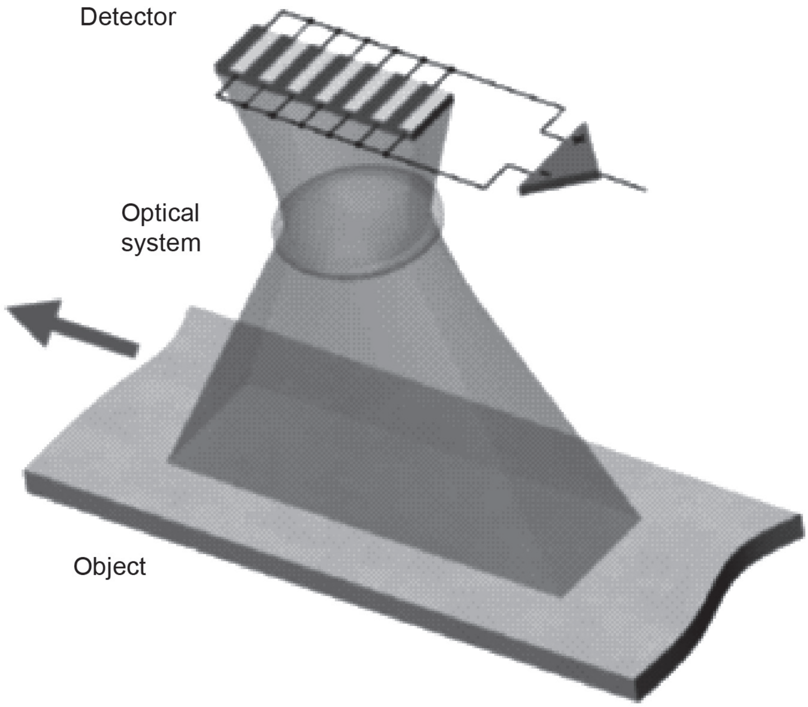

Fig. 7. Method of optical sensor operation [2]

Measurement of speed with use of the abovementioned sensor requires its installation in a place, where its proper operation is possible. In the case of an underground locomotive additional lightening may be required to improve sensor operation. The recommended method of sensor assembly is given in Fig. 8.

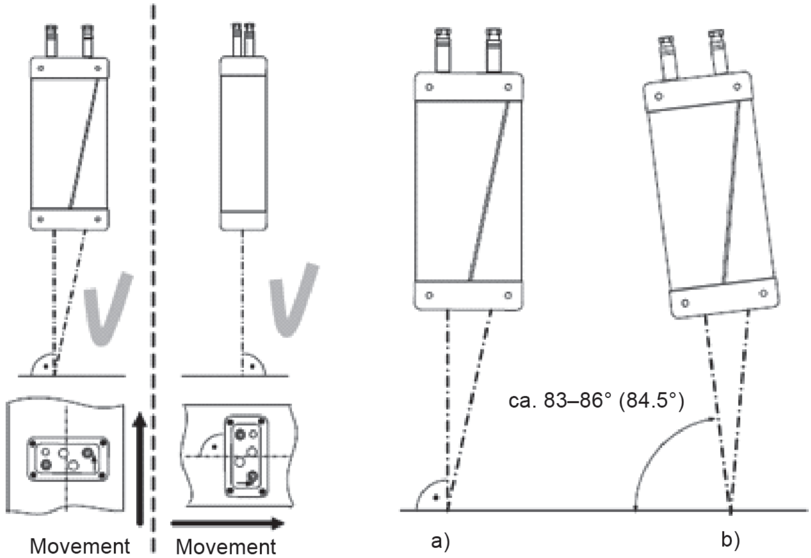

Fig. 8. Recommended method of the optical sensor assembly [2]

In the case of harsh operational conditions, the offered sensors are equipped with protective enclosures. Micro-Epsilon's device is an example [2].

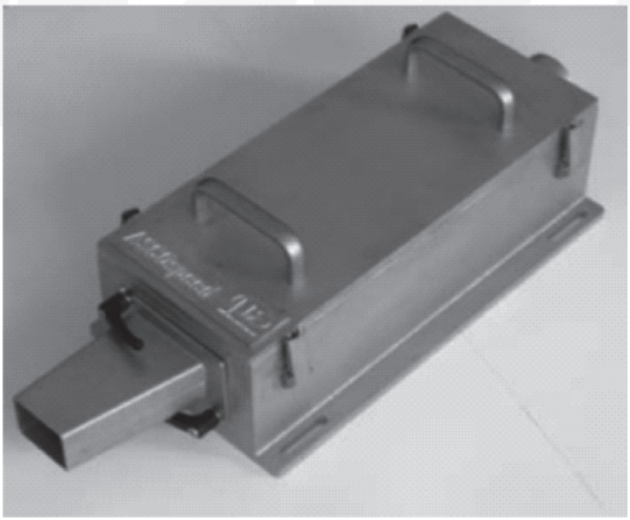

Fig. 9. Sensor's protective enclosure made of stainless steel [2]

The usability of modules, which are available on the market and used also for positioning of quadcopter units, should be indicated. An example of the PX4FLOW module is described in [3]. The module is offered as presented in Fig. 10.

