HGV safety research activities at the University of Hannover, Germany

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In Europe the total lenght of commercial vehicle combinations is limited. Since more and more lighter goods are transported the total loading volume of these vehicles has been increased by reducing the spaces within the combination. The systematic research work at the University of Hannover has shown important connections between coupling condition and directional behaviour of the vehicle parts in critical driving conditions. This research work was done not only by theoretical simulation but also by accompanying driving tests with those HGV combinations which are simulated. Because the accuracy of simulation-models is deeply depending on the knowledge of the forces in the tyre contact zone a tyre test vehicle for HGV-tyres has been developed.

INTRODUCTION

Commercial vehicles are important for each economy. In Germany about 80% of the total transport performance is produced by about 2.8 million commercial vehicles. About 5% are so-called Heavy Good Vehicles HGV with a total weight over 14,000 kg.

Highest standards concerning safety are required in view of increasing density of traffic and higher velocities detectable on freeways and highways. We must especially take notice of articulated vehicles and road trains because they represent multi-link systems with large masses. Oscillations of the rear part of a truck trailer combination can cause larger required traffic areas which might be dangerous for other road users. In cases of emergency, for instance if a sudden evading manoeuvre is necessary, the control of the vehicles can be lost, especially on roads with less tire grip. The directional stability can be seriously influenced by the different coupling conditions within the combination. Therefore systematic research work on this subject has become necessary. In Germany this was mainly executed at the University of Hanover.

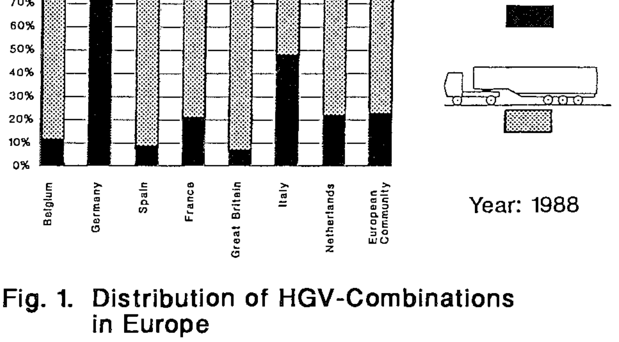

Fig. 1. Distribution of HGV-Combinations in Europe

ROAD TRAINS

The distribution of HGV vehicles in Europe is shown in Fig. 1. In Germany the road train version is still predominating though its part is decreasing slightly. Therefore, the research work in Germany was concentrated to the road train construction.

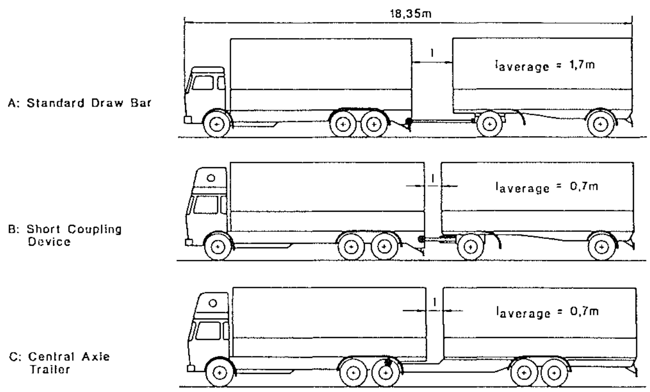

Fig. 2. Typical Truck-Trailer Combinations

In Fig. 2 truck trailer combinations typical for Europe are shown. The total lenght of the elongated train is limited to 18.35 m. Because of the draw bar a space of about 1.7 m between truck and trailer is necessary.

Since more and more lighter goods have to be transported the total loading volume had to be increased. One of the means being used was the introduction of so-called short coupling devices. The space between truck and trailer could be reduced to about 0.7 m, in extrem constructions to less than 0.4 m.

Heavy vehicles and roads: technology, safety and policy. Thomas Telford, London, 1992.

But directional driving quality, reverse manoeuvring peculiarities, maintenance costs and some other characteristics have proved themselves in some cases not to be fully satisfactory. Therefore, about 1980 the first large capacity road train with central axle trailer appeared. The space, on average about 0.7 m, depends from the point of coupling beneath the truck. Though there are some peculiarities, for instance coupling is not very simple, the road train is sensible to load distribution within the system, and there are vertical interactions between the two parts, this type of road train is increasing on European roads.

The aim of the research work at the University of Hanover was to find out more about the driving qualities of these types of truck trailer combinations in order to improve the safety on the roads. For controlling the quality of the results it was necessary that the research work was not only done by theoretical simulation but also by accompanied driving tests with those vehicles which were simulated.

