vehicle dynamics; ABS simulation; ABS logical block

Maxym DYACHUK
Prydniprovsk State Academy of Civil Engineering and Architecture
Chernyshevskogo Street, 24a, 49600, Dnipropetrovsk, Ukraine
Corresponding author. E-mail: m_dyachuk@mail.ru

MODELING OF TRUCK'S BRAKING DYNAMICS WITH ABS

Summary. In the article some questions of ABS simulation on the basis of plane vehicle's dynamics and automatic modeling are considered. The author's algorithm of ABS modulators control is presented.

МОДЕЛИРОВАНИЕ ТОРМОЗНОЙ ДИНАМИКИ ГРУЗОВОГО АВТОМОБИЛЯ С ABS

Аннотация. В статье рассматриваются вопросы имитационного моделирования системы АБС на основе автоматического моделирования плоской динамики транспортных средств. Представлен авторский алгоритм управления модуляторами АБС.

1. TOPICALITY

The vehicle's intellectualization is one of the most demanding directions of modern automotive industry today. It became possible due to intensive development of the microelectronic industry for the last 20 years.

Automation and control of vehicle's nodes, systems and aggregates by rather new direction – mechatronics are provided. In the field of vehicles the mechatronics is based on the scientific direction "vehicle dynamics" which has been intensively developed in Europe from the 60s.

As development of electronic devices (controllers) is a prerogative of automatics experts, tasks of mechanics specialists are the following: development of the general principles of functioning of mechatronics devices, algorithms of controlling, development of regulation criteria, information sources definition (sensors).

ABS is one of the most important means of vehicle's braking properties and its active safety. Despite the number of already developed ABS types, the improvement of systems and their rivalry are displaced in area of control algorithms, which are realized as a software code in ECU. Thus the role and weight of "an intellectual part" grows in costs of ABS type systems.

2. RESEARCHES ANALYSIS

Such scientists and sources as R.R. Guntur [1], T.D. Day & S.G. Roberts [2], E. Sokolovskij [3], Ming-Chin Wu, Ming-Chang Shin [4], K.Z. Rangelov [5], Wijaya, Moh. Lutfi [6], Bosch automotive handbook [7], etc., offered ABS control algorithms description.

ABS basics are considered in the work [1]. Results of laboratory experiments, methods of threshold values determination and system control are given. Justifications of adaptive braking control usage are given. Optimal criteria of a wheel blocking are defined. Criteria for definition of a wheel blocking are: fixed threshold value of angular deceleration; relation of angular deceleration and angular wheel speed; the combined criterion on angular deceleration and the relation of angular deceleration and wheel's angular speed. For theoretical researches the car model had 2 axes and a plane. For algorithm of ABS the characteristic "μ-s" is used (Tire slip algorithm). Two types of modulators were used in experiment: the on-off modulator has one valve on a wheel (two position valve); modulator works by 4 phases and has 2 valves (inlet and outlet). It is not absolutely clear how modulator works. A number of parameters which allows to adjust system in a first approximation are defined in work.

Work [2] describes the new ABS model realized in the HVE simulation environment. It is the general model suitable for usage with HVE compatible vehicles simulation. The model is applicable for the development of ABS and also for road accident probe at loss of roadability of ABS equipped cars. For the first time basic control and characteristics of usual ABS control are considered. Dependences on pressure from time for two simulations of ABS on road surfaces with various characteristics of adhesion were compared with experimental data. We should also note a very interesting study of automobile braking discussed in the article [3].

The algorithm of Bosch ABS system is used in simulations and based on wheel acceleration and critical threshold value of wheel slip.

The nonlinear mathematical model of ABS [4] was constructed; simulations and experimental research of ABS were executed. Two controllers of a sliding mode are developed and tested: the first realizes the pulse-width modulation; the second is a switching adjuster. Comparison of simulation results and experiment received by these two control methods is considered. Controlled emergency braking by means of the standard electronic control package was also executed at the dynamic test bench and was compared with the results of the developed system. Results of simulations of the offered mathematical model of ABS are well corresponded to experimental data. The advantages are: nonlinear mathematical model of the hydraulic modulator and braking system of a car; Simulink ABS model is presented; simulation of emergency braking from ABS on various road surfaces; usage of test bench; the algorithm of ABS model is based on determination of optimal adhesion coefficient according to the characteristic "μ-s" (Tire slip algorithm); bench tests were carried out with the regular ABS and the braking system equipment; in simulations, proceeding from the given ABS model, the criterion of a blockage of a wheel in the form of wheel slippage was used. The shortcomings are: vehicle model is the mathematical quarters model of a car; for the description of pressure increase and decrease when opening and closing valves the normalized characteristics of opening percent of the valve depended on time were used; ECU working algorithm is stitched by the producer and is not presented in the article.

