22nd International Conference
ENGINEERING MECHANICS 2016
Svratka, Czech Republic, 9 – 12 May 2016

SIMULATION OF ADHESION CONDITIONS ON ROAD VEHICLES

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Abstract: *The article deals with the possibilities of controlled affecting of adhesion in the contact between vehicle wheel and road. In the first part some of currently used ways of affecting of adhesion are stated. These are briefly compared subsequently. Further new proposal of system for affecting of adhesion is introduced followed by its comparison with SkidCar system. The proposed system and SkidCar system are simulated in simplified form and resultant behavior of the car is evaluated in enclosed graphs. The article is processed in primary version of particular system for verifying of vehicle stability. This article aims to highlight the fact that it is possible to change the adhesive conditions of road vehicles using an additional system without preventing the movements of a body.*

Keywords: vehicle, adhesion, shear, driver, wheel.

1. Introduction

The size of a total adhesive force between a tire and a road is the product of radial wheel reactions and an adhesion coefficient. Thus, there will be two possible ways to change the adhesive force. The first category changing the adhesion coefficient includes the Slide Surfaces, Skid Tires and Easydrift Ring. The second category, which reduces radial wheel reactions, contains the SkidCar System and our system SlideWheel.

While reducing the adhesive conditions, a vehicle reaches the limit of a skid already at a lower speed than it would do under realistic conditions. Achieving a safer border car test is thus ensured. Simultaneously, it is possible to simulate the behavior of a vehicle on ice, although in fact it moves on a surface of a higher adhesion coefficient.

The article describes the difference in the behavior of the car with systems SkidCar and SlideWheel. SlideWheel is a system designed by the authors. Both systems operate on the principle of reducing the adhesive forces transmitted by the wheels of a vehicle.

2. SkidCar system

From the perspective of the authors, it is an electrohydraulic wheeled steel frame which allows a moving vehicle to achieve various types of skids. The frame is mounted under the floor of a car and, using an electronic controller, it allows for a partial lightening of the front axle or rear axle or both axles simultaneously in any range. Lightening or lifting a car is done by changing a position of hydraulic piston and cylinder in placing of the revolving wheels to the frame using an increase in hydraulic oil pressure. This intervention will evoke the possibility of a car skid situation with a front or rear-wheel drive, taking into account the different degrees of adhesion between the wheel and the road.

Strengths:

- the system can be used on any car,
- a possibility of continuously adjustable traction for any axle of a car,
- a possibility of changing the adhesion conditions while driving,

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- a possibility of saving an adhesive setting for repeatable tests,
- keeps the car electronic systems active,
- a road bears no optical or other information on the change of adhesion conditions,
- can be used in vehicles with front, rear or with both driving axles,
- almost impossible to overturn a car,
- possible to use any tires,
- ensures a repeatability of adhesive conditions in different tests.

Weaknesses:

- a vehicle has auxiliary wheels on the sides – a larger width of the tested car is a negative feature while doing driving maneuvers,
- a car body attached to the SkidCar frame – not possible to tilt the sprung masses against the unsprung masses; the body does not tilt or incline while doing driving maneuvers,
- an operation of electrohydraulic unit and electromagnets is heard in the vehicle; a driver is notified of the change of adhesion conditions,
- increasing a car mass and reducing the elevation coordinates of a car center of gravity,
- a need for a relatively flat surface of sufficient size under the considered testing,
- changing a rolling resistance and tire directional properties of a wheel due to the reduced radial reaction transmitted around.

3. SlideWheel - Custom system design to reduce vehicle adhesion conditions

We approach to the change of adhesion conditions by changing the radial car wheel load. The first option is to pass the required proportion of the car mass to the supporting units directly from the body, which are the sprung masses (*Fig. 1*). To some extent, it is a similar system as the SkidCar, only the supporting units are placed under the vehicle. Thus, a plan profile of the test car has not increased, and at the same time, the added mass of the vehicle has decreased. The system does not contain any supporting frame, connecting each of the supporting units. Therefore it would be possible to use this system for driving corridors. The supporting units do not allow a roll of the body when the centrifugal and inertial forces resulting from a passage of a vehicle through a corner are applied, the system does not simulate the real conditions of vehicle behavior. This system is only a thorough approach to reality. This disadvantage is eliminated in the second proposed solution.