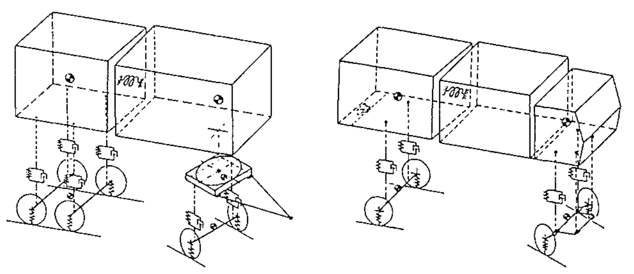

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Fig. 3. Mathematical Simulation Model A: Standard Draw Bar

INVARIABLE DRAW BAR
The systematic research work started with the standard road train with an invariable draw bar, Fig. 3.

A truck trailer combination represents a very complex vibrational system with a large number of degrees of freedom, inhomogeneous distribution of masses and many spring and damping elements, many of them with nonlinearities. As it is necessary to identify the mathematical simulation model with reasonable efforts, the model has to be simplified to a three-dimensional two-lane model with totally nine body and axle masses, which are connected by spring and damping elements free of mass.

Safety research means dealing with vertical, longitudinal and lateral oscillating problems. The model shown in the figure was generated mainly for lateral studies.

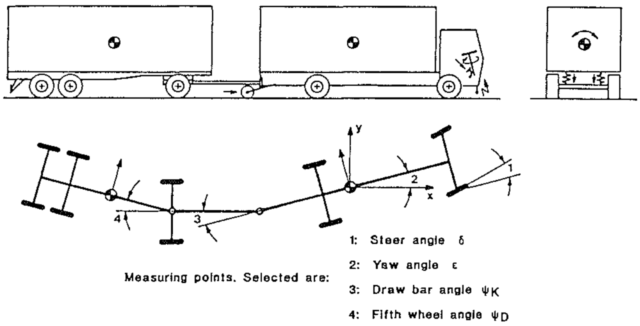


Fig. 4. Measurements with Truck-Trailer Combinations

MEASURING TECHNIQUE
The aim of the measuring technique, Fig. 4, is to determine the amount of motion of the vehicles. Normally about twelve to fourteen measuring points are adequate. For the following explanation only four are necessary and therefore selected:

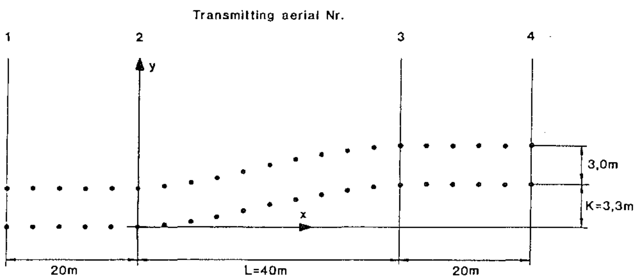
- Steer angle 1
- Yaw angle 2
- Draw bar angle 3
- Fifth wheel angle 4

But the results of all measuring points are required to validate and control the simulation model.

TEST PROCEDURES
Known standard test procedures for driving stability problems specified by the ISO Committee are among others

- Steady-state cornering
- Frequency response
- Double-lane change manoeuvre

All these tests were executed. Steady-state cornering offers information about the stationary directional response while the inertia properties are not involved. The frequency response is examined by sinusodial steering or steering with random orientation. These manoeuvres give information about the nonsteady directional response. Both tests are necessary to validate a simulation model.



$$y = K \cdot \left(\frac{x}{L} - \frac{1}{2\pi} \cdot \sin 2\pi \cdot \frac{x}{L}\right)$$

Fig. 5. Single Lane Change Manoeuvre

The lane-changing manoeuvre is less appropriate for a scientific analysis of the driving quality. When velocity is changed also three important conditions will be altered at the same time:

- the frequency of the excitation, because the steering speed increases with the velocity of the vehicle
- also the amount of the excitation as a result of higher lateral acceleration, and
- the damping factor of the pendulum oscillation, because the quotient of lateral to longitudinal velocity of the tire changes which alters the tire damping.

But the lane-changing manoeuvre offers a close reference to reality. It corresponds to a situation which might occur in daily traffic, for instance if the driver has to avoid collision with an unexpected obstacle. In 1975 ISO had proposed a lane change test but it has not been standardized. Therefore, a modified single-lane change manoeuvre was chosen for our research work, Fig. 5. The lane is 3.0 m wide, and the change of lane was set to 3.3 m within a distance of 40 m. Pylons were used to mark the lane.

