Slovak University of Technology in Bratislava
Institute of Information Engineering, Automation, and Mathematics

PROCEEDINGS

of the 18$^{\text{th}}$ International Conference on Process Control

Hotel Titris, Tatranská Lomnica, Slovakia, June 14 – 17, 2011

ISBN 978-80-227-3517-9

http://www.kirp.chtf.stuba.sk/pc11

Editors: M. Fikar and M. Kvasnica

Juhás, M., Seman, P., Bodi, S.: ABS/TCS Simulator, Editors: Fikar, M., Kvasnica, M., In *Proceedings of the 18th International Conference on Process Control*, Tatranská Lomnica, Slovakia, 598–601, 2011.

Full paper online: http://www.kirp.chtf.stuba.sk/pc11/data/abstracts/082.html

ABS/TCS Simulator

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Abstract: This paper gives information about development of laboratory device - simulator for automotive applications. The design of simulator allows the use of different setups for simulating braking of vehicle's front and rear wheel as well as acceleration of front and rear wheel driven vehicle. Main use of simulator is development and evaluation of control strategies for anti-lock braking system and traction control system, but device can also be used as general mechatronic system with non-linear behaviour for testing of control system designs.

1. INTRODUCTION

The anti-lock braking system (ABS) and traction control system (TCS) are important safety systems that monitors and controls wheel slip during vehicle braking and acceleration (Gillespie 1992). ABS improves vehicle stability and reduces stopping distances when braking on slippery road surfaces. Rolling wheels usually have more friction available, than locked wheels. This is also used by TCS to reach better traction during acceleration. Control algorithms for both systems are being continuously developed and optimized for better performance. The aim of this work was to design laboratory device that can be used for experimental evaluation of suggested improving control techniques.

2. ABS/TCS SIMULATOR CONCEPT AND DESIGN

For purposes of anti-lock braking system analysis a quarter vehicle model is often considered (Solyom 2004). This model consists of single wheel attached to a mass – Fig. 1.

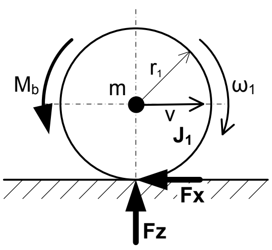

Fig. 1. Quarter model of vehicle: m – vehicle mass, v – vehicle longitudinal velocity, J_1 – wheel inertia, r_1 – wheel radius, ω_1 – angular velocity of wheel, M_b – brake torque, F_x – wheel/road friction force, F_z – vertical force

The equations of motion of quarter vehicle model are given by:

$$J_1\dot{\omega}_1 + M_b - F_x r_1 = 0 \quad (1)$$

$$m\dot{v} - F_x = 0 \quad (2)$$

Maximum braking force must be less then available friction:

$$|F_x| \le F_z \mu \quad (3)$$

where μ is the friction coefficient between road and tire.

For the simulator design the vehicle dynamics is substituted using second wheel as shown in Fig. 2 .

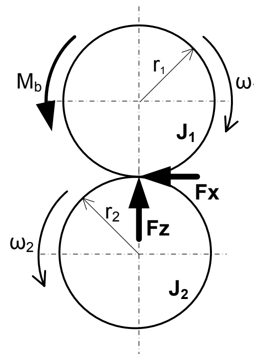

Fig. 2. Quarter model of simulator: J_1 – vehicle wheel inertia, r_1 – wheel radius, ω_1 – angular velocity of wheel, M_b – brake torque, F_x – wheel/road friction force, F_z – vertical force, J_2 – vehicle dynamics substituting wheel inertia, r_2 – substituting wheel radius

Equation (1) is valid for new system too, while (2) is changed:

$$\frac{J_2 \dot{\omega}_2}{r_2} - F_x = 0 \tag{4}$$

New configuration is well suited for construction of physical laboratory model and forms a basis for ABS/TCS simulator design – Fig. 3, 4.

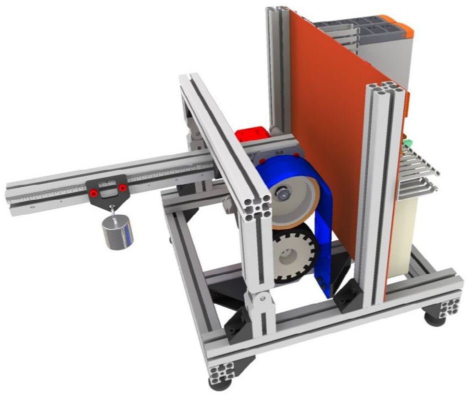

Fig. 3. Mechanics of ABS/TCS simulator – concept

The design of simulator allows the use of different setups for simulating braking of vehicle's front and rear wheel as well as acceleration of front and rear wheel driven vehicle. This functionality is provided by simulator frame kinematics and by possibility to control the torque of both wheels via servo-drives. Table I shows available simulator configurations for different vehicle types and driving conditions.

