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Diagnostic simulation testing of the suspension system of an automotive vehicle

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A physical model of the diagnostic system used for the testing of automotive vehicle suspension defects together with the vehicle specimen tested has been presented in this paper. Moreover, results of computer simulation tests carried out with the use of the Working Model 3D software for one type of input oscillations of the vibratory platform have been shown and compared with experiment results. On these grounds, the model developed has been found suitable for further work on the problem of detection of defects in suspension systems of automotive vehicles.

1. Introduction

Theoretical studies and experimental research work on the diagnostics of suspension systems of automotive vehicles are carried out at the Technical University of Łódź, Department of Vehicles and Fundamentals of Machine Design. Within these activities, a diagnostic test stand has been designed and built [1]. Major components of the prototype test facility as well as the types of the kinematic inputs applied are shown below (Figs. 1 and 2).

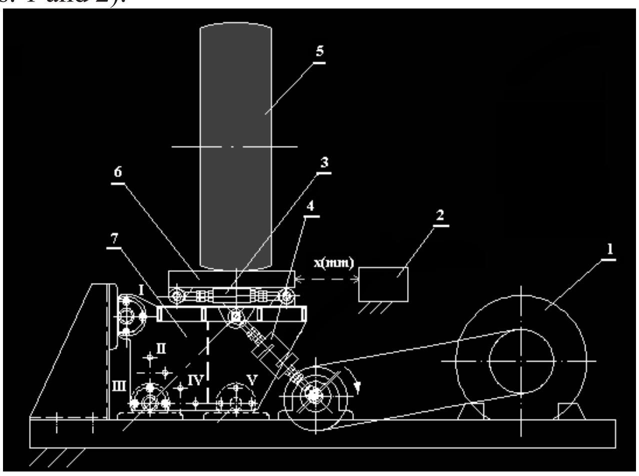

Fig. 1. Schematic diagram of the multi-purpose vibratory platform

Legend:
1 – Electric motor with inverter-controlled speed
2 – Laser sensor to measure instantaneous platform displacements
3 – Load cell to measure instantaneous lateral forces
4 – Load cell to measure instantaneous ‘vertical’ forces
5 – Road wheel of the vehicle under test
6 – Moving upper test platform
7 – Moving lower test platform
I – Platform pivot enabling “vertical” vibrations of the road wheel
II, III, IV – Platform pivots enabling simultaneous vertical and horizontal vibrations of the road wheel
V – Platform pivot enabling “horizontal” vibrations of the road wheel