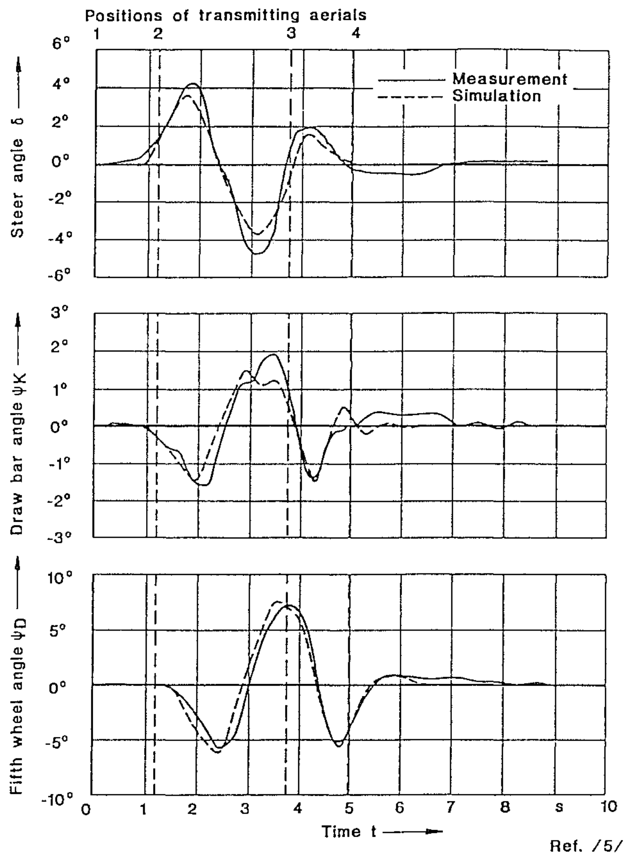


Fig. 6. Comparison Measurement and Simulation
Example at 60km/h, vehicles loaded

SIMULATION AND MEASUREMENT

After having validated the simulation model as described, the intended test runs were made, with the vehicles on the test ground of Continental Tire Company Hanover, and with the simulation model in one of the computing centers of northern Germany. As Fig. 6 shows, the correspondence between measurement and simulation is not bad. The drawing compares, as one example of many test runs, the measured and computed values with time of the steer angle, the draw bar angle and the fifth wheel angle of the loaded vehicles making the lane change manoeuvre at 60 km/h.

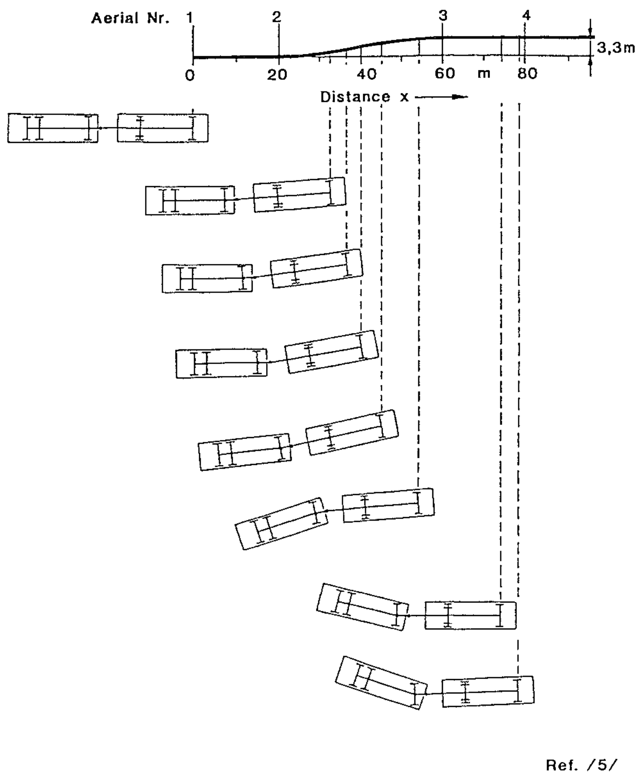


Fig. 7. Positions of the Road Train
Example at 60km/h, vehicles loaded

Fig. 7 shows for the same example the positions of the two parts of the road train while making the lane change. The overshot of the trailer at the end of the manoeuvre can be recognized very clearly.