In thesis [5] the model of a car's quarter is investigated and used for study of braking efficiency at rectilinear vehicle's braking on smooth and uneven road surface by the Matlab/Simulink software. The model of the vehicle includes suspension model, tire model (SWIFT) and the ABS model. The developed ABS model includes the modulator of a braking pressure and the block of the central processor. The model of the central processor block consists of signal processing block model and logical controller block model. During research of braking efficiency various criteria of definition of a wheel blockage were used. Comparisons of braking distances on smooth and uneven road surface are executed when using these criterias. In addition, control strategy is tested. The strategy is based on the assumption that information of tire load and tire moment transmitted to road are known.

Results of simulation were used for determination of distinction between criteria of a wheel blocking and their influence on a braking distance. On the smooth road the best braking efficiency was reached when criterion of brake torque control was a tire moment. The following criteria in the list defined efficiency and relation between wheel peripheral acceleration and wheel peripheral speed (algorithms of Bosch ABS are used): wheel peripheral deceleration; wheel slip; combined criterion of peripheral deceleration and wheel slip; relation of wheel's peripheral deceleration and peripheral speed; tire moment.

Thesis [6] describes intellectual approach to ABS control, using a gradient descent method for online adaptation of the sliding mode controller with fuzzy logic (online Fuzzy-Sliding Mode Controller). It is a new method applied on ABS that considers determination of studied parameters for minimization of a prediction error between desirable and valid output value in a feedback control cycle. The fuzzy system (with fuzzy logic) includes adaptive fuzzy-neural output system (on-line Adaptive Neuro-Fuzzy Inference System) by means of training of the entrance and output data of ABS based on control of a mode of sliding. This theory also describes new approach to robust control of ABS using the scheme of active forces control (Active Forces Control). The main goal of the offered control strategy is to control optimum value of ABS wheel sliding which includes nonlinearity, uncertainty of parameters and disturbances to prevent controlled wheels from coming full blocking. Simulation was strictly executed on the simplified model of a car quarter braking. The comparative analysis of control strategy for demonstration of distinctions in productivity is made. Simulation results showed that strategy online of FSMC showed the superiority in ABS control, than in strategy of SMC (Sliding Mode Control). Also simulation showed better robustness of AFC scheme even in the disturbances presence.

3. TASK STATEMENT

Modeling of anti-blocking system for one wheel consists in the following: creation of a wheel's dynamic model, modeling of an executive part, synthesis of controller operation algorithm. Modeling of truck's braking dynamics with ABS consists in ABS logic block algorithm's usage in a vehicle dynamic model.

4. ACCEPTED ASSUMPTIONS

The following assumptions are accepted in cause of task simplification: a wheel is longitudinally absolutely rigid; the nonlinear characteristic of the tire's adhesion factor with a road surface is fixed for a certain type of road (the characteristic "friction - slip"); transitional characteristics of modulator's valves operation are not considered; forces of wheel rolling resistance are neglected in cause of small influence; velocities of wheels centers are calculated by integrating of dynamics equations.

5. MAIN PART

The camion wheel tire 295/80R22,5 with equipped ABS pneumatic brake contour is chosen as object of modeling. The closed cycle of control based on angular acceleration as a wheel locking criterion is accepted in ABS model.

The characteristics of adhesion coefficients (Fig. 2) are given on the basis of [x], which represents the overall trend and are not clarified for a specific tire. This doesn't affect the essence of the control process, which should be adequate regardless of a curve's shape and a local maximum's position.

Let's present flat wheel dynamics in a brake mode. Vertical loading, road reaction, brake moment and also inertial power factors - act on a wheel movement (fig. 1). Road longitudinal reaction R_x:

$$R_x = \varphi_x \cdot R_z = \varphi_x \cdot m_{gw} \cdot g \tag{1}$$

where: φ_x - longitudinal adhesion factor; m_{gw} - mass of a wheel with vertical loading; g - free fall acceleration.

The adhesion factor φ_x of tires with a road surface is determined by interpolation of tabular data depending on slip s (fig. 2). Slip factor of a wheel is expressed as follows:

$$s = 1 - V_{theor}/V_{real} = 1 - \omega_{theor} \cdot r_{eff} / (\omega_{real} \cdot r_{eff}) = 1 - \omega_{theor}/\omega_{real} \quad (2)$$

where: V_{theor}, ω_{theor} – are theoretical linear and angular speeds corresponding to a wheel's free mode rolling respectively; V_{real}, ω_{real} - the actual linear and angular speeds corresponding to a wheel's braking mode with sliding respectively; r_{eff} - dynamic effective radius of a wheel rolling.

