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Estimation of light commercial vehicles dynamics by means of HIL-testbench simulation

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Abstract. The high level of active safety of vehicles is impossible without driver assistance electronic systems. Electronic stability control (ESC) system is one of them. Nowadays such systems are obligatory for installation on vehicles of different categories. The approval of active safety level of vehicles with ESC is possible by means of high speed road tests. The most frequently implemented tests are “fish hook” and “sine with dwell” tests. Such kind of tests provided by The Global technical regulation No. 8 are published by the United Nations Economic Commission for Europe as well as by ECE 13-11. At the same time, not only road tests could be used for estimation of vehicles dynamics. Modern software and hardware technologies allow imitating real tests with acceptable reliability and good convergence between real test data and simulation results. ECE 13-11 Annex 21 – Appendix 1 “Use Of The Dynamic Stability Simulation” regulates demands for special Simulation Test bench that could be used not only for preliminary estimation of vehicles dynamics, but also for official vehicles homologation. This paper describes the approach, proposed by the researchers from Nizhny Novgorod State Technical University n.a. R.E. Alekseev (NNSTU, Russia) with support of engineers of United Engineering Center GAZ Group, as well as specialists of Gorky Automobile Plant. The idea of approach is to use the special HIL (hardware in the loop) -test bench, that consists of Real Time PC with Real Time Software and braking system components including electronic control unit (ECU) of ESC system. The HIL-test bench allows imitating vehicle dynamics in condition of “fish hook” and “sine with dwell” tests. The paper describes the scheme and structure of HIL-test bench and some peculiarities that should be taken into account during HIL-simulation.

1. Introduction

There are a lot of papers describing the positive usage experience of simulation results for prediction of active safety of vehicles equipped by ECS [1…4]. At the same time it is easy to see that different vehicles (passenger cars, vans, trucks and heavy trucks) are simulated with using of different methodologies.

This paper describes the approach, proposed by researches from Nizhny Novgorod State Technical University n.a. R.E. Alekseev (NNSTU, Russia) with support of engineers of United Engineering Center GAZ Group as well as by specialists of Gorky Automobile Plant (Russian light commercial vehicles (LCV) producer).

The main purpose of current research is to develop methods for justification and selection of the simulation model parameters that are necessary for providing acceptable modeling results that would properly match the road tests results.

2. HIL-testbench description

The general scheme of HIL-test bench developed in NNSTU shown on figure 1. The proposed HIL-test bench consists of a computer (3) with installed software that allows creating dynamic models of simulated vehicle, a real-time computer (1) that interacts between the hardware (2) and virtual parts of the test bench. The hardware part consists of the electro-hydraulic control unit (ECU) of the ESC system with the possibility of switching it off, the brake pedal unit including the brake master cylinder, brake fluid nozzle and vacuum brake booster assembly. For creating a vacuum, a vacuum pump is connected to the vacuum brake booster by a pneumatic conduit. Hydraulic pipelines connect the pedal assembly to the ECU and equipped with pressure sensors. It also connects the actuators of the front and rear axles, respectively, to the ECU and equipped with pressure sensors.

