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ABSTRACT

In this paper, a new kinematics and compliance test rig will be presented. Particularly the design and construction of the test bench is explained. Moreover a typical measuring procedure will be presented in which a certain driving situation is going to be simulated at the test bench.

It will also be shown how to validate the computer model of a vehicle for the simulation tool ADAMS with the results of the test bench. By simulating a certain driving maneuvers with ADAMS, the influence of the compliance steer on the road performance of a motor vehicle will be shown in conclusion.

INTRODUCTION

For the understanding of vehicle handling characteristics, investigations on suspension kinematics and compliance steer are of major interest. Kinematics means the movements of the wheel relative to the body that result from spring travel. Compliance steer results from additional forces in the contact area of the tires. These forces caused by lateral or longitudinal accelerations of the vehicle deform the suspension parts and its bushings and lead to additional camber and toe angles [DIN94].

Compliance steer of axles has a great influence on the handling performance of vehicles. By a specific interpretation of the suspension elements, the engineer is being forced to get a compliance steer that supports a controlled road performance of the complete vehicle. Some types of axles have however conceptionally caused disadvantages regarding compliance steer such as twist-beem rear axles [ZOM87]. These shall be minimized in the most effective way by constructive features.

Because of the diminution of vehicle development time it is necessary to get object measuring results from new axles very fast and easily. These results are also necessary to validate the compliance steer of vehicle models for the simulations of vehicle dynamics. The quality of the model compliance steer influences very clearly the results of the multy-body-simulations. Pure static mechanical models do not deliver adequate simulation results for modern vehicles.

CONCEPT AND DESIGN OF THE TEST BENCH

The ika kinematics and compliance Test Rig can be used for the measurement of the influences of vertical deflections and both lateral and longitudinal forces on the axle geometry of complete vehicles or of axle-systems. By the help of four hydraulic cylinders that are fixed to the four wheels arbitrary wheel suspension positions can be realized [Fig. 1].

The test bench mainly consists of 12 hydraulic actuators (one for longitudinal, lateral and vertical force generation on each wheel) that can be operated individually. In Fig. 2 two possible designs for the test bench are demonstrated. In order to simulate a contact zone between wheel and the ground the test bench can be equipped with aerostatic bearings. Highly sophisticated sensors, amplifiers and measurement data acquisition systems record any value in the course of time that might be of interest. Fig. 2 shows the optical Autocollimator sensors that are used to measure the camber and toe angles.

A large number of fastening devices, which serve to fix the vehicle body to the test rig, eliminate the influence of body stiffness on the measurement. Moreover, the fastening systems allow the easy fixing of any car to be tested without the need to produce costly adapters. Apart from that it is also possible to fix and to examine single axles and wheel suspensions without examining the complete vehicle.

Figure 1. ika-kinematics and compliance test rig

The complete system is controlled by a reliable computer system to reduce the operator's influence on the results and to achieve an optimum reliability and repeatability of the measurements. Extensive routines shall exclude a malfunction of the test bench to avoid a damage of the vehicle.

Typical characteristics which are supposed to be examined are: roll axis position, roll stiffness or steering compliance. But also complete driving maneuvers such as 'steady state cornering' or 'breaking maneuvers' can be simulated at the test bench. Knowledge can be gained about the self steering properties of the vehicle by using this method.

The technical data of the test rig are:

- variable wheelbase: 2000 to 3250 mm
- variable track width: 1180 to 1650 mm
- max. vertical displacement at the wheel: 400 mm
- max. wheel load: 14 kN
- max. lateral force (per wheel): 10 kN
- max. brake force (per wheel): 10 kN
- max. traction force (per wheel): 5,5 Kn

Because of the compliance steer forces, and moments between the tire and the ground cause changes to the kinematic qualities of a suspension.

In Fig. 4 - 6 typical measurement results of the test bench are shown. Fig. 4 shows the toe and camber angle as function of the suspension travel of an typical twist-beam rear suspension. Fig. 5 shows th same curves for an McPherson front suspension system. In Fig. 6 toe and camber angle are shown as function of the lateral force in Fig. 7 as function of braking force for an twist-beam rear suspension.

