349. Computer-aided modeling of the adaptive intelligent vehicle safety systems

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Abstract. The paper presents classification of type of movement of motor vehicles and reports on computer-aided modeling and virtual design of active safety systems. An algorithm of identification of the moment of transition of wheel sliding from a steady range of sliding to unstable is described as well. In the presented research work results of computer-aided modeling of anti-lock braking systems (ABS) that are based on a force principle are discussed and important questions of modeling and design of active safety system in CoDeSys environment are considered.

Keywords: vehicle safety, adaptive systems, intelligent systems, computer aided modeling.

Introduction

Since eighties anti-lock braking systems (ABS) started to be installed in passenger vehicles and lorries. Since 1992 in Europe the introduction of ABS for heavy lorries and intercity buses is regulated by the legislation. The car equipped with ABS keeps controllability and course stability at braking on roads with low factor of coupling. ABS allows to increase average speeds of movement and prolongs service life of trunks. According to expert estimations, obligatory use of electronic system of stabilization of movement ESP and ABS will result in reduction of death rate on roads of the Western Europe by 4000 person per year and number of serious accidents by 100 000.

A large number publications and patents [1, 2, etc.] is devoted to the description of principles of functioning, the theory and practice of creation of classical type ABS. Force type ABS was offered for the first time in [3]. Here we shall consider active safety systems (ASS) of a new generation in which the functioning is based on the force principle and Fourounjiev regulator [4, 5]. The method of intelligent control of ASS and other mechatronic systems of vehicles was proposed by R. Fourounjiev in the patent [6]. Algorithms of identification of extreme situations and ASS computer-aided modeling of new generation are considered in works [7, 8]. Works [9-14] are devoted to various algorithmic aspects and software for modeling of mechatronic systems.

1 Type of vehicle movement

Fig. 1 presents classification of types of rectilinear and curvilinear movements of vehicles.

For each kind of movement the extreme events (EE) are characteristic. The extreme event leads to loss of stability or controllability of the vehicle, can appear as a consequence of: (a) sharp changes of properties of the environment under wheels; (b) certain actions of the driver (e.g. upon specific brake or acceleration pedal usage, abrupt steering, etc.); (c) at change of condition of the vehicle (sudden malfunctions of components and units such as, sticking of pedals of an accelerator, a leak in the working brake cylinder, etc.); (d) combinations of these factors. When designing vehicles and control systems it is necessary to model the situations leading to the occurrence of EE during various types of movement.

When modeling the user can choose any type of movement:

- rectilinear;
- curvilinear with constant radius of movement;
- curvilinear with changeable radius of movement.

User can choose a mode of movement:

- braking;
- extreme braking.