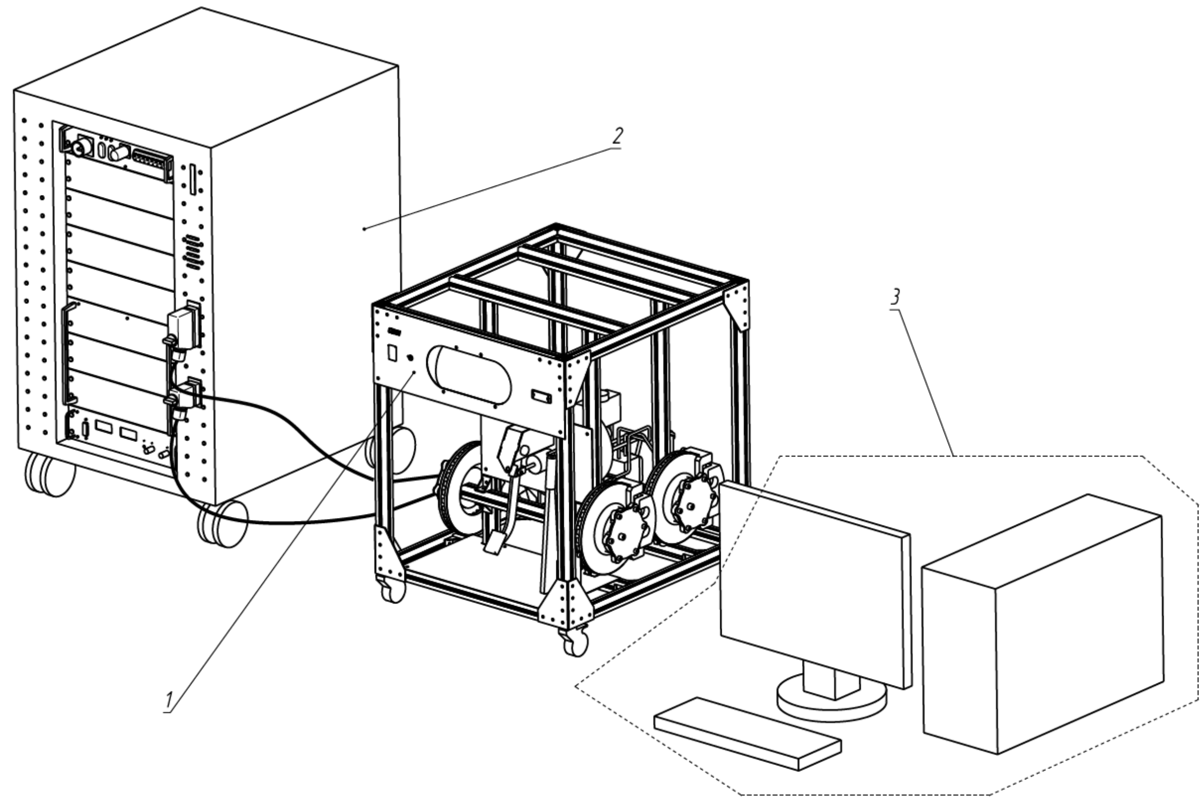

Figure 1. The general scheme of HIL-testbench.

The principle of HIL-test bench operation is based on real time communication between virtual and physical parts. In special real-time software the virtual vehicle model and conditions of all necessary dynamic tests are implemented. Such virtual parameters appearing during high speed maneuver as the speed of wheels rotation, the angle and angular speed of rotation of the steering wheel, the rotational speed of the internal combustion engine, longitudinal and transverse accelerations, and the yaw rate are transmitted to a real-time computer that realizes the interaction of the virtual and physical parts of HIL-test bench, sending signals on the physical part of the stand and vice versa at each time step. Depending on the conditions of the virtual tests, the braking system operates in a way as it would do if it were installed on a real vehicle: either by the brake pedal robot or directly by the electro-hydraulic control unit of the ESC ECU actuating the brake mechanisms. The signals generated from the brake force sensor on the brake pedal, the pressure sensors of the hydraulic pipelines emulate signals that are necessary for the operation of the ESC ECU. Real time PC converts pressure values to the brake moments that applied to a virtual vehicle model, thereby adjusting the speed and trajectory of the movement. The results of the simulation performed on a real time PC are visually reproduced at each time step of the simulated process and demonstrates vehicle dynamics under the given conditions. Thus, the result of simulation of each time step is available online in a real time mode, as if the process was started in a natural environment. Switcher allows disabling ESC ECU to simulate vehicles dynamics without ESC support.

Figure 2. Photo of HIL-testbench assembled in NNSTU.