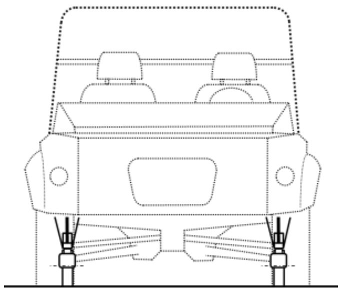

Fig. 1: Lifting the sprung masses

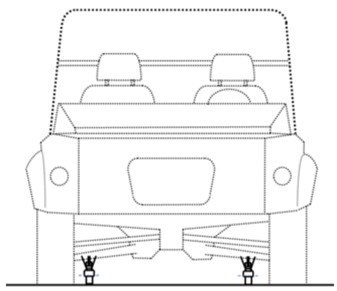

Fig. 2: Lifting the unsprung masses

The second option is to reduce the radial car wheel reaction by lifting the unsprung masses with the help of the supporting wheel units (*Fig. 2*). This system is called SlideWheel. The connection points are the lower arms of axle of the car. This ensures that the body is allowed to tilt when cornering and it can simultaneously pitch while changing a brake or thrust force.

Strengths:

- a possibility of continuously adjustable traction for any axle and any wheel,
- a body pitch corresponds to real conditions,
- the car outer outline dimensions do not change; all components are placed inside a car or under the axle arms,
- a low mass of the entire system,
- a change of adhesion conditions occurs by a primary lifting of the unsprung masses allowing for pitch and roll of the vehicle body,
- the system can be used on any car if slightly modified,
- a possibility of changing the adhesion conditions while driving,

- keeps the car electronic systems active,
- a possibility of saving an adhesive setting for repeatable tests,
- can be used in vehicles with front, rear or with both driving axles,
- possible to use any tires,
- ensures a repeatability of adhesive conditions in different tests,
- a hydraulic circuit operation is silent; a driver does not hear the change of adhesive conditions,
- a vehicle movement on a classic road, without any obvious visual differences of places with different adhesion surfaces.

Weaknesses:

- the system is for lower driving speeds,
- increasing a car mass but lower than with SkidCar,
- reducing the elevation coordinates of a car center of gravity,
- a need for a relatively flat surface of sufficient size under the considered testing,
- changing a wheel rolling resistance due to the reduced radial reaction,
- a need to calibrate the system for a given vehicle.

The system of car wheel lifting is operated electro-hydraulically using a control panel of the vehicle interior. The system can operate under the influence of random adhesion conditions or as required by an operator who is a fellow-passenger in the car.

The SlideWheel system advantages as compared to the SkidCar system are evident in allowing the body movement as seen from the below mentioned diagrams (*Fig. 3*, *Fig. 4*). The computational model of the car with the SlideWheel system (according to *Fig. 2*) has been done in SW Adams/View (Multibody dynamics simulation software) so far only in a simplified form. Also further described simulations were performed in this software.

4. Simulating the body movement

A time-varying longitudinal thrust force has been used for the movement of the model vehicle. A gradually increasing longitudinal force applied to the rear wheels in a time interval from t = 1.2 to 6.8 s has been used for a forward movement. All-wheel brake force is used at the time of from 10 to 14 s. A longitudinal force simulates the acceleration and deceleration of the vehicle.

The size of a body inclination α is determined by the equation (*1*), where H_{1i} (H_{2i}) – a distance of a measurement point on the front (rear) part bow (stern) of the body from the road at time t_i; A_x – a distance between measurement points in the longitudinal plane of the vehicle; H_{10} (H_{20}) is a distance of a measuring point corresponding to a steady vehicle velocity.

$$\alpha_i = \tan^{-1}\left(\frac{(H_{1i} - H_{1o}) - (H_{2i} - H_{2o})}{A_x}\right) \quad (1)$$