Figure 2. Measuring of camber and toe angles with optical Autocollimators

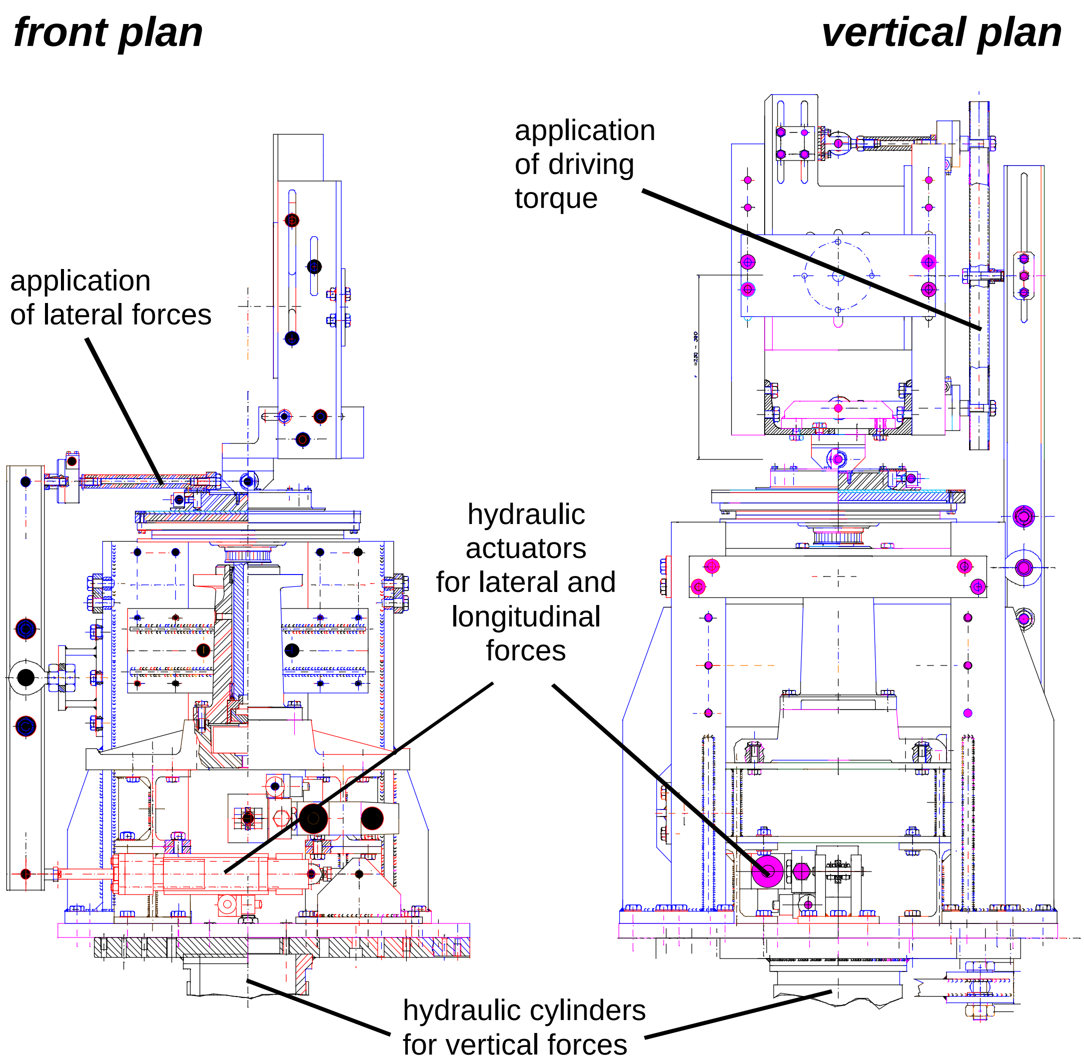

Figure 3. Configurations for the simulation of lateral and longitudinal forces in the wheel contact area to the ground