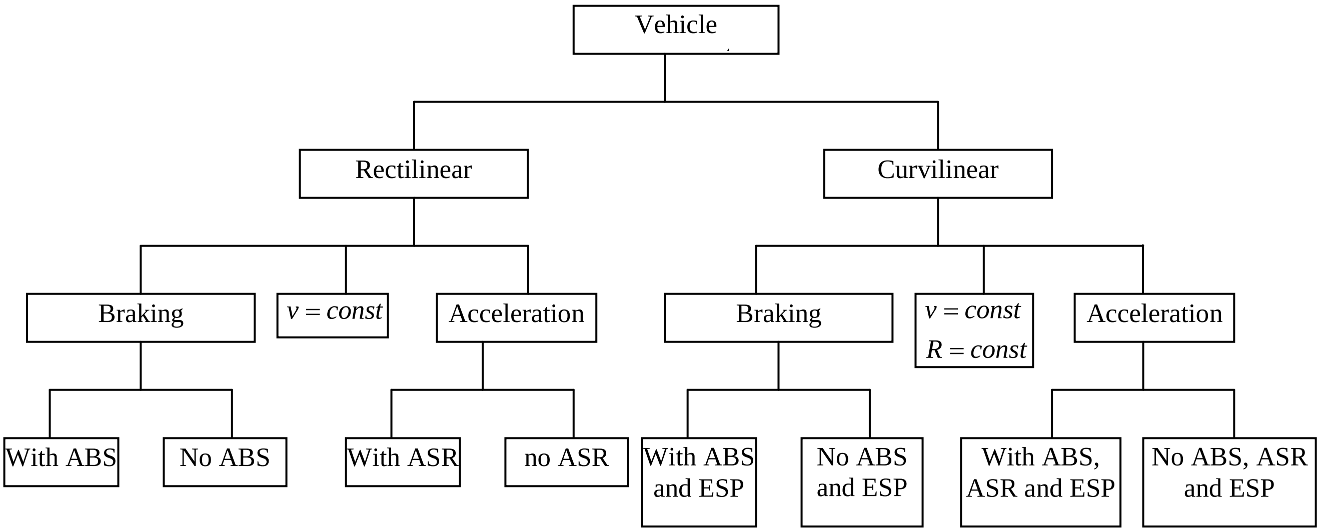


Fig. 1. Classification of vehicle movements types

2 Identification of extreme situations

Basic purpose of ASS is maintenance of stability and controllability of vehicle movement in any possible conditions of movement. So, the task of ABS is maintenance of a braking wheel in a mode of optimum relative sliding at which the longitudinal factor of coupling of the trunk with a basic surface is in an optimum range. This problem consists of two stages:

- identifications of the moment of approach of EE leading to sliding or blocking of a basic element;
- definitions of operating influences on executive mechanisms with the purpose of maintenance of admissible conditions of movement irrespective of a condition of an environment or action of the driver.

For the decision of the given problem into the structure of ABS enter:

- sensors (forces/moments, deceleration of the vehicle body, angular speeds of wheels, etc.);

- the control block receiving the information from sensors, processing it and forming control which then moves to the input of an actuator. In case of ABS signals of control move on modulators of pressure of a working body which, in turn, influence executive mechanisms - working brake mechanisms of wheels, etc.).

ASS, based on a classical (kinematic) principle, process of identification of a curve of “factor of longitudinal coupling-sliding of a wheel” (in the further curves $\mu - s$) and definitions of size of course (linear) speed of vehicle movement is difficult enough. In patents [1, 2] (1988, 1992) factors of coupling of wheels with the road $\mu_{il}(K),\ i = 1,...,n;\ l = 1, 2$, systems describing a condition "road-trunk-car", pay off during the consecutive moments of time $(T-1), T, (T+1),...$ on the basis of the measured sizes of angular speeds of wheels ω_{kil}, settlement course speed of the vehicle, brake pressure and some other sizes, using the various equations and known, difficult enough, algorithms of identification. The obtained factors of coupling $\mu_{il}(K)$ are used for definition during each moment of time of an inclination $K_{\mu il}$ of $\mu - s$ curves:

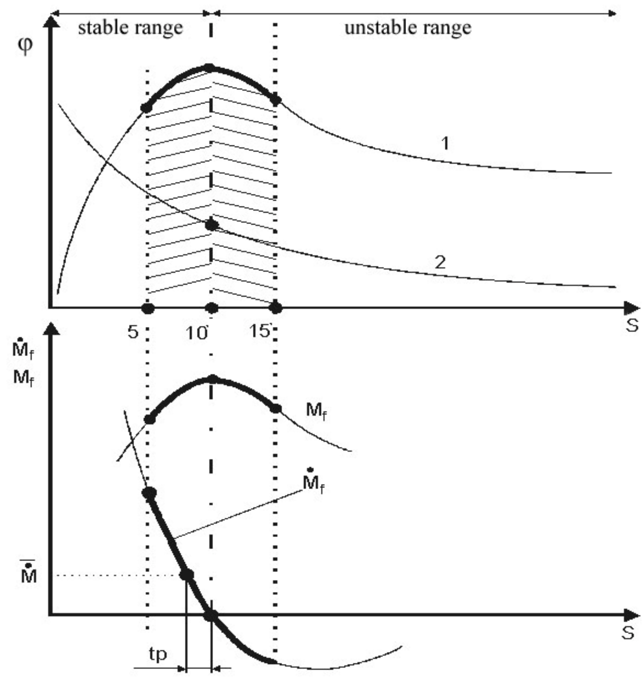
$$K_{\mu il} = d\mu_{il} / ds_{il},$$

This is used for optimum control of angular speed of each wheel. For regulation of an inclination K_{μ} the PI-regulator is used, which factor of amplification during the consecutive moments of time $(T-1), T, (T+1),...$ varies according to the calculated factor of coupling $\mu(K)$. Thereby adaptability of a control system is achieved.

This factor in many respects defines a working range of speeds of vehicle movement. On the other hand, constant modernization of components, increase of speed of executive mechanisms as well as accuracy of measurement of angular speed of rotation and optimization of algorithms of identification lead to improvement of quality of operation. Thus difficult algorithms of identification and expensive equipment are used. Complexity of modern ASS results in high cost, which can make up to 5...10 % of cost of the vehicle depending on its class.

In the present work the new approach based on a force principle to identification of the event leading to blocking/sliding of the trunk concerning a basic surface is proposed. This approach consists in supervision by sensors and the analysis of derivative of actual brake force/moment in contact of system «wheel-basic surface-car».