TABLE I
Description of ABS/TCS Simulator Configurations

Configuration	Upper wheel rotation	Upper wheel torque	Lower wheel torque
Front wheel braking	positive	negative, ABS controlled	0
Rear wheel braking	negative	positive, ABS controlled	0
Front wheel braking downhill	positive	negative, ABS controlled	positive, constant
Rear wheel braking downhill	negative	positive, ABS controlled	negative, constant
Front wheel acceleration	positive	positive, TCS controlled	0
Rear wheel acceleration	negative	negative, TCS controlled	0
Front wheel acceleration uphill	positive	positive, TCS controlled	negative, constant
Rear wheel acceleration uphill	negative	negative, TCS controlled	positive, constant
Friction estimation	positive	positive, velocity control	negative, velocity control

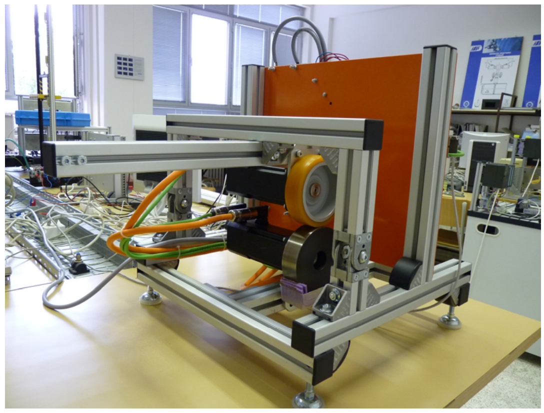

Fig. 4. Mechanics of ABS/TCS simulator – real system

3. CONTROL SYSTEM ARCHITECTURE

Hardware of control system for simulator is based on standard industrial components of B&R automation. Central part of solution is X20 PLC which runs the control program and controls the torques of both simulator wheels via ACOPOS servo drives. Device utilizes utilises Ethernet Powerlink bus, which is used for fast torque and velocity closed loop control of servo drives, as well as for data acquisition of process data into PLC memory during runtime. Human machine interface runs as a task on the same PLC and is available over Ethernet network via VNC console. Main parts of simulator's control system architecture are shown at Fig. 5 and Fig. 6.

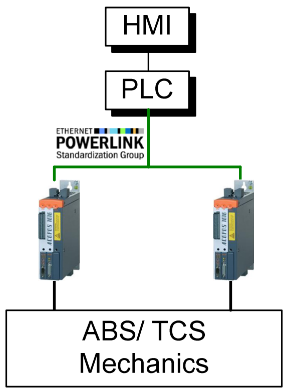

Fig. 5. Control system architecture for simulator

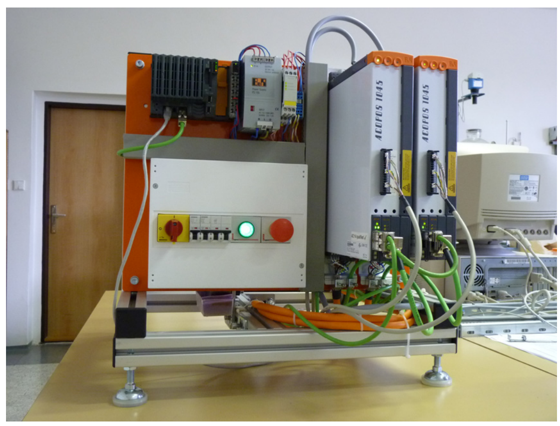

Fig. 6. Control system of ABS/TCS simulator – real system

Software of simulator can be split into two parts – system software and user software. System software deals with safe control of servo drives, data acquisition and data logging tasks and human machine interface services. User part of software implements actual control strategies for anti-lock braking or traction control. This software is prepared within MATLAB/Simulink environment. The code for PLC is then automatically generated using Real Time Workshop addition of and incorporated into the structure of automation project for industrial system. Architecture of software is at Fig. 7.