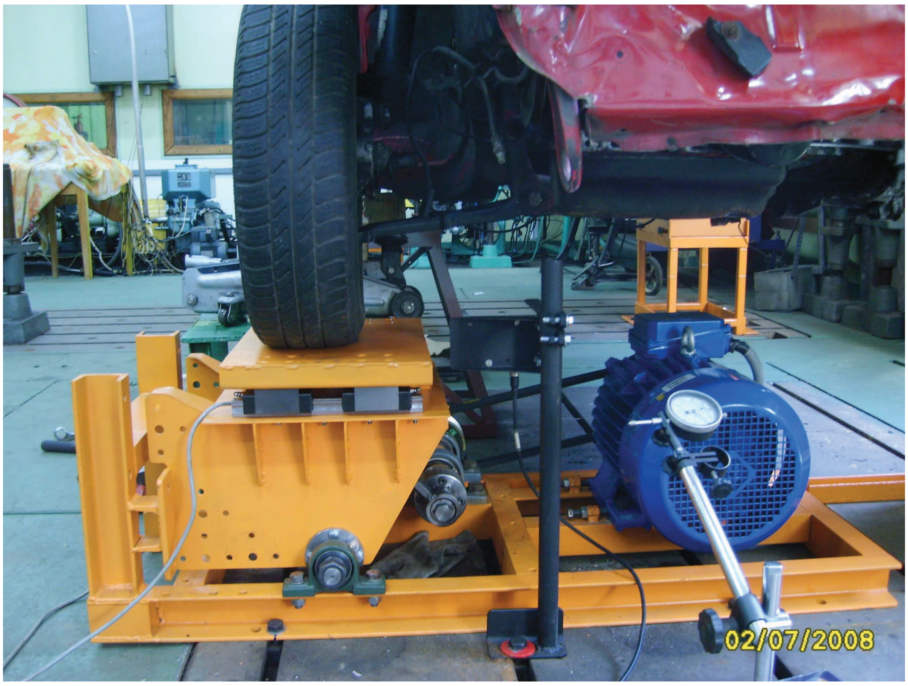

Fig. 2. The vibratory platform of the test stand

A concept of the simulation model of the diagnostic system together with the vehicle specimen tested is shown in Fig. 3. The model was used to carry out computer simulation tests with the use of the Working Model 3D software (Fig. 4).

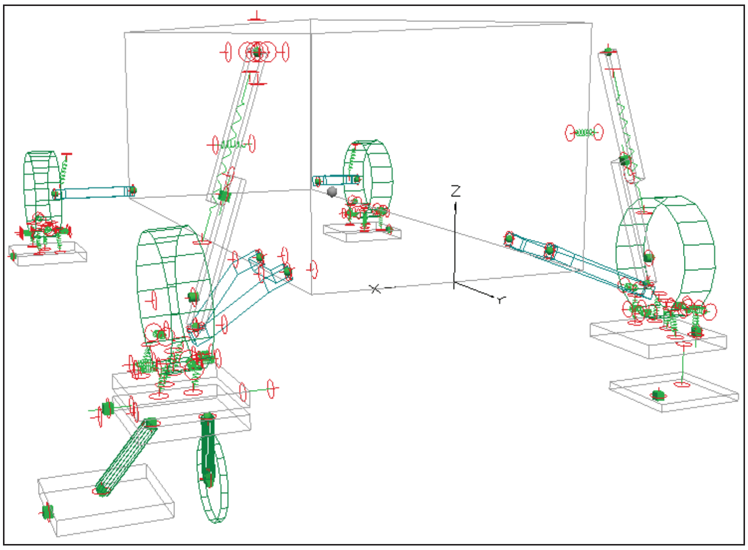

Fig. 3. The simulation model of the diagnostic system together with the vehicle specimen tested, Working Model 3D software

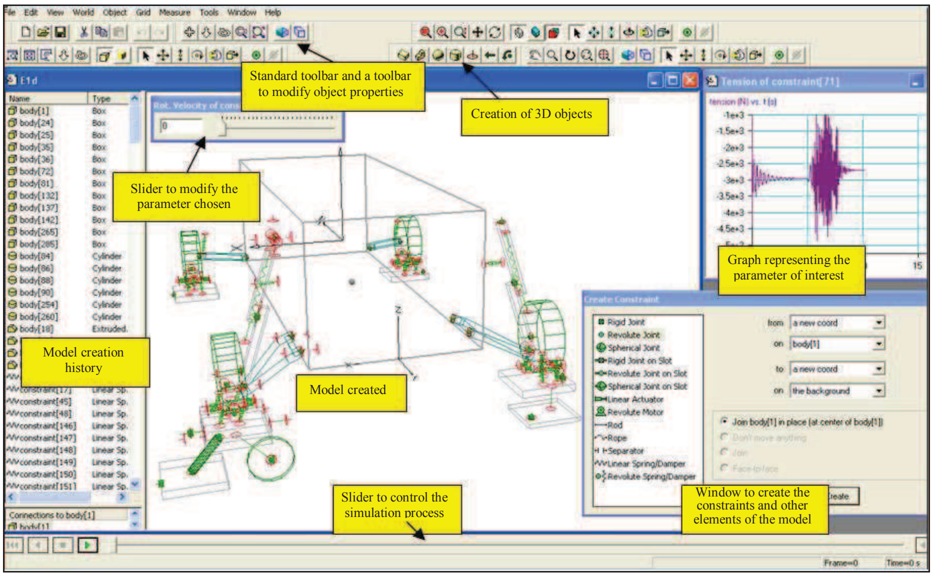

Fig. 4. Screen of the Working Model 3D software

In the simulation model presented, the vibration actuator represents the kinematics of the actual unit used at the laboratory test stand. At the simulation tests, mixed-type input vibrations were applied (type III input equivalent to type III input vibrations of

Fig. 1). This input type proved to be appropriate (as one of 3 options) for the testing of technical condition of the suspension system on the diagnostic stand proposed [2].