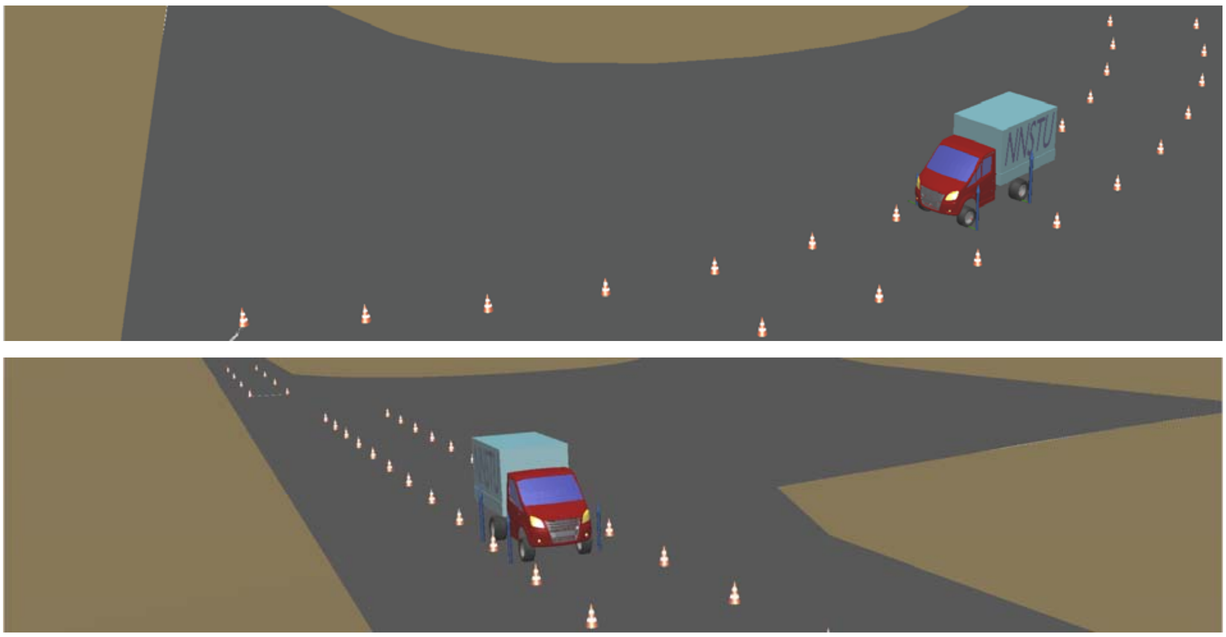

Figure 3. Visualisation of HIL-Simulation of LCV behaviour in a real-time mode.

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It is possible to point out several important problems that should be solved for precise simulation:
- determination of vehicles axial moments of inertia;
- determination of tires characteristics;
- an adequate simulation of engine processes.

3. Estimation of vehicles axial moments of inertia

Axial moments of inertia can be determined analytically by presenting of vehicles design as a set of individual elements: wheels, axles, cabin, frame, body and etc. It is possible to determine the moment of inertia of the entire vehicle by using its detailed CAD model, specifying the density of the material and determining the mass and moments of inertia of individual vehicles parts. Nevertheless, an experimental verification of this approach is required, since it is difficult to take into consideration liquids (fuel, coolant and others); interior materials of the cabin and others "fine points", which can affect the value of the moment of inertia.

The method of calculation where the vehicle is approximated by a set of simplified geometric shapes with the use of empirical coefficients increasing the accuracy of calculations are described in [5]. The main advantage of calculation methods is the physical absence of the researching object. However, the actual vehicle differs from the ideal calculation model. Therefore, experimental methods have higher measurement accuracy.