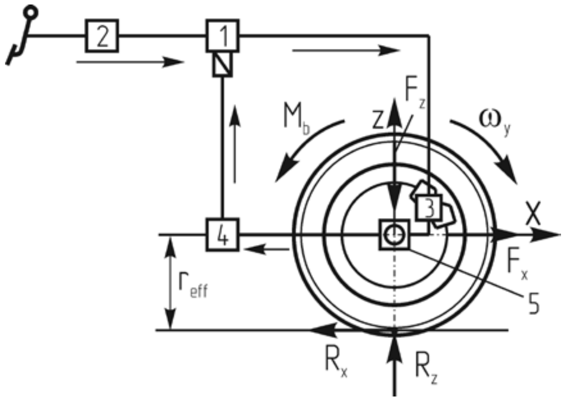

Fig. 1. The scheme of forces action on a wheel in a brake mode and ABS control circuit [7]: 1 - hydraulic modulator; 2 - brake master cylinder; 3 - wheel brake cylinder; 4 - ECU; 5 - wheel's angular velocity sensor

Рис. 1. Схема действия сил на колесо в тормозном режиме и контур управления ABS [7]: 1 - гидравлический модулятор; 2 - главный тормозной цилиндр; 3 - колесный тормозной цилиндр; 4 - ECU; 5 - датчик вращения колеса

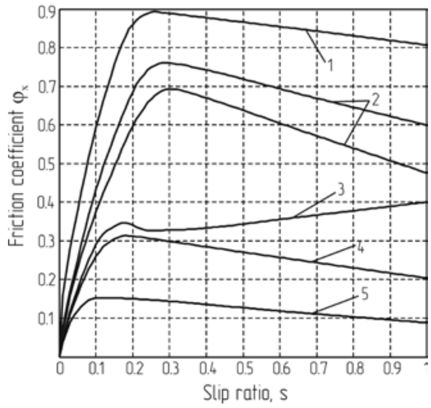

Fig. 2. Dependences of adhesion factor on slip ratio [8]: 1 - dry asphalt; 2 - wet asphalt; 3 - fresh-fallen snow; 4 - rolled snow; 5 - ice

Рис. 2. Зависимости коэффициента сцепления от коэффициента скольжения [8]: 1 - сухой асфальт; 2 - мокрый асфальт; 3 – свежевыпавший снег; 4 - укатанный снег; 5 - лед

Braking torque for a disc brake:

$$M_b = 2 \cdot S_p \cdot p_b \cdot \mu_b \cdot R_{fric} \quad (3)$$

where: S_p - brake cylinder piston area; p_b - pressure in a brake hydraulic circuit; μ_b - friction coefficient; R_{fric} - average friction radius.

The equations of wheel movement not connected with the camion in a brake mode are [9]:

$$\begin{cases} m_{gw}\, d^2x/dt^2 = -R_x \\ J_w\, d^2\phi/dt^2 = M_b - R_x \cdot r_{eff} \end{cases} \quad \text{or} \quad \begin{cases} d^2x/dt^2 = -R_x / m_{gw} \\ d^2\phi/dt^2 = (M_b - R_x \cdot r_{eff}) / J_w \end{cases} \quad (4)$$

where: $J_w = m_{gw} \cdot r_{eff}^2 / 2$ - is a wheel inertia; x is the longitudinal coordinate of a wheel's center, and ϕ is the angular coordinate of a wheel's rotation.

Programming and calculations are executed in the MATLAB/Simulink software. Further the Simulink-model of the logic control block [10] on threshold values of wheel's angular deceleration is presented. A control signal is the step impulse corresponding to the phases' changes commands of ABS cycles: 1 - pressure increase, -1 - pressure decrease, 0 - pressure delay (fig. 3).

The ABS algorithm is represented by a proportional controller, which controls a cycle's phases depending on the threshold values of angular accelerations. The logic block's input value is an angular wheel deceleration [e] (Fig. 3). After beginning of braking the angular deceleration's value increases. The threshold value of first cycle is limited to 80 rad/s^2 for faster increasing of braking torque. The subsequent cycles are limited by threshold deceleration value 35 rad/s^2 for a smoother regulation.

While the angular deceleration doesn't exceed a threshold value the logic unit instructs output signal "1" - the pressure increase. As soon deceleration exceeds a set value the output signal is changed to "-1" - pressure decrease. In this case the angular deceleration reduces its value. After that the angular deceleration changes sign and a wheel starts to accelerate. At this point, the logic unit generates a signal "0", which corresponds to a phase of pressure delay. The wheel's angular acceleration is also limited by threshold value. After exceeding the threshold value the output signal becomes "1" and the cycle repeats again. After the vehicle speed reaches 7 km/h ABS is disabled. Of course, the thresholds setting are individual and in this example it's defined by selection.