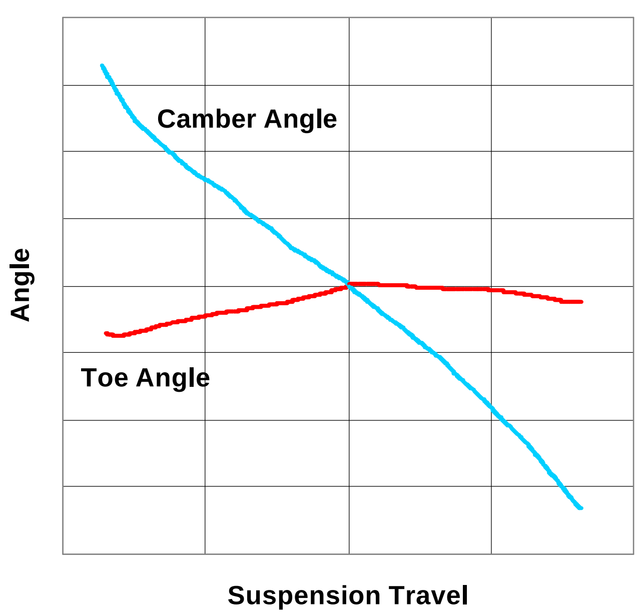

Figure 4. toe angle and camber angle as function of suspension travel of an twist-beam suspension

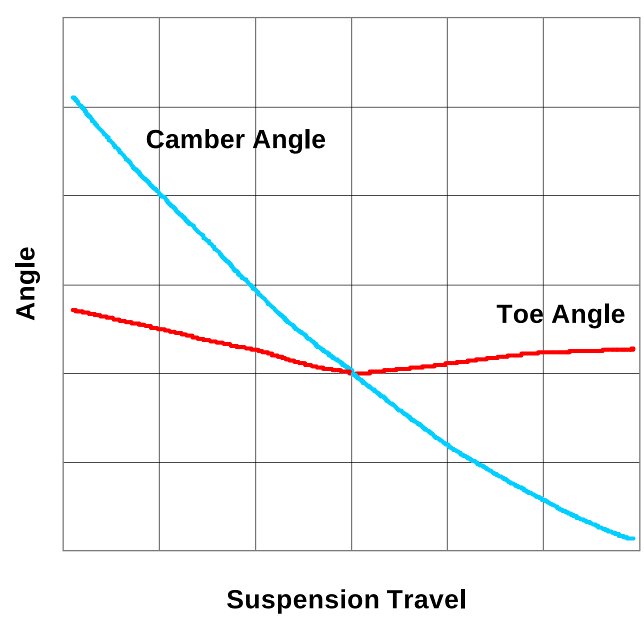

Figure 5. toe angle and camber angle as function of suspension travel of an McPherson-Suspension

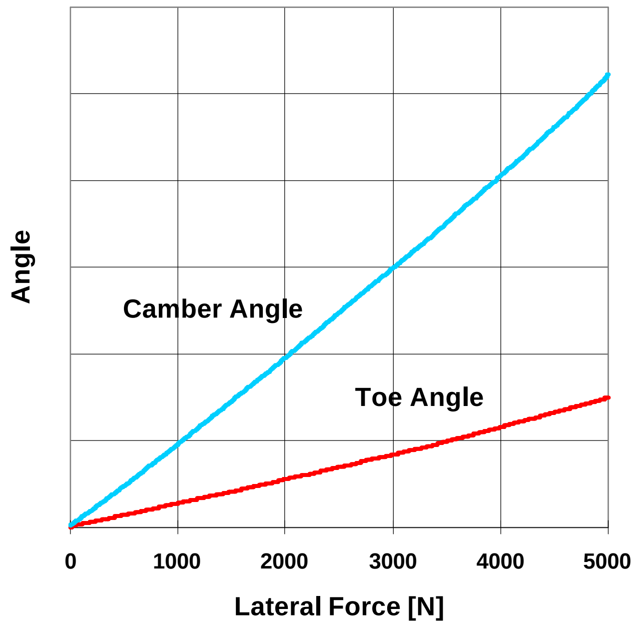

Figure 6. toe angle and camber angle as function of lateral force of an twist-beam suspension

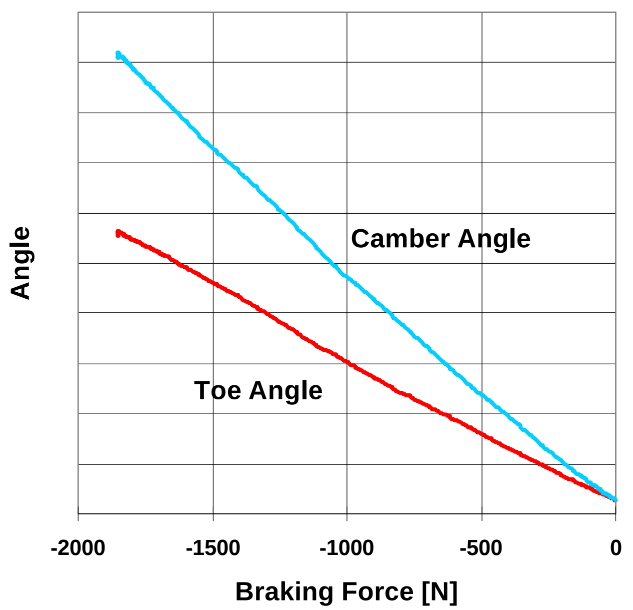

Figure 7. toe angle and camber angle as function of breaking force of an twist-beam suspension