The analysis of the previous scientific works shows that a new trend of the vehicle moments of inertia calculation is being observed. In the paper [6], the authors do not try to measure the mass and yaw moment of inertia of the vehicle using any kind of test benches they present the possibility of the yaw moment of inertia calculation, during the vehicle motion. The disadvantage of this approach is using a bicycle model of the vehicle in the calculation algorithm. This model has a number of assumptions. There are many effective developments among the existing measuring methods as well as test bench structures. The most universal is the original method and the experimental facility, presented in [7]. There are test benches of the moments of inertia measuring, with the use of three string [8] and bifilar [9] pendulums. In these studies, the measurement objects are the scale models, which are much smaller than their originals in dimensions and mass.

The authors of current paper propose the method of oscillating platform on the basis of the review and analysis of existing experimental methods of calculation of the vehicle moment of inertia. The essence of this method lies in the implementation of free angular oscillations of the platform with a vehicle located with respect to a certain axis of rotation (movement force caused by a spring). In this case the moment of inertia of the vehicle with the respect to the Y axis passing through its center of mass parallel to the axis of rotation can be determined as follows:

$$J_{YY} = \frac{(T_s^2 - T_{pl}^2) \cdot c \cdot l^2}{4 \cdot \pi^2} - m_a \cdot d^2$$

where: m_a - the mass of the vehicle; c - spring rate; d - the distance between the mass center of the vehicle and the axis of rotation; T_{pl} - oscillation period of the platform without vehicle; T_s - oscillation period of the platform with vehicle; l - the distance between the attachment point of the spring and the axis of rotation.

4. Determination of tires characteristics

There are different methods of tire characteristics determination. The most reliable is the determination of tires characteristics by results of special skid-trailer tests on real roads [10].

According to the test results, it is possible to have a set of curves (dependencies) for different loads appeared on the wheel as well as:
- dependence of the longitudinal slip ratio from longitudinal force taking into account different values of vertical force and wheel camber angle;
- dependence of the lateral force from the wheel slip angle taking into account different values of vertical force and wheel camber angle;

- dependence of the lateral force, longitudinal force and stabilizing moment from the longitudinal force taking into account different values of vertical force and wheel camber angle.
- The received data with the help of special software allows to create a separate file with the characteristics of the tire which is subsequently used in real-time simulation.

5. Operating modes of the engine

Reproduction of correct engine operation at the HIL-Test bench (an adequate response of the engine to requests from the ESC ECU) is one of the most difficult tasks.

Vehicles power unit is used to achieve the target lateral acceleration. Thus, the engine model should provide the torque for transmission and wheels, taking into consideration appropriate transmission configuration (front / rear wheel drive, four-wheel drive, electric motor wheels, differential configurations, etc.).

Such parameters of engine as power, speed of response to the rotation of the throttle, clutch parameters, etc., may not be taken into account in the HIL-Test bench. However, when the chassis control system is activated, any parameters of the power unit affecting the controller's performance of the system must be included in the model.

As an example, figure 4 presents a diagram of engine operation during the maneuver "fish hook" (real road test data). This maneuver begins at a speed of 80 ± 2 km/h, with the steering robot acting on the vehicle's steering wheel (the gas pedal always remains pressed). Because the speed of a vehicle is high enough, the successful maneuvering (without rollover) is possible only for a condition when the ESC system "strangle" the engine to reduce (regardless of the desire of the driver) the torque. The ESC ECU sends the corresponding signal to the engine control unit that "executes the appropriate instructions".