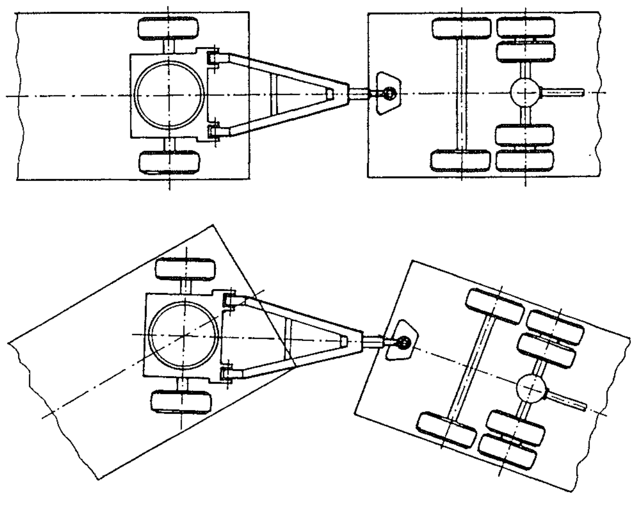


Fig. 8. Standard Draw Bar

SHORT COUPLING DEVICES
So far the tests were made with the standard draw bar coupling as shown in Fig. 8. Short coupling devices of which are known more than 50 different constructions can roughly be devided in the so-called

- Draw bar elongation systems, Fig. 9, and
- Additional steering systems, Fig. 10.

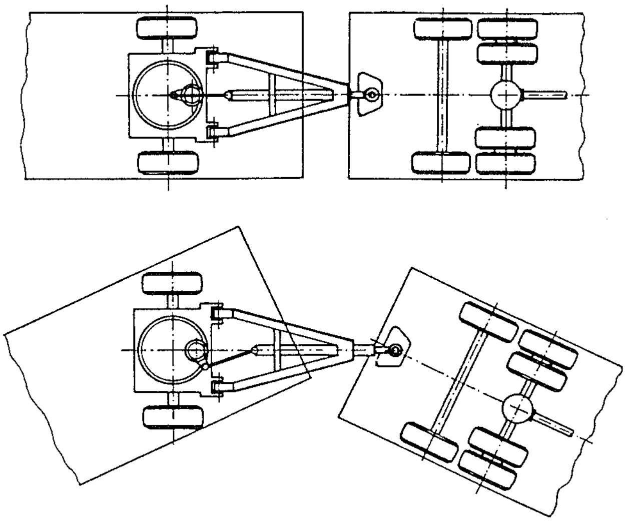


Fig. 9. Short Coupling Device
Example: Changing of Length

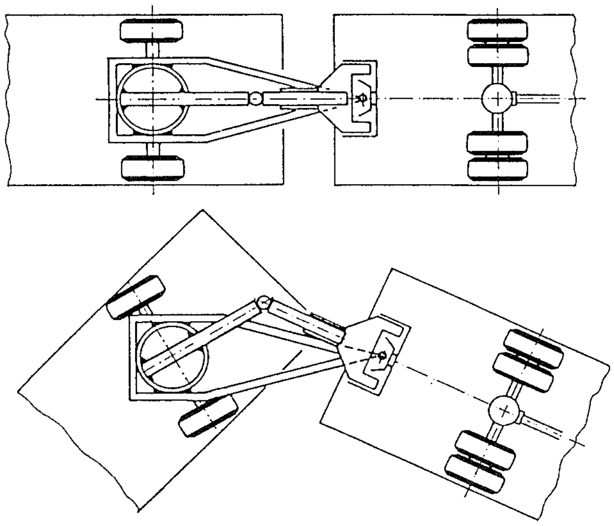


Fig. 10. Short Coupling Device
Example: Additional Steering

Both systems are suitable to avoid collision between the two parts of the vehicle when manoeuvring in narrow curves or reverse. In all elongation systems the bar eye is moved out as a function of the fifth wheel angle. These systems are more frequent. In the additional steering systems the front axle of the trailer has to follow another steering lock angle as it would correspond to the position of the draw bar. This is executed by an additional steering arm.

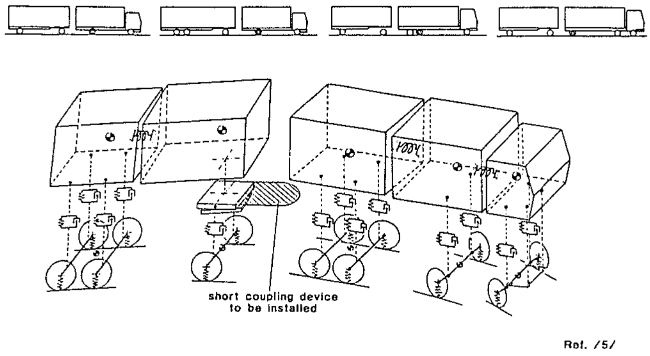


Fig. 11. Mathematical Simulation Model
B: Short Coupling Divice

Fig. 11 shows the improved mathematical simulation model. The truck part has now got four axles in order to imitate all possible variations as shown on top of the drawing. A subroutine had been developed for the different short coupling devices to be installed.

Measuring techniques, test runs on the Continental test ground as well as in the computing centre, and the kind of assessment of the results were the same as alredy described.