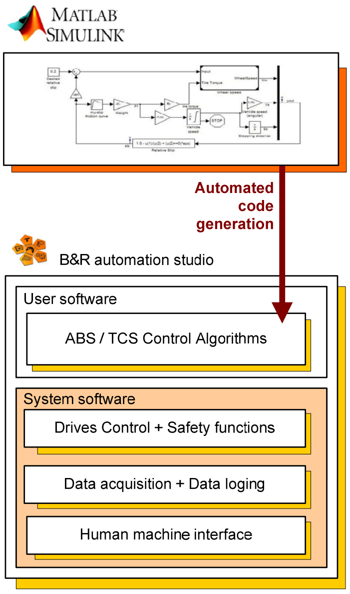

Fig. 7. Software solution architecture for simulator

4. EXPERIMENTAL WORKS

First experimental works were aimed at estimation of slip friction curves for different tire/road conditions – dry rough surface and wet smooth surface. Afterwards implementation of anti-lock braking was experimentally verified on wet surface.

4.1 Slip friction estimation for dry concrete road surface

The task of this experiment was the estimation of friction torque between wheel with rubber surface (representing tire) and wheel with concrete surface (representing road). Photo of experimental setup is at Fig. 8.

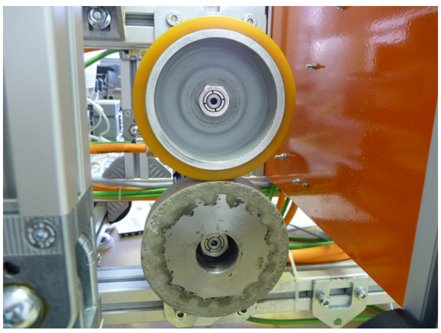

Fig. 8. Experiment setup for dry concrete road friction curve estimation

During experiment rotational velocity of "road" wheel was maintained at constant value. Starting rotational velocity of "tire" wheel was the same with opposite direction of rotations. During experiment "tire" wheel velocity was decreased in steps while measuring torques at both servo drives. These values were corrected for the effect of mechanical losses. Resulting slip friction curve is at Fig. 9.

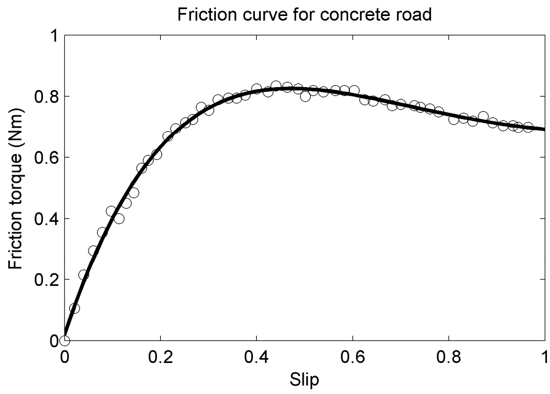

Fig. 9. Friction torque curve for rubber and concrete

4.2 Slip friction estimation for wet slippery road surface

The task was to estimate the available friction between wheel with rubber surface and wheel with slippery wet surface. Photo of experimental setup is at Fig. 10, which also shows maintaining of thin wet film at "road" wheel. Experimental procedure and data processing was the same as for previous experiment. Resulting slip friction curve is at Fig. 11.

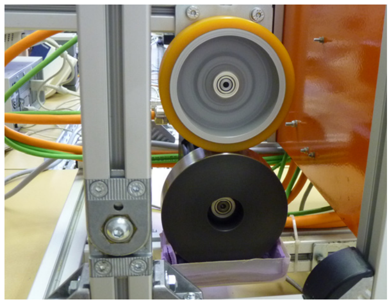

Fig. 10. Experiment setup for wet smooth road friction curve estimation

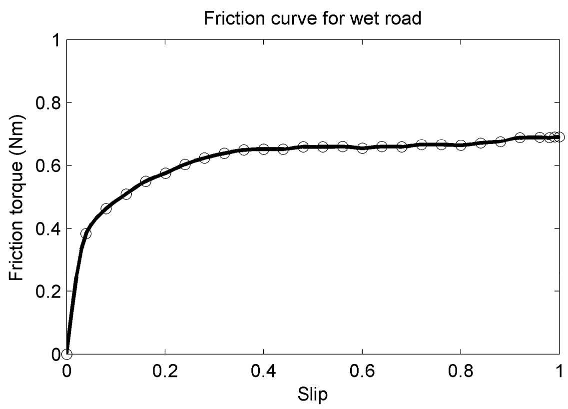

Fig. 11. Friction torque curve for rubber and for wet smooth surface

4.3 Anti-lock braking on wet slippery road

Experimentally estimated friction curves were used during ABS control synthesis. Resulting PI based controller was verified in front wheel braking configuration with and without anti-lock function active. Results are given in Fig. 12 and 13.