SIMULATION

Computer aided simulation of vehicle handling characteristics is nowadays universally acknowledged as an efficient method in the process of developing new vehicles. Simulation software tools are used both by automobile manufacturers and suppliers to an increasing extent. The outstanding quality of simulation results for chassis development is acknowledged without exception. ADAMS® as a multybody-simulation-tool is in service in automotive engineering all over the world. The dynamics of rigid bodies can hereby be analyzed mathematically very exactly.

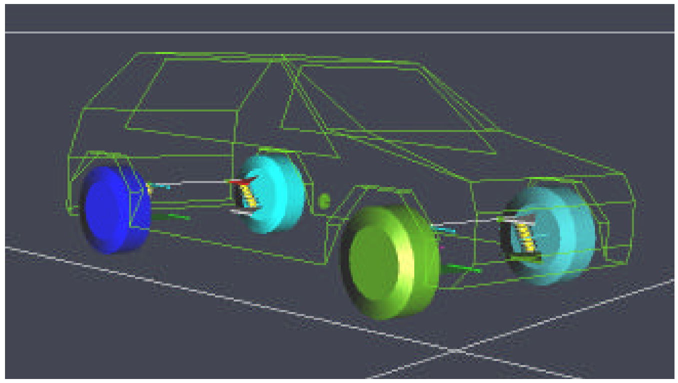

Figure 8. ADAMS®-Model of a complete vehicle

By the connection of different bodies with joints, models of complete vehicles become reality. This can be used in the simulation of standard driving maneuvers to examine the road performance of the vehicle. To get more detailed simulation models, the joints have to be replaced by elastic elements, the so called ‘bushings’. These bushings can be characterized by defined spring and damper characteristics in any direction. By this the compliance steer of a suspension can be integrated in the simulation model. In Fig. 8 an ADAMS®-model of a complete vehicle is being shown, which shall be used for the simulations described in this chapter. The model is equiped with an double-wishbone suspension at front and with the twist-beam rear axle, that was examined before oh the K&C test bench.

VALIDATION OF THE COMPUTER MODEL – The kinematic qualities of vehicle axles are obviously defined by the geometry of the suspension bearing points. But for the elastic qualities of the axles more than design information are necessary to create an exact model of the axle. Particularly the assembly of all the different flexible elements of a suspension have to be verified only by measuring the complete axle on a test rig.

In the simulation, a similar procedure has to be carried out. Therefore the complete kinematics and compliance test rig has to be built up in simulation to verify the actual simulation model which is equipped with elastic elements, as is shown schematically in Figure 9.

Similar to reality, the vehicle body has to be fixed to the ground. Common tire models are not designed for simulations without any velocity [STR96]. Therefore the tire model in this simulation has to be replaced by simple springdamper elements. This, however, doesn't influence the results. In the contact area between the tire and the test bench, forces or moments can be applied like has been done on the real test rig. In this way any displacements or angles between the wheels and the body can also be determined as function of the applied forces and moments in the simulation.

After comparing the results from the simulation and the testing, the simulation results can be changed by modifying the qualities of the elastic bushing-elements in the computer model. This modification will be repeated as long as the results of the simulation and the testing don't match. In Fig. 9 the results of the test bench are compared to the results of the ADAMS-Model. The similarity of both curves is so precisly that the validation of the model can be considered as quite perfect.