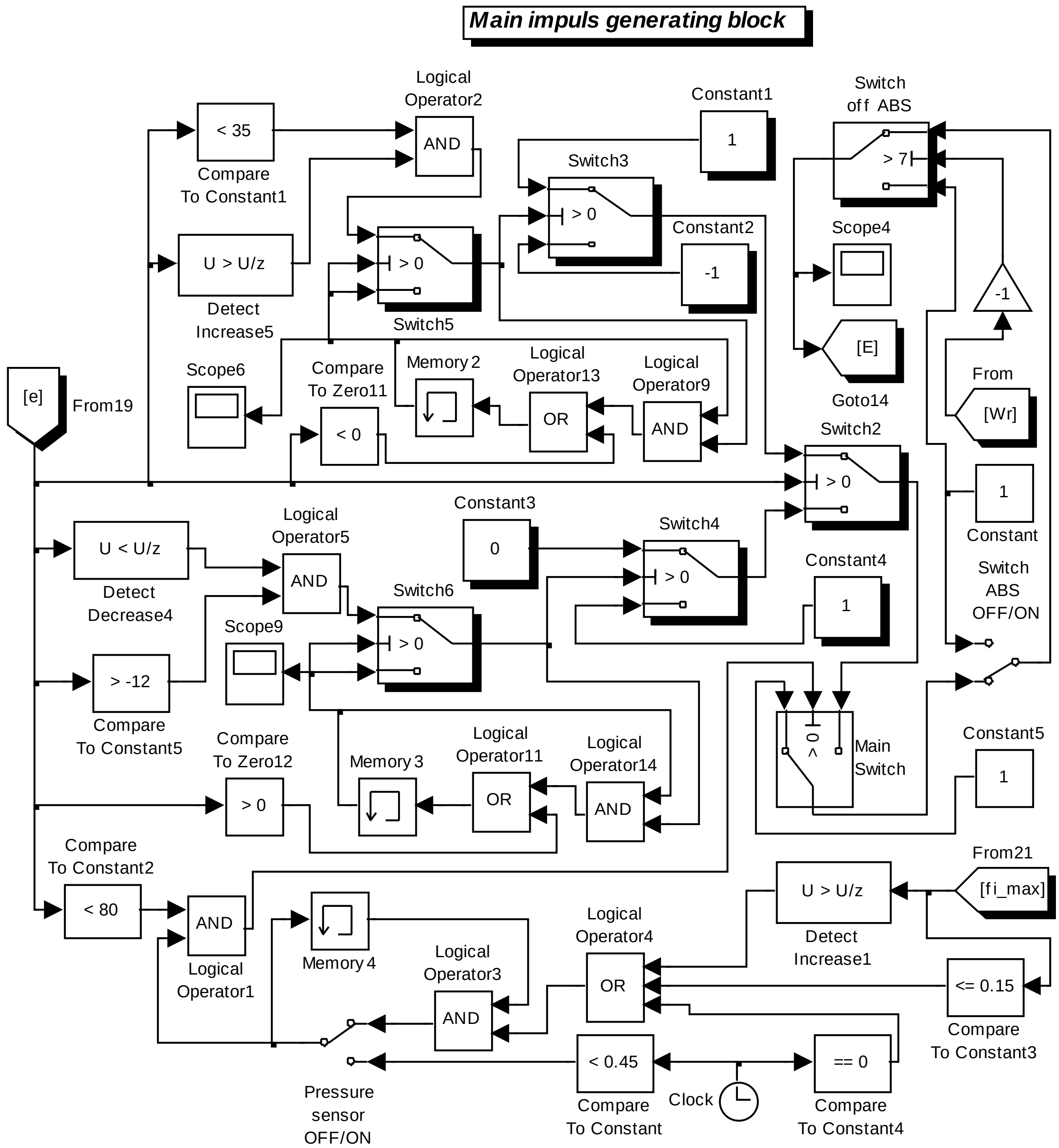

Fig. 3. Simulink model of ABS controller’s functioning algorithm by impulses generator
Рис. 3. Simulink модель алгоритма функционирования генератора импульсов контроллера ABS

6. RESULTS

For example we will simulate system processing when braking wheel is on the wet asphalt, and after, we will compare output characteristics with similar when ABS will be switched off.