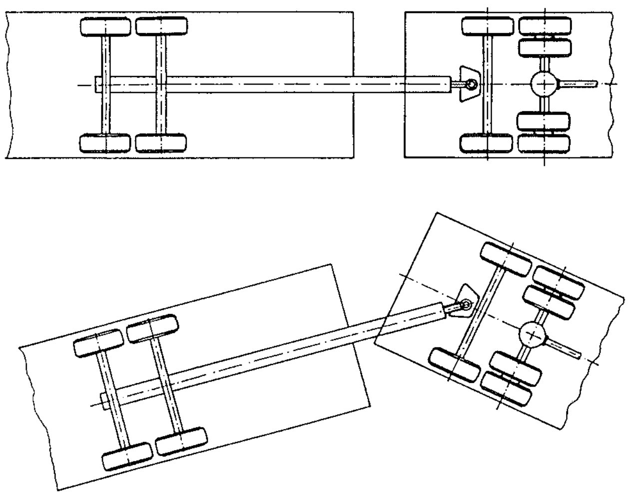


Fig. 12. Central Axle Trailer

CENTRAL AXLE TRAILER
Because of some disadvantages in the driving quality of short coupled trailers the central axle trailer became a success, Fig. 12. As it can easily be seen, connecting the two parts of the combination might be somewhat inconvenient. The trailer needs a support leg. The vertical coupling load is approximately 20 kN what represents about a quarter of a standard semitrailer's coupling load.

The accompanying simulation model is shown in Fig. 13. Because of the vertical interactions between the two parts of the combination, especially on rough roads, this model was also used

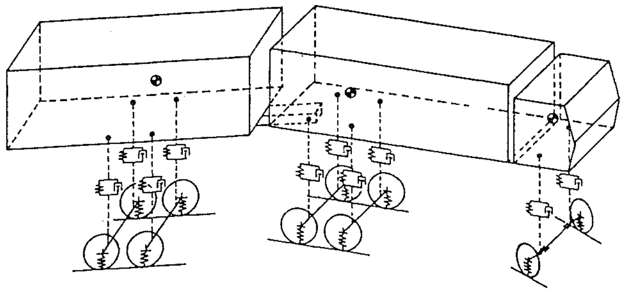


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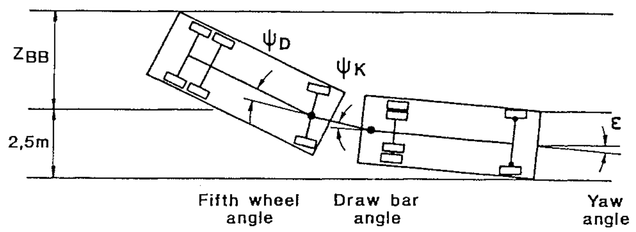
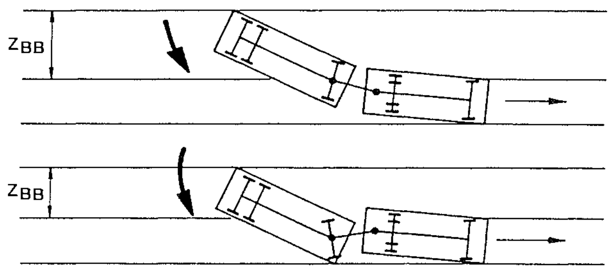
Fig. 13. Mathematical Simulation Model
C: Central Axle Trailer

for vertical oscillation problems including inclination. Practical and theoretical test runs were made as already described.



a. Additional required width Z_{BB}



b. Position of the trailer, indicated by the slip angle of the first trailer axle

Fig. 14. Some Assesment Criterions

RESULTS

The results of the comprehensive research work were quite interesting. They help designing engineers to improve their products, and they help traffic experts to estimate actions which might improve the safety on the roads.

Only a few results can be offered within a survey. But the results of the single lane changing menoeuvre give a good impression of the driving quality of the investigated types of road trains.

As seen before, the trailer tends to overshot at the end of the manoeuvre. Due to this fact, it is possible to derive a so-called "additional required width" as it is defined in Fig. 14a.