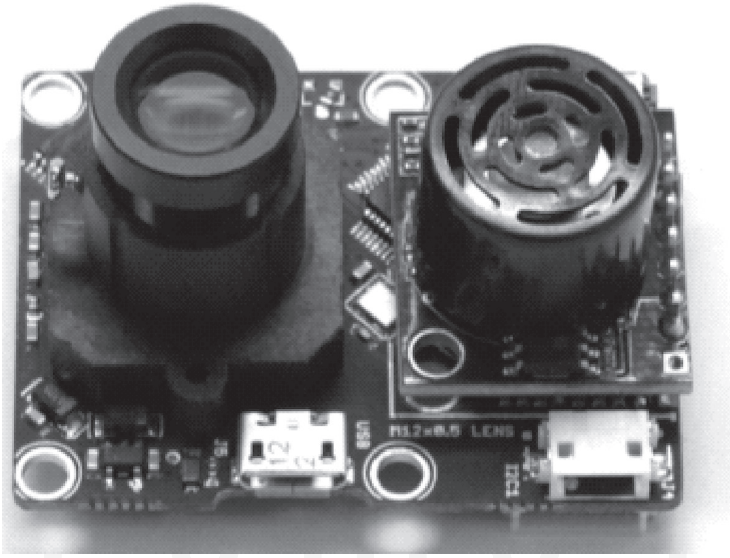

Fig. 10. Module PX4FLOW [3]

It is also possible to use other sensors, which have a similar principle of operation, e.g. use the optical sensor of a computer mouse [3]. However, it requires verification tests to confirm their usability in the specific conditions, as well as to select indispensable additional equipment such as lighting or an air nozzle to clean the lenses of object glasses.

6. Potential advantages of the developed system

Because the suggested solution does not have its equivalent in the state of the art, its advantages go beyond the product's quality improvement. Damage to drive transmission systems is the main reason for the failure of vehicles used in transportation. Slippage and overload of the driving system, occurring during acceleration and braking, is the main reason of such damage. Traction conditions of the drive system should be monitored to avoid such situations. Reduction of overloads to the drive system can increase its reliability and reduce the costs of maintenance of the transportation vehicle. Improved efficiency of the drive transmission system also increases the operational safety.

Total elimination of unwanted occurrences would result in the reduction of operational costs associated with replacement of damaged components of the drive system. Total costs are not only the cost of components but also servicing costs and the cost of breakdowns. Repair services made during locomotive operation concern the following components:

- hydrokinetic gear,
- jointed shafts,
- reversible gear,
- gears at wheel sets,
- rims of wheel centres.

Elimination of unwanted conditions in the drive system, like slippage, can increase its life and improve its reliability. Additionally it can reduce the operation of engine at highest operational parameters (revolutions, fuel consumption). Automatic adaptation of engine operational parameters (revolutions, fuel consumption) to the actual conditions (transported load, parameters of wheel-rail coupling, inclination) will enable avoiding the engine operation at too high power. In the case of a drive system without control of traction parameters, too high power generates too high torque, which in consequence causes a break in wheel adhesion and driving force is lost. Higher fuel consumption is an additional disadvantage as the quantity of harmful substances in exhaust gases emitted to the work environment increases. Thus, it is recommended to develop a technical solution that would eliminate these disadvantageous conditions in drive system operation.

7. Summary

The method for using the additional measuring equipment described in the paper is the first stage of the project aimed at developing an innovative system for controlling traction parameters, intended to be used in mine rail vehicles. Proper operation of the suggested optical sensors and the use of carriageway objects as the reference system will enable them to be used in an active system for the control of traction parameters. In addition to the measurable benefits resulting from the elimination of disadvantageous traction conditions with overload to drive system components, there are also not measurable benefits associated with exposure of workers to exhaust gases containing harmful substances. The negative impact of such substances in exhaust gases like carbon monoxide, nitrogen oxides, and hydrocarbons as well as other substances has been confirmed, so emission of exhaust gases should be maximally reduced. There is an additional benefit, which is difficult to be described using simple quantitative relationships, which reduces the factor responsible for increasing the incidences of certain types of diseases [5]. Research work associated with development of the suggested system will be realized in a mechatronic project, which combines different fields of knowledge. The project will require tests with use of the real available machines as well as with use simulation models.

References

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