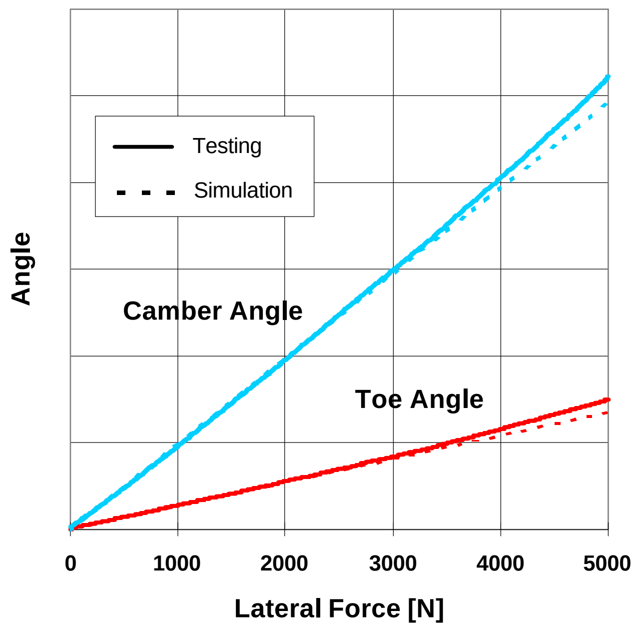

Figure 9. toe angle and camber angle as function of lateral force of an twist-beam suspension in simulation and testing

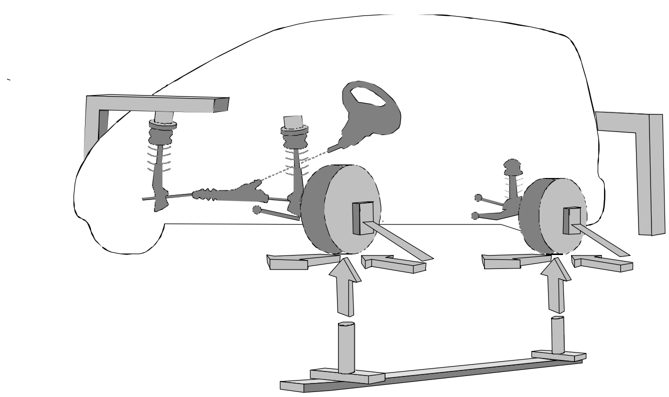

Figure 10. In principle construction of the test rig in the simulation

SIMULATION OF STANDARD DRIVING MANEUVERS

Simulations of standard driving maneuvers are carried out with the validated ADAMS®-vehicle model. These maneuvers are used worldwide to characterize the quality road performance of vehicles [ZOM87, ROM94].

In this paper the maneuver 'Steady state cornering' is presented. Fig. 10 shows the results of this simulation: steering angle as function of lateral acceleration. In addition to the results of the model with compliance steer, results of a rigid body model without compliance steer are also shown.

The figure shows that both vehicles have understeering self-steering properties. The steering wheel curve of the model with compliance steer is little bit lower than the one of the rigid model. That means that the rigid model understeers more than the model with comliance steer.

To explain this effect we have to look at the compliance steer angles of the rear axle. Particularly the outer wheel must be observed. As Fig. 11 shows, the angle of the rigid model is as expected zero. The compliance angle of the outer wheel of the model with compliance steer rises proportionally to the lateral accelaration.

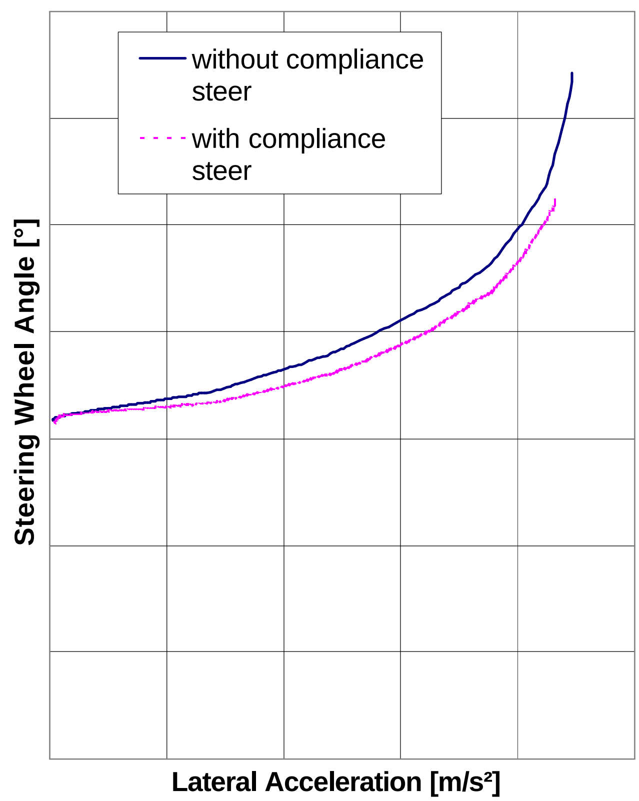

Figure 11. Steering wheel angle as function of lateral acceleration

The compliance steer behaviour of the vehicle shown in this simulation leads to a decreasing understeering tendency of the complete vehicle. This effect has to be judged of course negatively but is typical for a twist-beam rear axle that was simulated here.