During the tests carried out with the use of the Working Model 3D software, four cases of the suspension system technical condition were simulated, defined as follows:

– **Good (reference):** The front suspension system of the vehicle under test with a shock absorber in good technical condition and a new suspension arm complete with two rubber bushes and a ball joint;
– **1 mm backlash at the ball joint:** The front suspension system of the vehicle under test with a shock absorber in good technical condition, a new suspension arm complete with two rubber bushes, and a ball joint with simulated 1 mm backlash;
– **Damaged rubber bushes:** The front suspension system of the vehicle under test with a shock absorber in good technical condition and a new suspension arm with damaged (de-vulcanised) rubber bushes;
– **Backlash at the MacPherson strut bearing:** The front suspension system of the vehicle under test with a shock absorber in good technical condition, a new suspension arm complete with two rubber bushes and a ball joint, and backlash at the main bearing of the MacPherson strut.

To analyze the results of the simulation and experimental tests, an index value [1, 2, 3] was used, estimated from the lateral force acting on the platform and averaged for one cycle ($\acute{s}rF_y$):

$$W_y = \frac{\acute{s}rF_y}{F_{z0}} \tag{1}$$

where: W_y – lateral stiffness index of the suspension system,
F_{z0} – static vertical load of the specific vehicle axle,
$\acute{s}rF_y$ – lateral force on the platform, averaged for one cycle.

$$\acute{s}rF_y = \Sigma abs(\acute{s}rF_y) \tag{2}$$

2. Simulation model of the diagnostic system

2.1. Front suspension system

In the physical model of the system under tests, front suspension geometry (Fig. 5) consistent with the geometry of an existing vehicle (Citroen AX) was adopted, with damping and elasticity coefficients of 1 500 [N·s/m] and 40 000 [N/m], respectively. During the tests, the values of these parameters may be changed depending on the actually required technical condition of the suspension system. For the sake of simplification of the suspension system model, linear system characteristics were assumed.

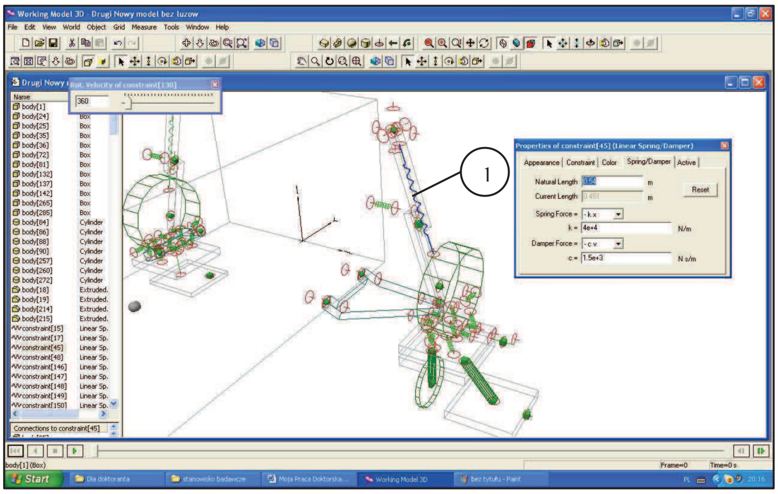

Fig. 5. Working Model 3D: Front suspension (MacPherson type)

2.2. Steering system

In the simulation model, the steering system was replaced with a spring (2) with damping and elasticity coefficients of 3 000 [N·s/m] and 200 000 [N/m], respectively. These values were chosen based on experiments, for the modelled steering system to behave like the existing one.