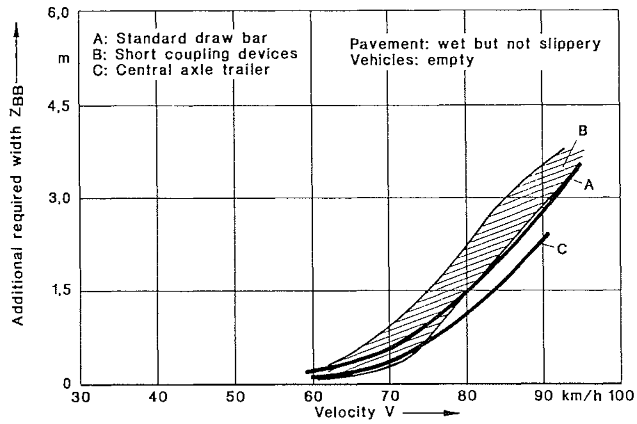


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Fig. 15. Additional required Width at Single Lane Change Manoeuvre

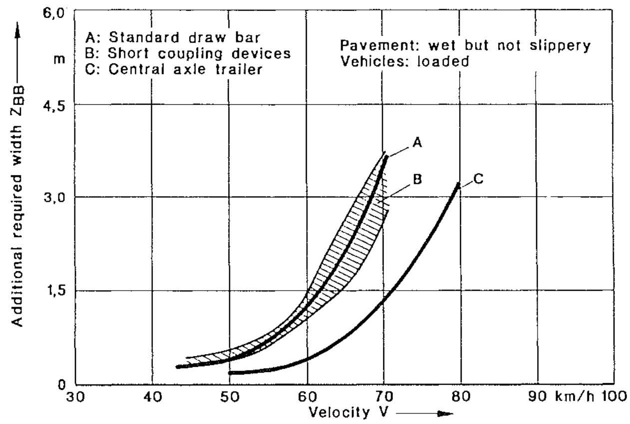

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Fig. 16. Additional required Width at Single Lane Change Manoeuvre

This traffic area can be calculated mainly from the yaw angle, the draw bar angle, the fifth wheel angle and the geometrical dimensions of the train. The results are summarized in Fig. 15 for the empty, in Fig. 16 for the loaded vehicles. The results for the short coupling devices B are comprehended to a field.

As assumed, the required width expands with increasing velocity of the vehicle. There are only few problems to expect with empty vehicles. But the results for the loaded vehicles offer some more difficulties. Especially the draw bar trailers, with the standard design as well as with short coupling devices, cover an additional width of already about 3 m as soon as the velocity reaches 70 km/h. Of course it has to be considered that this statement is only valid for the given conditions mainly concerning the quality of the pavement and the dimensions of the passing lane. The latter were rather tricky.

The central axle system had proved itself to be the construction which needs the smallest amount of additional width. This corresponds with the experience in daily traffic life. The results for the draw bar trailers, both the standard and the short coupled ones, are less sufficient. When driving in curves the subjective behaviour of the short coupled trailer is for some conditions much worse. Obviously the assessment criterion "additionel width" is not enough. In Fig. 14b two extreme positions of the trailer are outlined within the same amount of additional width. It is obvious that more information about for instance the yaw and the slip angle of the trailer are required.

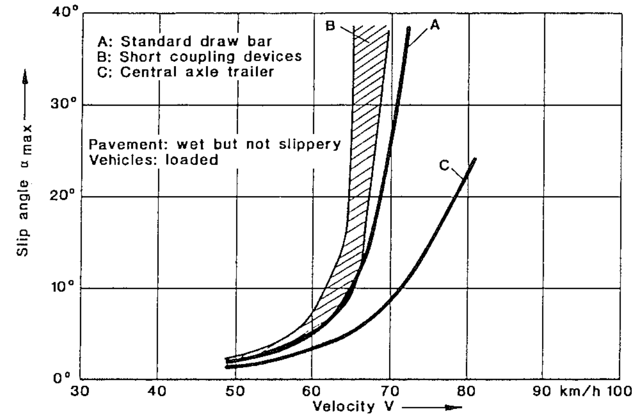

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Fig. 17. Largest Slip Angle at first Axle Single Lane Change Manoeuvre

In Fig. 17 the largest slip angles determined at the first trailer axle are plotted versus velocity of the vehicle. The drawing shows impressively that the limit of adhesion in the tyre contact zone is evidently reached earlier with the short coupled trailers. This is due to some additional moments inside the short coupling device as a result of special kinematics. These moments have to be supported by the tyres. The adhesion conditions are getting overcharged much earlier than by the other constructions.

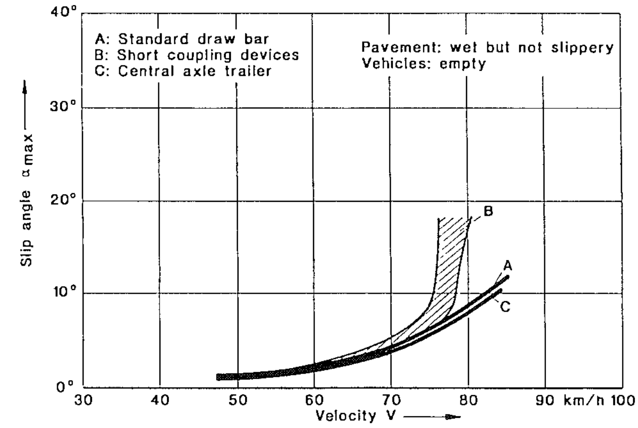

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Fig. 18. Largest Slip Angle at first Axle Single Lane Change Manoeuvre

The conditions for empty vehicles, Fig. 18, are less distinct but still impressive for the short coupled trailers.