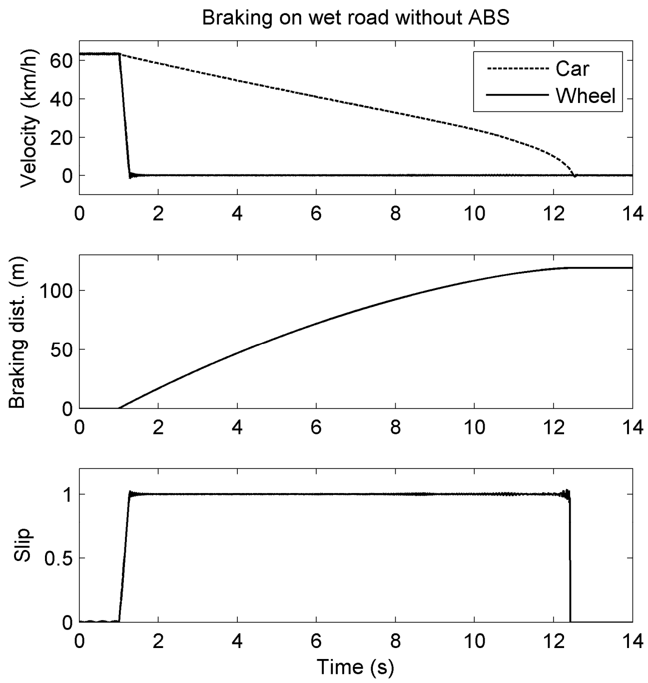

Fig. 12. Braking with ABS function off

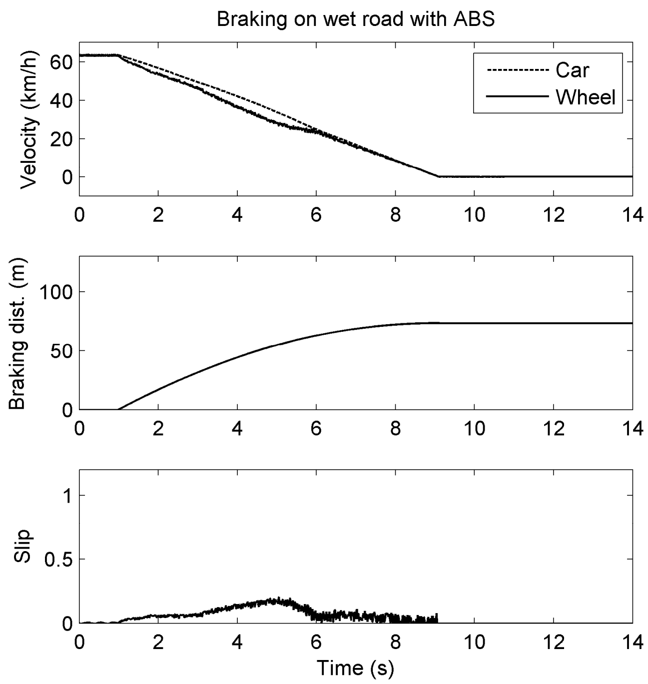

Fig. 13. Braking with ABS function on

In both cases simulator wheels were slowly accelerated to starting speed. Braking was activated in time of 1 s. During braking with ABS off the upper braking wheel locked after short time and remained in this state throughout all braking process (Fig. 12). ABS controller in next experiment tried to maintain the slip at value of 0.4. This effort was only partially successful, but effect of active ABS is clearly visible (Fig. 13) – braking time was reduced by app. 30 % and braking distance was reduced by app. 40 %, compared to experiment without ABS function.

5. CONCLUSIONS

Paper describes laboratory device for anti-lock braking system and traction control system simulation. Main use of simulator is development and evaluation of control strategies for anti-lock braking system and traction control system.

First experimental results are promising and proved functionality of simulator design. Simulator is still in development phase and works are in progress to improve its features.

Future works include creation and adjusting of mathematical model of simulator, optimization of simulator software and development of HMI interface.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support granted by the Slovak Research and Development Agency under the contracts VMSP-P-0030-09 and APVV-0160-07, and reviewers' comments. This research is also supported by the grant from Iceland, Liechtenstein and Norway through the EEA Financial Mechanism and the Norwegian Financial Mechanism. This project is co-financed from the state budget of the Slovak Republic.

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