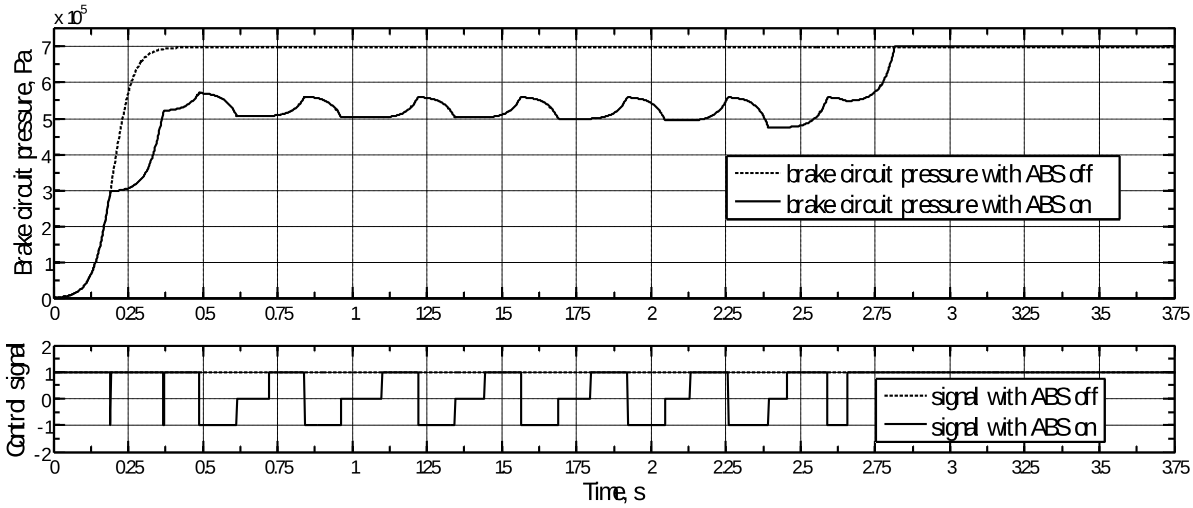

Fig. 4. Controller signal (above) and wheel brake cylinder circuit pressure (below) depending on time
Рис. 4. Графики сигнала контроллера (вверху) и давления в приводе РТЦ (внизу) в зависимости от времени

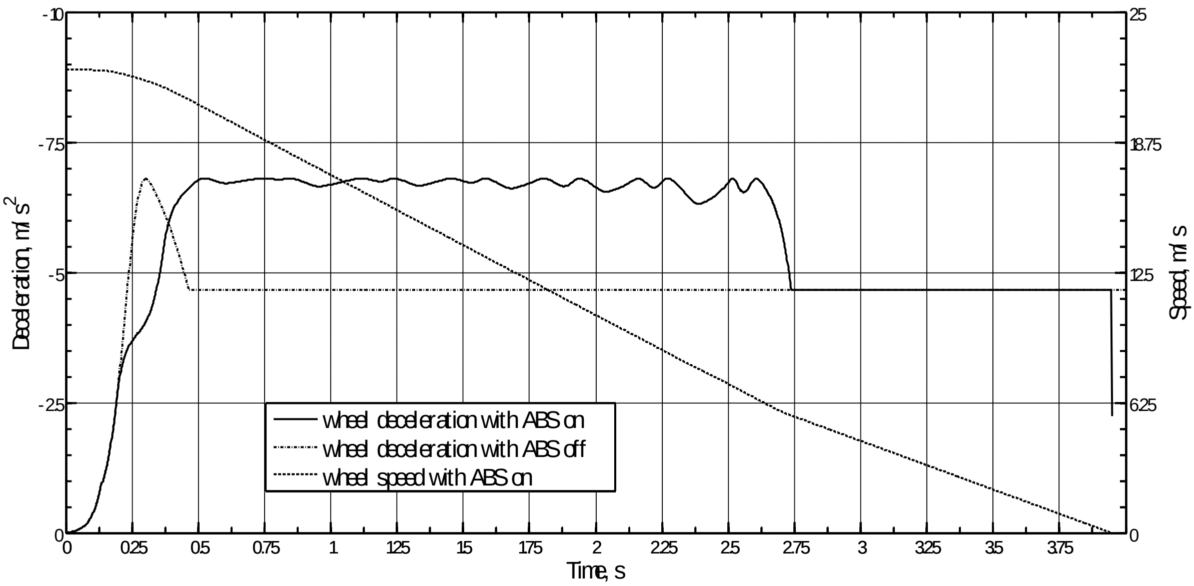

Fig. 5. Changes of wheel's linear velocity and deceleration
Рис. 5. Графики изменения линейных замедления и скорости колеса