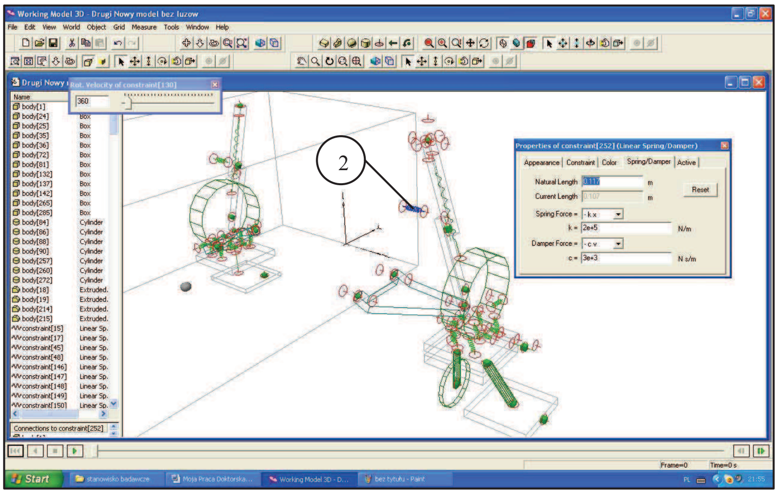

Fig. 6. Working Model 3D: Front suspension

2.3. Pneumatic tyre

In the simulation model, the pneumatic tyre (Fig. 7) was modelled so that the lateral and radial elasticity and damping coefficients were consistent with the data given in the reference literature [4]. Adequate values of these parameters were achieved thanks to the application of springs (2) in appropriate configuration.

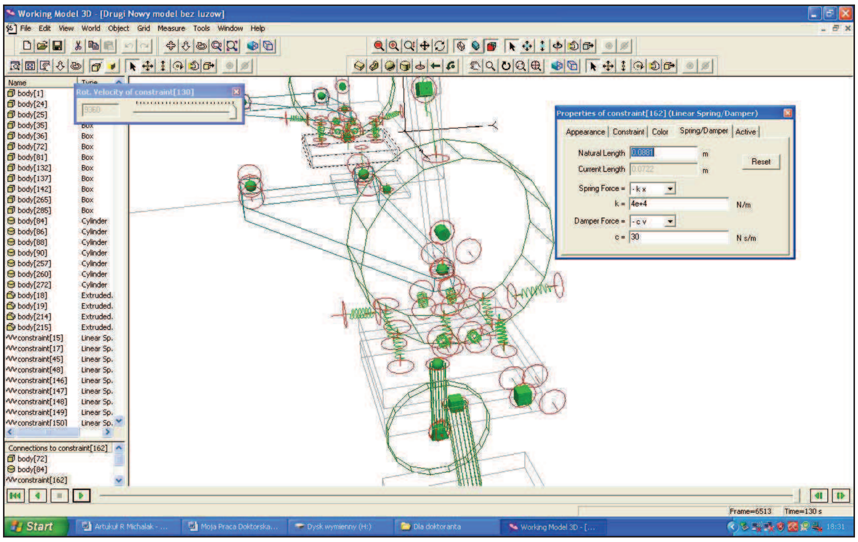

Fig. 7. Working Model 3D: Pneumatic tyre

2.4. Modelling of the backlash at the attachment of the MacPherson strut to the body

The simulation of backlash in the suspension system (Fig. 8) was accomplished by the application of a separator (4). The MacPherson strut (1) is connected with the vehicle body (5) by means of a ball joint (2). Thanks to the ball joint, the strut may only move in the vertical direction (along the "*z*" axis) in relation to the vehicle body and rotate around all the three axes (description of the degrees of freedom of the ball joint (2) (Fig. 8)). The ball joint (2) of the MacPherson strut is secured to the vehicle body with a special mount (3). The kinematic chain between the mount (3) and the ball joint (2) includes a separator (4), which restricts the vertical motion of the strut (along the "*z*" axis). Thanks to the separator (4), the backlash may be simulated. The modelling of the connection of the strut with the vehicle body as described here provides a possibility to simulate the backlash along the "*z*" axis (vertical backlash).