EE is identified on the basis of the measured actual values of brake force/moment M_f and/or its derivative. If during any moment of time t_i brake pressure in the main brake cylinder $p(t_i) > 0$ and $\dot{p}(t_i) \geq 0$ (that corresponds to pressing, deduction by the driver of a brake pedal or amplification of pressing of pedal) and an observable derivative of actual brake force $\dot{M}_f = 0$, during this moment $\varphi -$ the factor of coupling in a longitudinal direction will be maximal. Then during the subsequent moment of time t_{i+1} when $\dot{M}_f \leq 0$, the factor of coupling will start to decrease up to the value of factor of coupling at full sliding, and sliding of a wheel will pass in a unstable range of relative sliding. In Fig. 2 presents dependence of factors of coupling of wheels with road in longitudinal and transverse directions and also actually sold force/moment and its derivative as a function of sliding of a wheel.



1 - factor of coupling in a longitudinal direction; 2 - factor of coupling in a cross-section direction

Fig. 2. Dependence of coupling factors of wheels with road and actually sold force and its derivative of sliding wheel

3 Formation of control *U*

In classical ABS pressure in a drive increases at initial braking. The size of sliding of a wheel in a spot of contact with road increases and achieved border of steady and instable ranges of wheels roll. From this time, any further increase in pressure in a drive or the brake moment does not cause any further increase of size of brake force (F_T). In a steady range, sliding of a wheel is more likely deformation sliding, it has the increasing tendency in an unstable range.

Formation of operating signal in classical ABS is assigned to a PID-regulator for which exact option of parameters is necessary. If in movement there are attributes of blocking in one of the wheels, deceleration of rotation of a wheel and its sliding sharply increase. If they exceed critical values the block of management sends signals to the solenoid distributive valve for the termination of growth or reduction of pressure in the brake mechanism before the termination of danger of blocking. Then pressure should be restored for prevention of insufficient braking of wheels. During automatic control of braking it is necessary to constantly define ranges of steady and unstable wheels roll and to modulate brake pressure, creating the maximal brake effort.

In development of ABS the following factors are considered: variants of coupling between the trunk and road; the roughness of a road cover that cause fluctuations of wheels and axes; brake hysteresis; changes of pressure in the main brake cylinder from influence of a driver pressing the brake pedal; changes of radius of a wheel, for example, at installation of a spare wheel, etc.

Criteria of quality of control:

- maintenance of course stability during management of the car by maintenance of sufficient size of transverse force of coupling on back wheels;
- maintenance of controllability of the car by maintenance of sufficient transverse force of coupling on forward wheels;
- reduction of a braking distance in comparison with braking with blocked wheels;
- fast change of the brake moments for various factors of coupling, for example, when the car moves through small sites of ice-covered road;
- the control of low amplitudes of change of the brake moment over the warning of vibrations in tooth gearings;
- a high level of comfort of movement as a result of insignificant influence of a feedback on a pedal of a brake and application of silent executive mechanisms.

In the new approach based on a force principle, the operating signal is produced according to [3, 4].

4 Computer-aided modeling of new generation intelligent vehicle safety system

Results of computer-aided modeling of brake dynamics of the vehicle without ABS on icy covering are presented in Fig. 3, and with ABS - in Fig. 4. Fig. 3 indicates that the vehicle braking distance without ABS equals 56,89 m and the established deceleration constitutes 1,1 m/s^2. Fig. 4 indicates that the vehicle braking distance with ABS of a new generation equals 34,81 m, i.e. was reduced by 22,09 m, which is 40 % less in comparison to braking without ABS. The established deceleration in this case is 1,8 m/s^2. Longitudinal factors of sliding of wheels were in "steady" area of a curve $\mu - s$ and made 18-20 % of sliding of a wheel, providing a maximum of factor of coupling in a longitudinal direction.