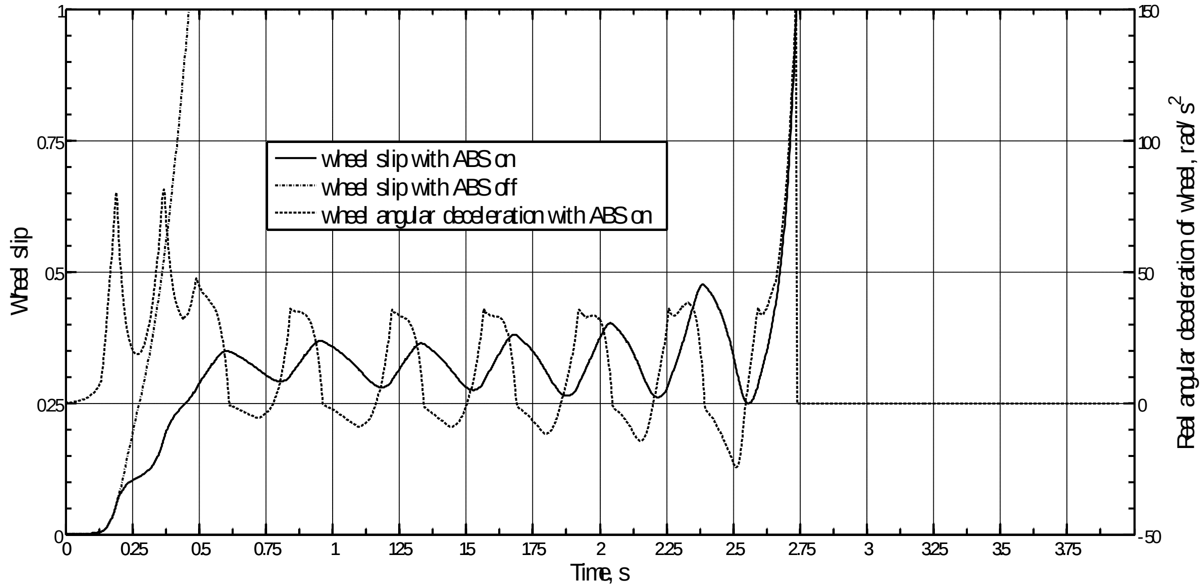

Fig. 6. Changes of angular deceleration and wheel slip ratio
Рис. 6. Графики изменения углового замедления и скольжения колеса

The initial conditions are following: emergency braking type, road surface's adhesion factor corresponds to the case of wet asphalt (Fig. 2); braking start velocity is 80 km/h.

Comparison of braking distances on fig. 8 shows that braking efficiency reaches 12,0 m from noncontrollable braking (43,4 m and 55,4 m respectively). ABS allows to hold optimum longitudinal adhesion and to realize deceleration about 6,7 m/s^2, while a locked wheel - only 4,6 m/s^2 (see fig. 5). Optimum slip ratio is kept on a value 0,3.

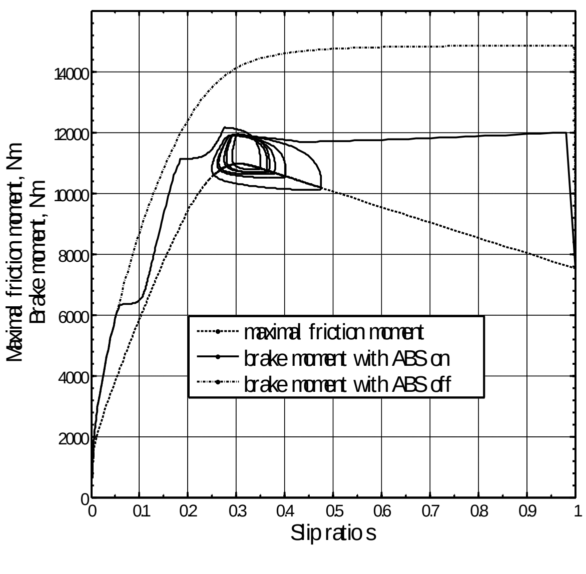

Fig. 7. Changes of braking moment and adhesion moment depending on wheel slip ratio
Рис. 7. График изменения тормозного момента и момента по сцеплению в зависимости от скольжения колеса

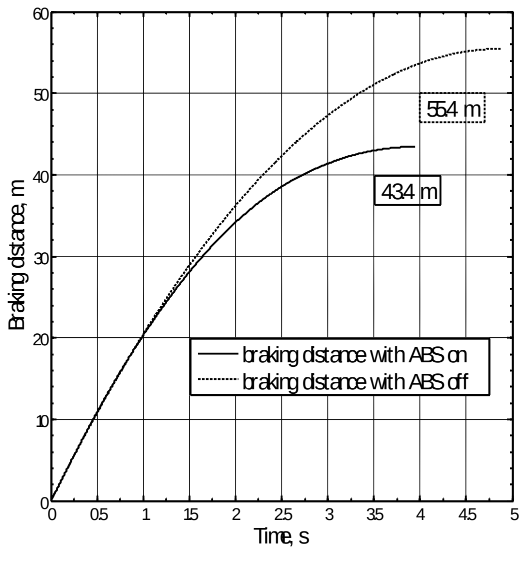

Fig. 8. Braking distance depending on time
Рис. 8. График изменения тормозного пути в зависимости от времени