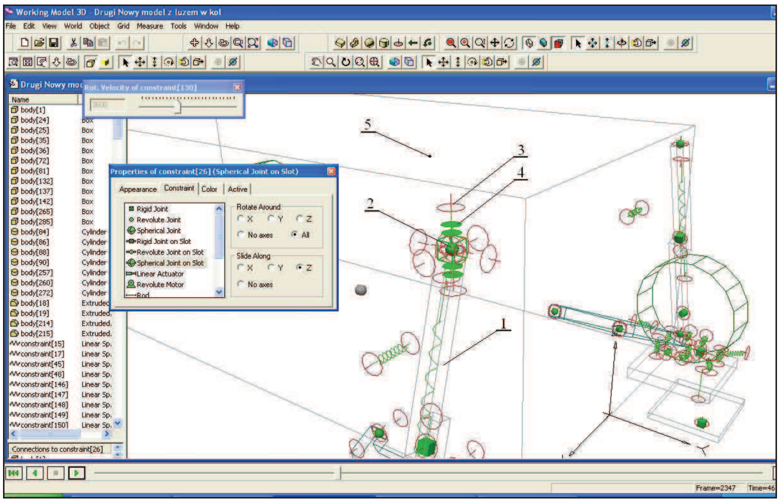

Fig. 8. Working Model 3D: Defect (vertical backlash) in the front suspension

2.5. Modelling of the backlash at the attachment of the suspension arm to the body

The backlash simulating damage to the rubber bushes is shown in Fig. 9. This backlash was modelled in a similar way as it was done in the case illustrated in Fig. 8, but now the backlash (between the suspension arm (1) and the body (2)) was oriented horizontally, i.e. along the "***x***" axis.

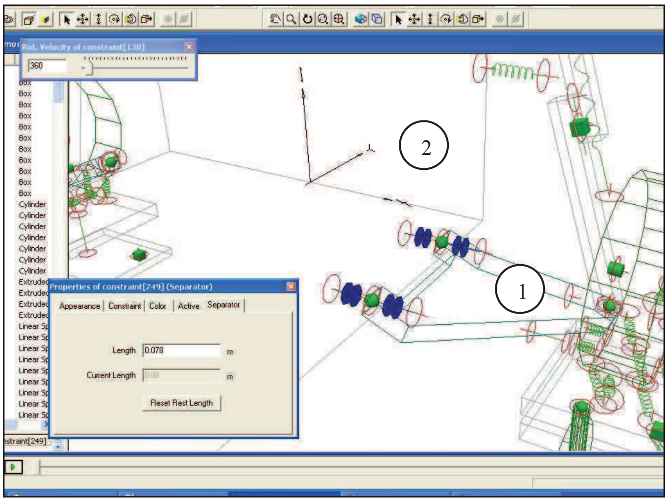

Fig. 9. Working Model 3D: Defect (lateral backlash) in the front suspension

2.6. Modelling of the backlash at the attachment of the suspension arm to the wheel hub

Fig. 10 shows the backlash simulating damage to the ball joint between the suspension arm and the part of the MacPherson strut that is integral with the wheel hub of the model of the vehicle under test. This backlash was modelled similarly to those described above; in this case, the backlash (between the MacPherson strut part (1) integral with the wheel hub and the suspension arm (2)) was again oriented horizontally, i.e. along the "***x***" axis.