The results as shown above are strikly speaking valid only for the chosen vehicles and conditions. But the researchwork could easily be extended to other HGV-combinations.

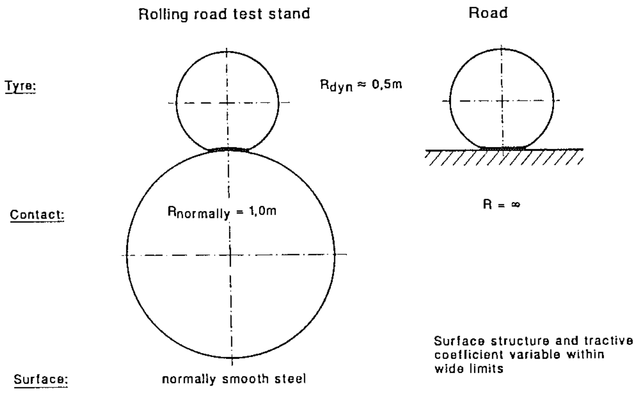

Fig. 19. Variations in Tractive Coefficient

TYRE TEST VEHICLE

The accuracy and reliability of this kind of research work depends strongly upon the accuracy of the measurement of the forces occurring in the tyre contact area. It had become clear that laboratory measurements made with rolling road test stands on HGV-tyres do not always reproduce the figures occuring on the road, Fig. 19:

- the difference between the tyre and the drum diameter is too small and the variation in the depression of the footprint of the tyre is too great, and
- the traction between the tyre and the drum does not correspond to actual conditions found on the road. The surface structure and tractive coefficients on the road are subject to wide variations.

Results closely approaching reality can therefore only be measured on real roads under actual weather conditions. For this reason a tyre test vehicle has been developed by means of which the important forces under actual conditions can be measured:

- the side force as a function of the angle of deviation between the tyre and the line of travel (slip angle), and
- the circumferential force as a function of the braking slip.

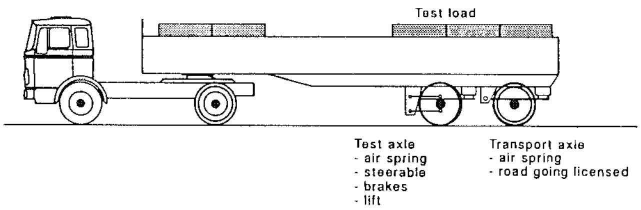

Fig. 20. Tyre Test Vehicle

DESCRIPTION

The test vehicle, Fig. 20, is in fact an articulated vehicle in which the trailer is equipped with two axles carried on air springs. The front axle is the measuring axle and the rear axle the "road going" one, so that the vehicle can travel to the test area with the measuring axle lifted clear of the road surface. The air spring pressure of each of the axles can be varied independently. In this way the loads applied to the test wheels can be varied from half of the test axle weight upwards.

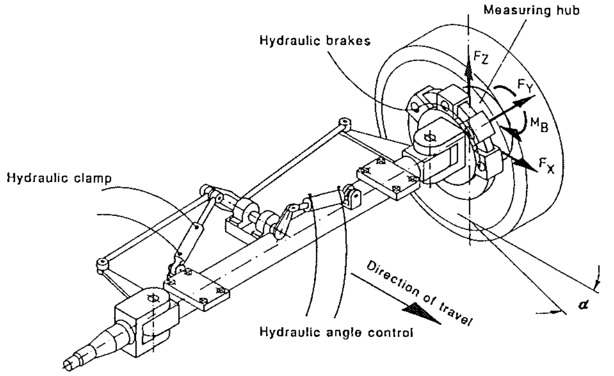

Fig. 21. Test Axle

The test axle may be braked and steered in order to generate the necessary forces, Fig. 21.

The test axle is a rigid beam axle and was selected much larger than is required to apply the necessary loads. The influences of axle deflection particularly in the region of the axle shaft end could thus be excluded.

In order to generate the side force Fy, both wheels can be steered symmetrically (toed in or out) between -2° and +15° by means of a hydraulic cylinder. Thus, by applying a symmetrical offset to the two wheels the side forces can be measured as the vehicle is travelling in a straight line. Unequal side forces occurring due to irregularities in the road surface are overcome by means of a special linkage (not shown in Fig. 21).