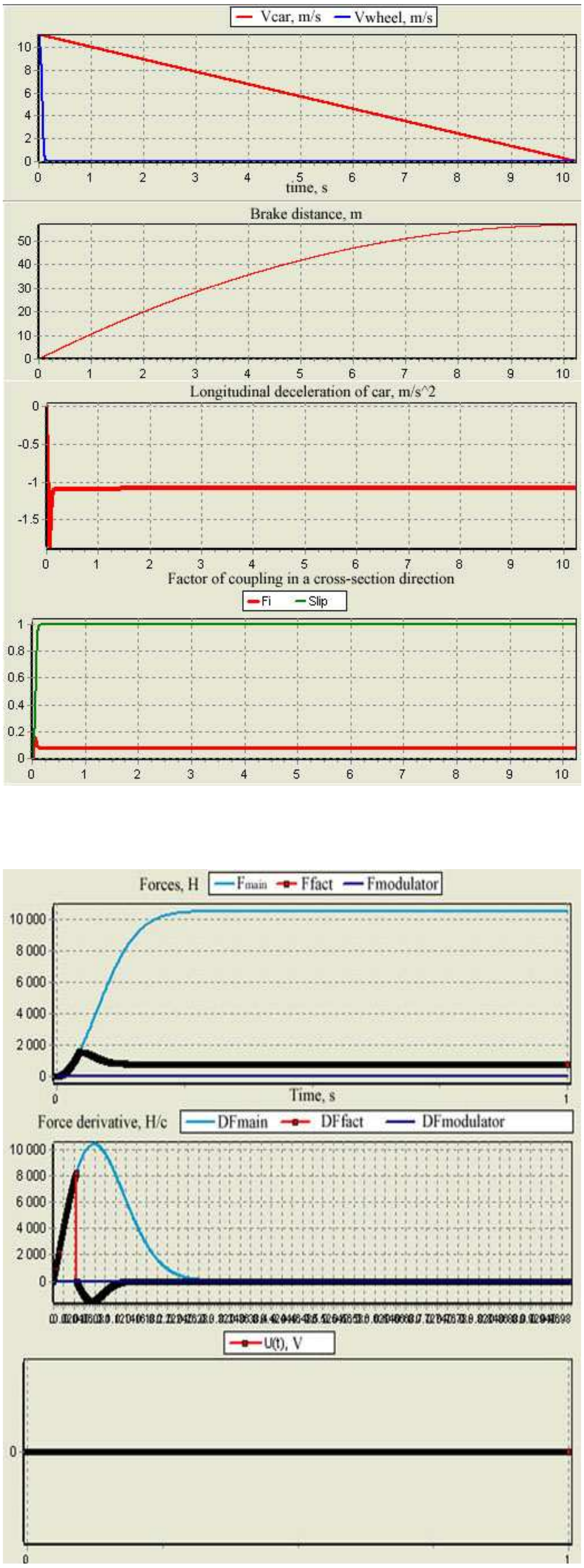


Fig. 3. Transients at vehicle braking without ABS. Initial speed of movement υ_0 = of 40 km/h (11.11 m/s)