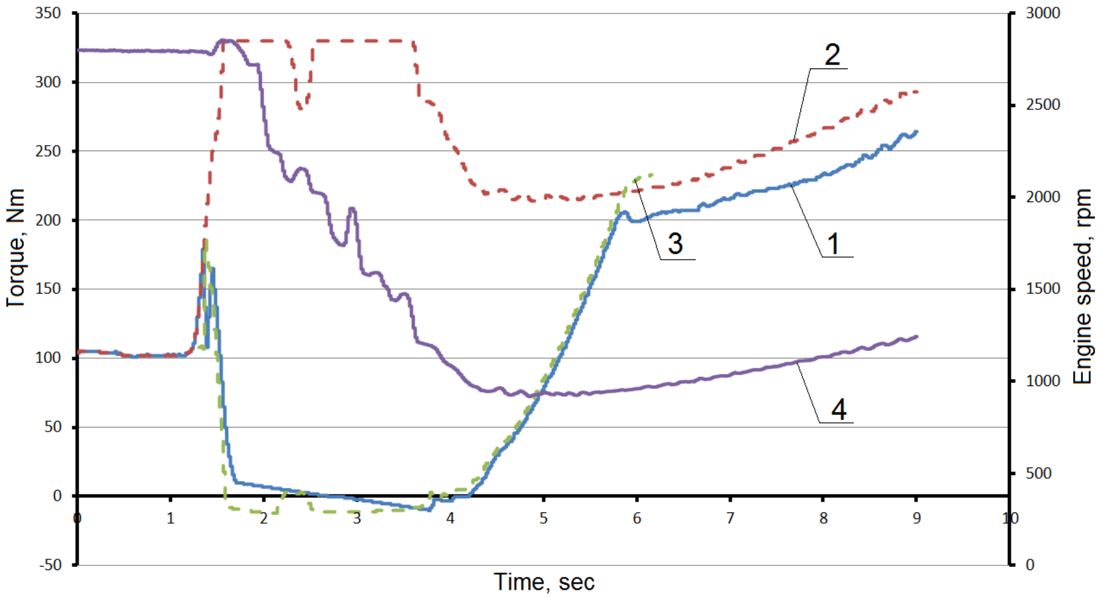

Figure 4. Engine operation during the maneuver "fish hook": 1 – torque, generated by engine ECU; 2 – driver demand; 3 – torque, required by ESC system; 4 – engine speed.

It is obvious that such "effect" should be fully reproduced on the HIL-Test bench during the simulation. The engine model must "obey" the ESC ECU commands. For this purpose, information about the CAN-matrix of the engine ECU is put into the HIL-Test bench software, which allows reproducing the correct operation of the engine.

6. Validation of HIL-Testbench

The requirements of ECE 13-11 Annex 21 – Appendix 1 “Use Of The Dynamic Stability Simulation” has some recommendations regarding to validation of HIL-Test bench which can be considered as suitable for virtual testing. At the same time it is reasonable to use others methodologies that are aimed at validation of vehicles dynamic simulation:

- ISO/DIS 19364: Passenger cars. Vehicle dynamic simulation and validation. Steady-state circular driving behavior.
- ISO/DIS 19365: Passenger cars. Vehicle dynamic simulation and validation. Sine with dwell stability control testing.

For example, one method is proposed to set values of lateral accelerations in accordance with the results of road tests that registered at a given speed at a certain angle of rotation of the steering wheel. From each point, the region of permissible deviations is plotted (a "corridor" of values). The results of simulation must be within this area. If the simulation data of the HIL-Test bench is inside the corridor, then the simulation results should be considered as adequate.

With the support of Russian State Scientific Research Center FSUE "NAMI", NNSTU engineers performed a range of road tests including “fish hook” and “sine with dwell” tests (figure 5) – all tests were conducted with front and rear outriggers, designed and produced by NNSTU. The experimental data will be used for test-bench validation that will be the subject of further papers.

Figure 5. Road tests of LCV equipped by ECS.

7. Conclusions

- The design of HIL-Test bench for simulation of vehicle dynamics equipped by ECS proposed.
- The detailed attention must be paid to estimation of vehicles axial moments of inertia that are necessary for adequate simulation. The estimation of the impact of the platform options on the error in the calculation of the vehicle moment of inertias by oscillation method was presented. It is discovered that the error caused by the distance between the platform axle and springs can be compensated by increasing the rigidity of the springs. There was a significant influence of the platform rigidity on the accuracy of results.
- Some proposals for determination of tires characteristics and adequate simulation of engine processes as well as methods of simulation validation are described.

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