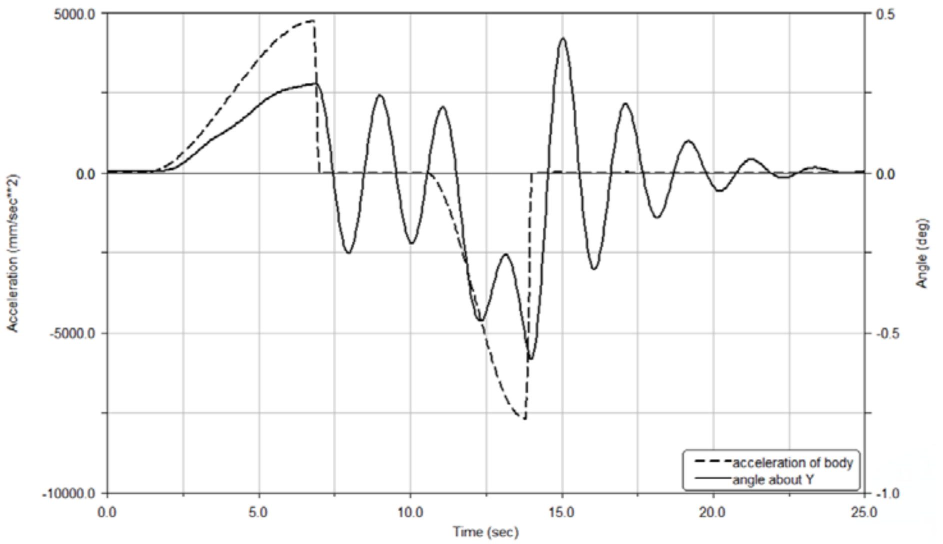

Fig. 3: Acceleration of the vehicle and body pitch according to the lateral axis

The process of the body inclination according to a lateral axis *y* is shown in *Fig. 3*. The maximum absolute value of the car body inclination is $\alpha = 0.58°$ which corresponds to the difference of a vertical lifting between the bow and stern of the absolute value of 38 mm on the length of the body.

When implementing the body roll examination, the model car has been set to motion at a constant velocity by the forward force applied on the front wheels. At the time $t = 15$ s, there has been a shift in a rack of the steering transmission to a left lock and further so as to make the car perform a track in the form of a figure eight and finally perform a simple lane change.

The process of the body roll according to a longitudinal axis *x* is shown in *Fig. 4*. The maximum absolute value of the car body inclination is $\beta = 1.53°$ which corresponds to the difference of a vertical lifting between the left and right side of the body with the absolute value of 69 mm on the width of the body.

$$\beta_i = \tan^{-1}\left(\frac{(H_{3i} - H_{3o}) - (H_{4i} - H_{4o})}{B_x}\right) \tag{2}$$

The size of a body roll angle β is determined by the equation (*2*), where H_{3i} (H_{4i}) – a distance of a measurement point on the left (right) side of the body from the road at time t_i; B_x – a distance between measurement points in the lateral plane of the vehicle; H_{30} (H_{40}) is a distance of a measuring point corresponding to a steady vehicle velocity (Zikmund T., 2006).

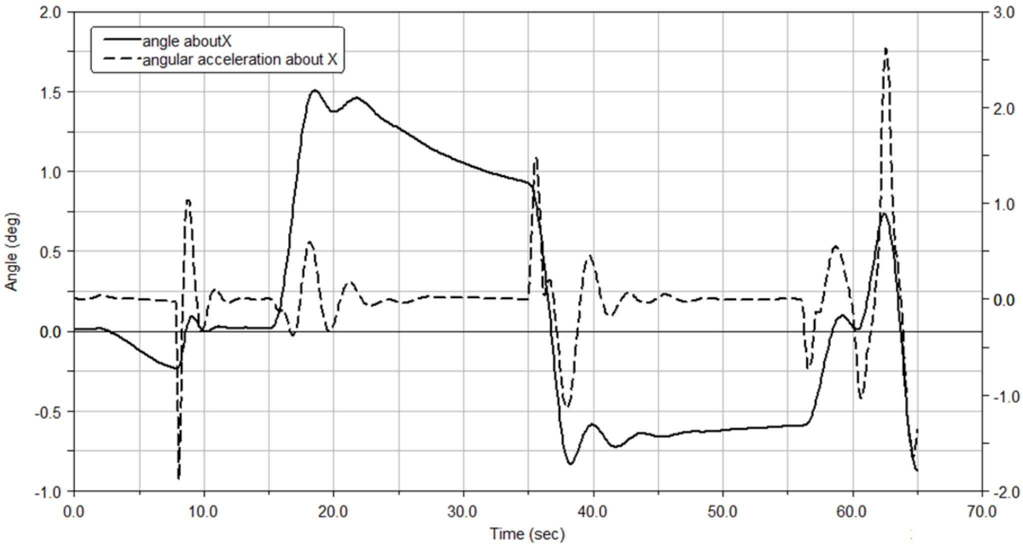

Fig. 4: Angle and acceleration of the body roll

5. Conclusion

The vehicle body movement simulation diagrams imply that every driving condition involving a change in acceleration causes a movement of the body. If it is necessary to change the adhesive conditions for the vehicle movement, it is possible to use slip surfaces or slip tires, or it is possible to influence a radial wheel reaction. To achieve the credibility of vehicle behavior change, we recommend providing the radial wheel reaction by lifting the unsprung masses. When lifting the sprung masses, the body does not change its position to a road plane and such a vehicle is applicable to a limited extent for training the drivers. Value of the body inclination for the SkidCar system is equal to zero due to its construction. From this perspective, the benefit of the SlideWheel system is evident.

A more detailed treatment of the vehicle behavior with lifting unsprung masses is subject to further work at the Department of Transport Means and Diagnostics of the University of Pardubice which aims to bring the structural solution of SlideWheel into a real form and undergo a driving test.

References

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