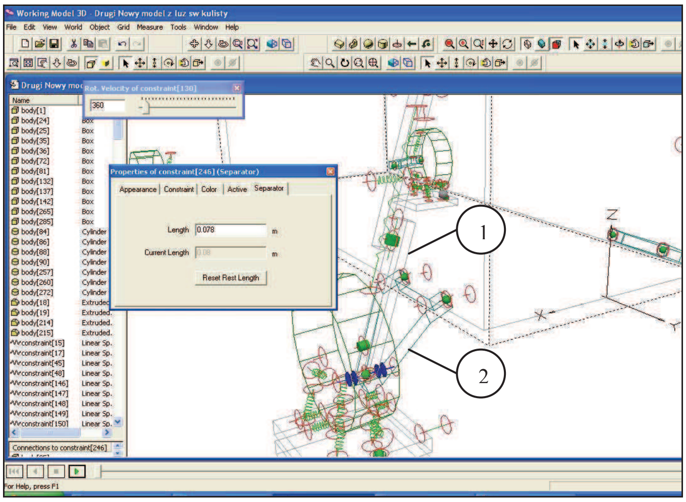

Fig. 10. Working Model 3D: Defect (lateral backlash) in the front suspension

3. Simulation and experimental test results

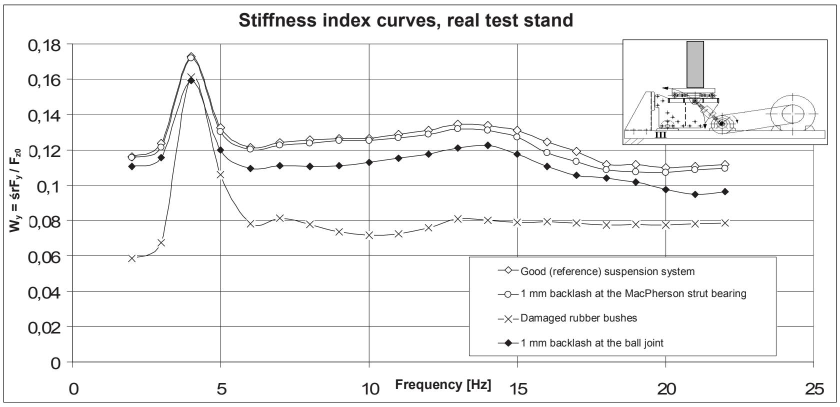

Fig. 11. Lateral stiffness index ($W_y = śrF_y/F_{z0}$) curves for various cases of suspension damage at lateral/vertical input vibrations (platform pivot point **III**, according to Fig. 1)

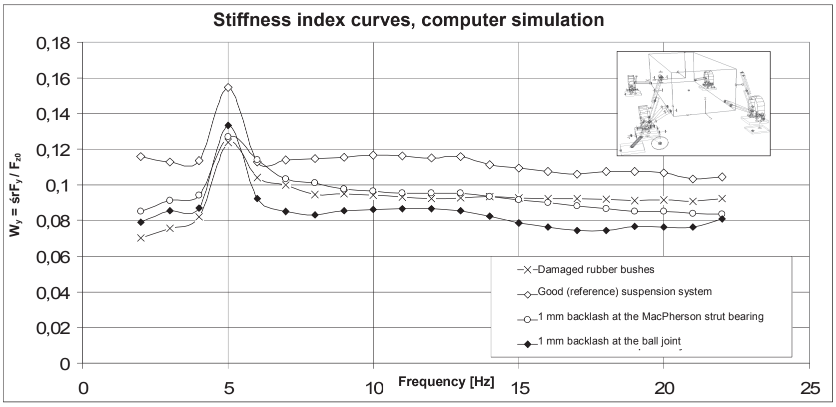

Fig. 12. Lateral stiffness index ($W_y = śrF_y/F_{z0}$) curves for various cases of suspension damage at lateral/vertical input vibrations (platform pivot point **III**, according to Fig. 1)

Results of tests of the technical condition of a suspension system (detection of damage to the system with the use of the W_y index), carried out for a real test stand and suspension system, are shown in Fig. 11. Fig. 12 represents results of the computer simulation of such tests, carried out for the same test conditions. A similarity in shapes and values has been found to exist between the corresponding W_y index vs. frequency curves plotted for various defects in the suspension system.

4. Conclusions

At the presented simulation tests carried out at backlash taking place, appropriate values of the coefficient of restitution for the specific pairs of materials of mating counterparts have been introduced, which had a considerable impact on the W_y index curves obtained from the tests.

Based on an analysis of the W_y index curves plotted for a real system under tests and for the simple simulation model presented, coincidence was observed between the test results obtained. The shapes and values of the stiffness index curves have confirmed the physical model built to be correct and, in consequence, to be suitable for further work on the problem of detection of backlash in automotive vehicle suspension systems of various types.

To achieve better conformity of the W_y index curves obtained from tests, further simulation tests are carried out with the use of a more accurate model of the pneumatic tyre and the suspension system with non-linear characteristics.

References

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