7. CAMION BRAKE DYNAMICS

Control of wheel braking connected with a camion, becomes complicated by variable character of different factors: dynamic wheel radius, inertia of the rotating masses, vertical loading, etc. It leads to some distortion of brakes moments' regulation algorithm. For efficiency checking of the offered regulation algorithm based on an angular wheel deceleration we will simulate the camion model dynamics in a brake model. Dynamic model of camion Scania P94DB 4x2 NA 220 is generated automatically on the basis of earlier works series [11]. Control of wheels' braking moments is accepted by IR (Individual Regulierung) principle.

The solution of equations system is realized in MATLAB software. Discretization of system masses and graph description and also external action forces are presented on fig. 9.

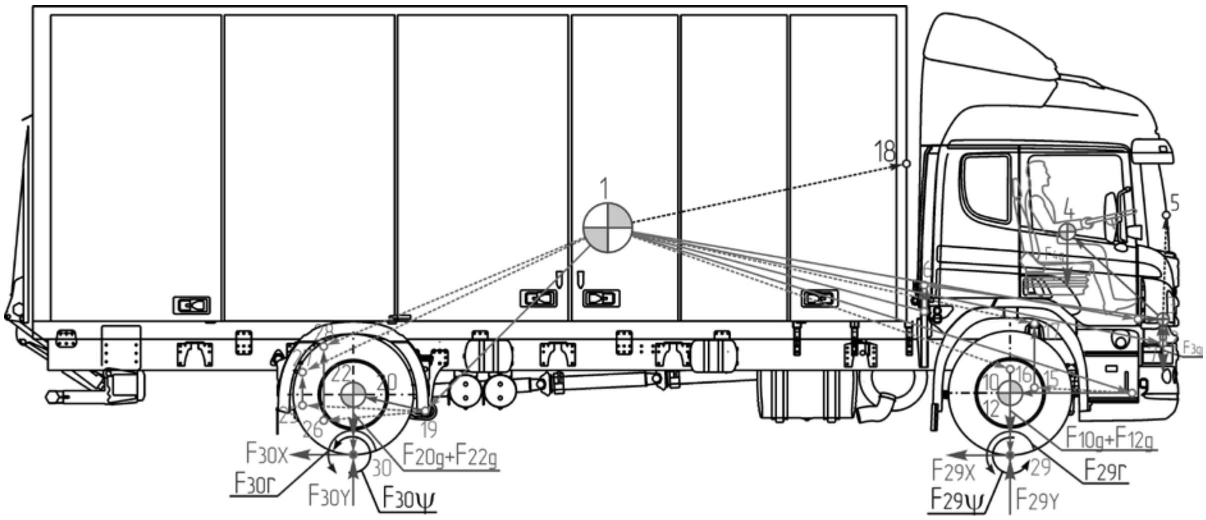

Fig. 9. Dynamic model of camion Scania P94DB 4x2 NA 220
Рис. 9. Динамическая модель грузового автомобиля Scania P94DB 4x2 NA 220