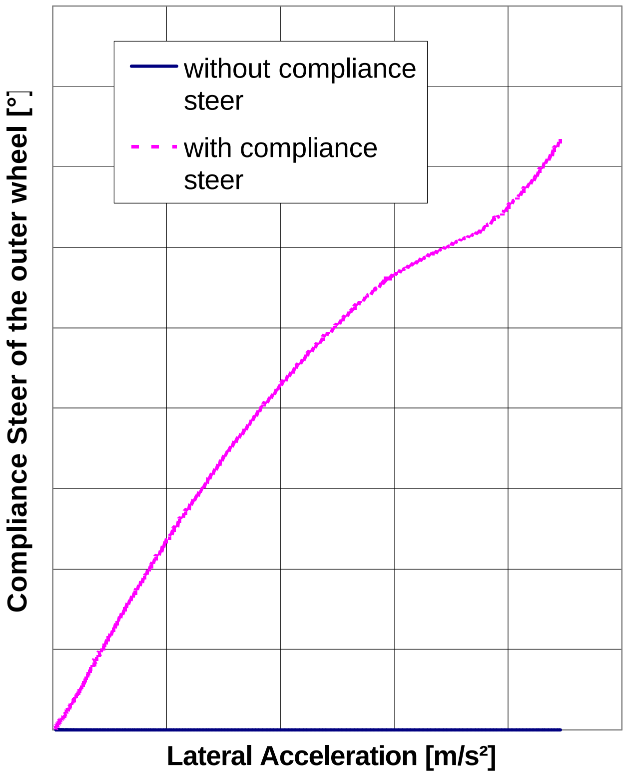

Figure 12. Compliance Steer Angle of the Outer Rear Wheel as Function of Lateral Acceleration

SUMMARY AND CONCLUSION

At the 'Institut für Kraftfahrwesen Aachen' a new test bench has been built up for the measuring of axle kinematics and compliance for complete vehicles and for suspension systems. By using this test bench, even prototypes can be analyzed to get all characteristic values of the axle geometry and the compliance steer. The complete system ist controlled by a computer system that produces values to simulate certain driving situations, as for example 'steady state cornering'. Based on this information, the self steering properties can be determined.

By the help of the multybody simulation tool it has been shown how to validate a computer model of a vehicle regarding its compliance steer values. With that model the maneuvers 'steady state cornering' and 'straitline braking' have been carried out. Moreover the difference was determined particularly between the elastic and the rigid model in terms of road performance. It could be pointed out, in what way the interpretation of the compliance steer improves the road performance of the vehicle. By further modifications to the elastic elements of the model, it will be possible to obtain further improvements in the road performance. If the result is satisfactory, requirements on the construction can be made from the simulation. As a consequence, the number of suspension prototypes can be reduced clearly.

Therefore a way was shown within this contribution how modern test benches and the use of modern simulation software can help to develop a complex new suspension systems with defined compliance steer. By using this method time and costs for the development of a new vehicle-chassis can be reduced.

REFERENCES

1. [DIN94]DIN 70 000
   Straßenfahrzeuge, Fahrzeugdynamik, Begriffe
   1994
2. [PAE96]PAEFGEN, F.-J.; TIMM, H.
   Der neue Audi A3
   Automobiltechnische Zeitschrift 98 (1996), Nr. 7/8, S. 370-378
3. [ROM94]ROMPE, H.; HEIßING, B.
   Objektive Testverfahren für die Fahreigenschaften von Kraftfahrzeugen
   Verlag TÜV Rheinland GmbH, Köln, 1994
4. [STR96]STRAETEN, F.
   Theoretische Reifenmodelle in der Computersimulation
   Studienarbeit am Institut für Kraftfahrwesen Aachen, RWTH Aachen, Aachen, 1996
5. [ZOM87]ZOMOTOR, A.
   Fahrwerktechnik: Fahrverhalten
   Vogel Buchverlag
   Würzburg, 1987

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