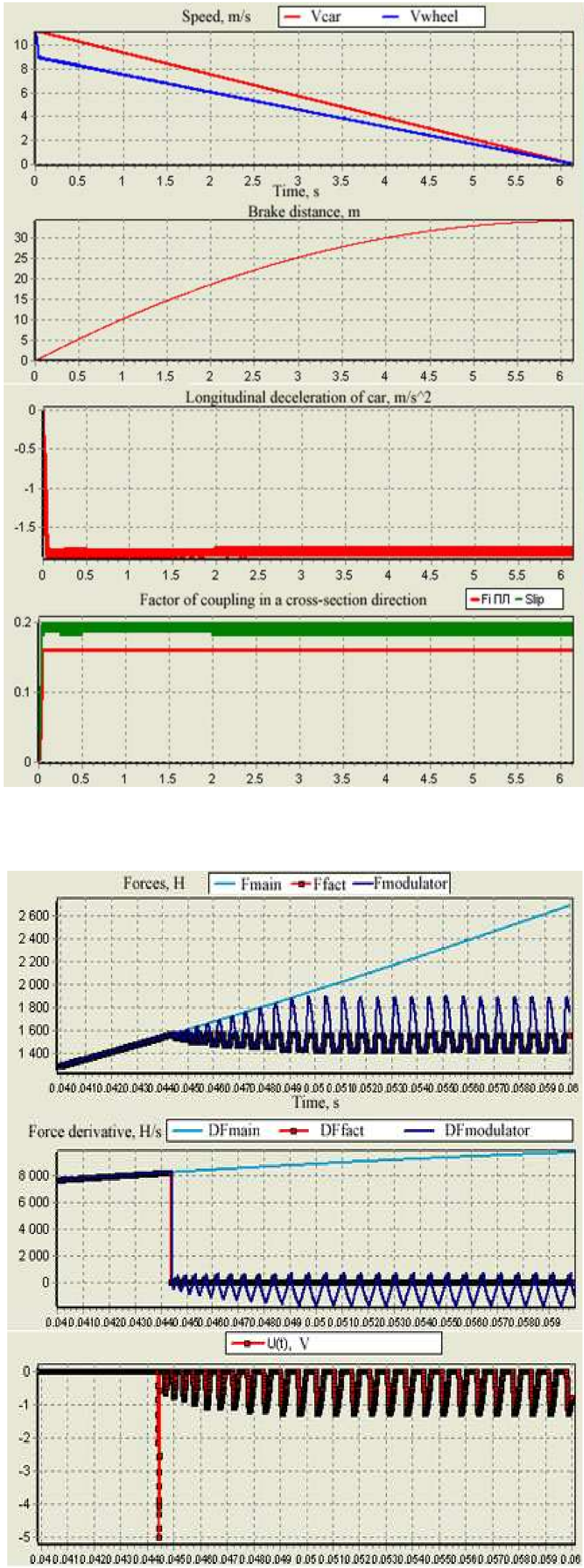


Fig. 4. Transients at vehicle braking with ABS. Speed of the two-position modulator t_M = 50 micro seconds

5 Prospects of ASS realization of new generation

Creation ASS of new generation is significantly accelerated by applying CoDeSys environment (Controller Design System), which enables solution of any associated problem represented in the form of the corresponding program. Owing to CoDeSys compiler it is possible to realize logic of management in the fast machine code optimized under the set hardware platform. The generated machine code is loaded further into the programmed logic controller. CoDeSys has the integrated debugger equipped with a wide set of functions for fast and effective debugging, testing and support of programmed logic of management. If the logic of management has changed, the changed fragments are compiled and loaded into the controller only.

To program ASS in CoDeSys the system of execution CoDeSys SP should be established. With its help any microprocessor device, including PC-compatible, gets PLC (Programmable Logical Controller) functionality with support of programming in MEC 61131-3 languages. Installation of execution system is carried out by the manufacturer of the device or experts of the 3S company. The customer does not participate in it. CoDeSys SP - scaled system, it is possible to change its functionality over a wide range, adapting to different hardware platforms and technical requirements.

CoDeSys SP can function under control of any operational system or even without it. Most often VxWorks, Windows CE and Linux are used. There are adaptations under RT-OS32 RTKernel, QNX Nucleus, pSOS, OS9, TenAsys Iteme. The manufacturer of the equipment can independently adapt CoDeSys SP under other OS.

Microprocessors family, supported by CoDeSys:

- Infeneon C167 and TriCore
- Intel 80186/80x86/Pentium x
- Motorola ColclFire
- PowerPC
- Hitachi SH 2/3/4, Hitachi H8

In real-time systems the solution of each of numerous tasks, assigned to the built-in system, as a rule, should keep within the time frameworks allocated to it. It means that any cyclic task should be caused through in advance at certain intervals of time.

The kernel of real-time expansion (RTE) in CoDeSys environments consists of 2 parts: system service RTService.exe and the driver of a mode of a kernel (3SRTE.sys). In a usual mode the system timer generates 2 hardware interruptions in a millisecond and thus causes planning RTE. The scheduler uses one interruption for a call of the tasks, and the second for returning the interrupted control to operational system (OS). Thus, all the tasks certain in CoDeSys, interrupt through each millisecond that OS could execute necessary for it actions. The parity of cumulative time of OS code performance and time of tasks performance of CoDeSys can be set up.

Input-output drivers (IO-drivers) shown in Fig. 5, used in RTE, should have certain interface, which is described in a package of developer IO-DriverToolkit. RTE does not change a code of a OS kernel at installation and during performance.

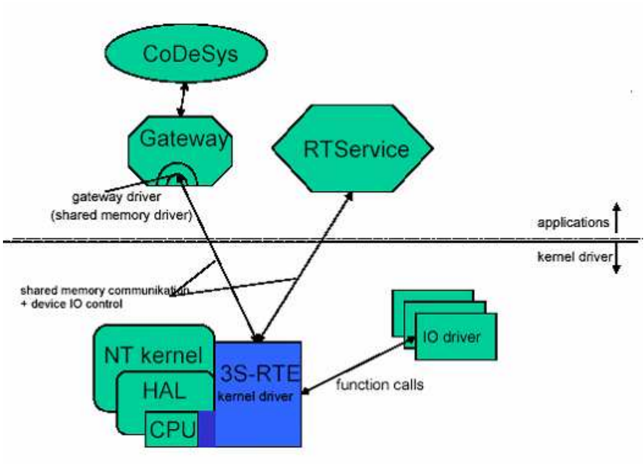


Fig. 5. Real time system CoDeSys V2.3

Conclusion

Results of computer-aided modeling of vehicle dynamics with ABS had demonstrated high efficiency of ABS of a new generation, particularly on a road with low factor of coupling. The application of CoDeSys and the programmed controllers operating the modulator of pressure in ABS, will accelerate development and manufacture of active safety system that are based a force principle.

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