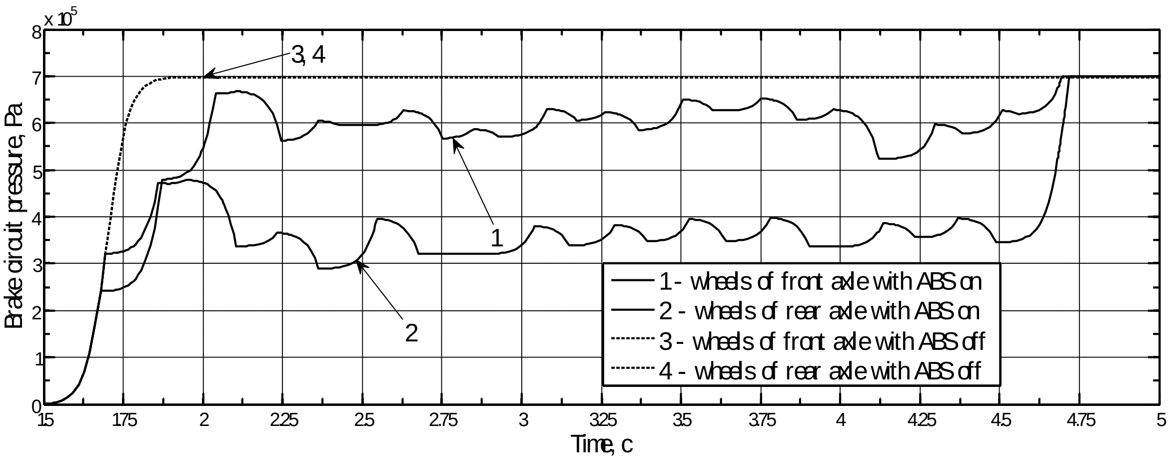

Fig. 10. Change of pressure in axes pneumatic circuits of Scania P94DB 4x2 NA 220
Рис. 10. Изменение давления в контурах осей автомобиля Scania P94DB 4x2 NA 220

The braking simulation's results of Scania P94DB 4x2 NA 220 on wet asphalt from initial speed 80 km/h is given for example. Results are presented graphically. Braking distances comparison on fig. 12 shows that braking efficiency with ABS is 9,7 m versus braking with switched off ABS (45,6 m and 55,3 m respectively). ABS allows to hold optimum longitudinal adhesion and to realize deceleration about 6,6 m/s^2, while a locked wheel - only 4,8 m/s^2 (see fig. 11). Optimum slip is kept at level 0,3.

8. CONCLUSION

It's proposed a simple algorithm for the ABS to demonstrate the feasibility of combining vehicle dynamics problems with its control systems simulation. The algorithm doesn't claim to innovation and its effectiveness is determined by simulation methods across comparing the braking process without ABS.

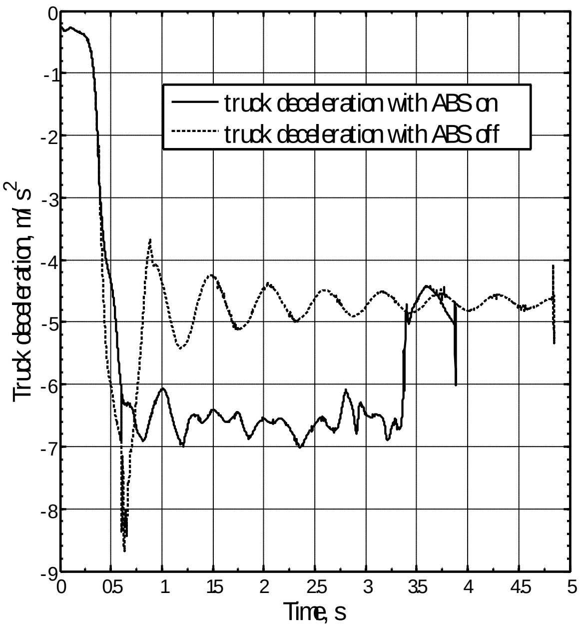

Fig. 11. Mass center point's deceleration of Scania P94DB 4x2 NA 220 body
Рис. 11. Замедление точки центра масс кузова автомобиля Scania P94DB 4x2 NA 220

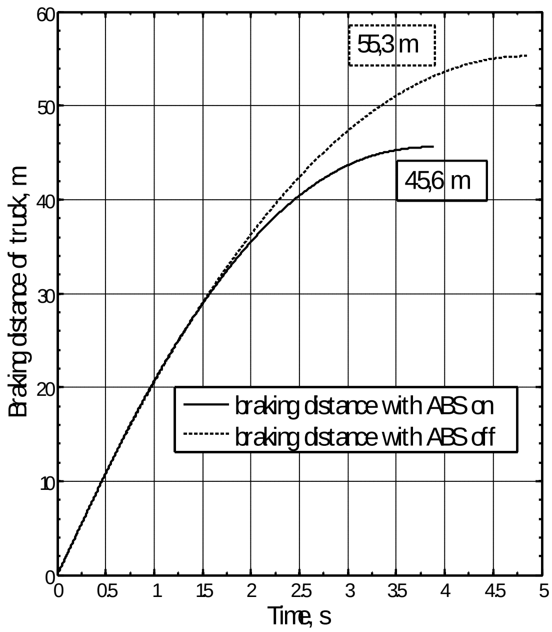

Fig. 12. Braking distance depending on time
Рис. 12. График тормозного пути в зависимости от времени

Thus, ABS control algorithm efficiency is proven. The offered algorithm works by switches. Threshold values of angular deceleration are used as wheel blockage criterion. Advantages of work are simplicity of algorithm and full flat vehicle model simulation.

Certainly, modern ABS should be adaptive therefore the presented algorithm though is effective, but demands further improvement.

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