The circumferential forces Fx are generated by applying a disc brake actuated by a hydraulic cylinder. A number of individually selectable brake callipers are fitted. This enables the variation of braking force with time to be more easily achieved. This is mainly important for measuring low coefficients of traction.

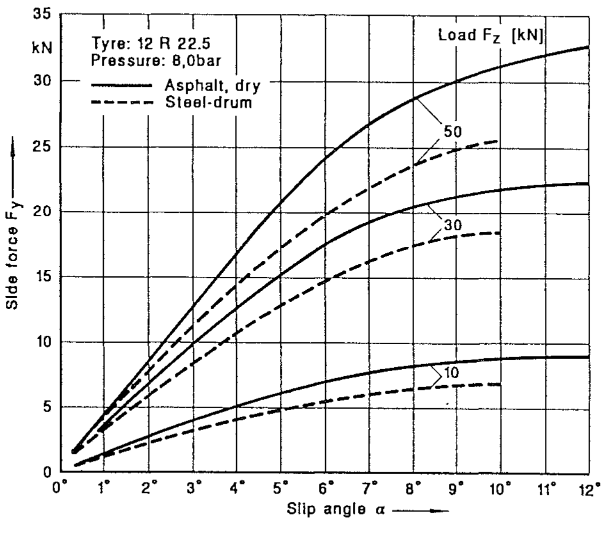

Fig. 22. Difference between Road Testing and Laboratory Testing (Example)

TYRE FORCES

Quite a few HGV-Tyres have been tested. It is useful to illustrate only some basic results as example, for instance Fig. 22. The differences in the response characteristic (cornering stiffness) and also in the limits of traction can be seen quite clearly. These will no doubt have a significant effect on computer calculations in the study of the dynamic response of moving vehicles.

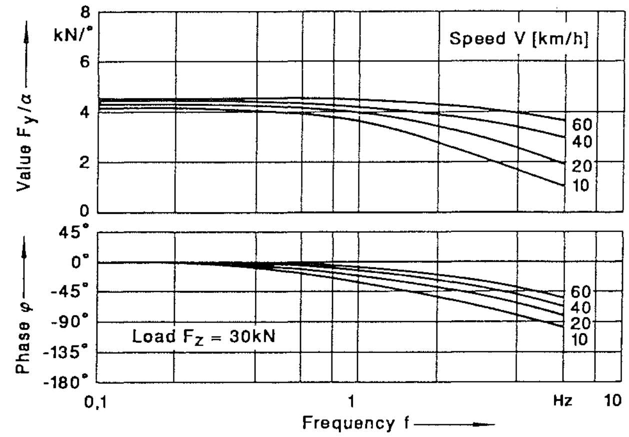

Fig. 23. Dynamic Response to Sideforces (Example)

For determining the dynamic response of tyres, the varying side force characteristic is also important. Fig. 23 shows typical results from such a test. The side force value related to the slip angle falls as may be expected with reducing speed and increasing frequency. The tyre test vehicle permits reliable results to be obtained up to 6 Hz, a limit which may be considered adequate for commercial vehicles.

Braking stiffnes (circumferencial force versus braking slip) so far has proved to be somewhat more difficult to measure mainly due to some weaknesses inside the mechanical system of the testing vehicle. Therefore the vehicle is just being improved.

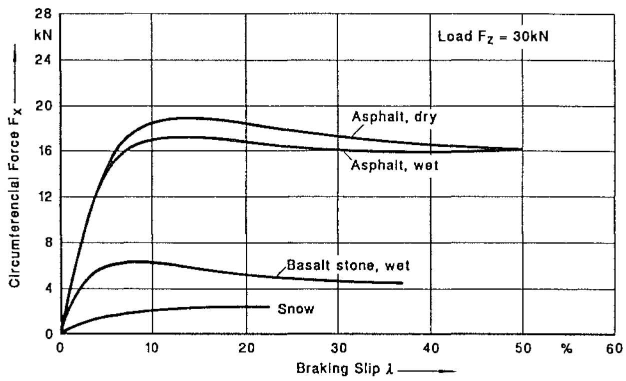

Fig. 24. Circumferencial Forces versus Braking Slip (Example)

However, in spite of the lack of sharpness in some cases, the required operating curves can be obtained for many test situations as shown in Fig. 24. These are some of the test results for the various types of road surface. They permit the characteristics of the tyre to be determined and provide a basis for discussion of anti-lock braking problems. Tests on tyres under winter conditions have proved particularly difficult. Mostly it was not possible to reproduce test results which therefore must be considered unreliable.

OUTLOOK

For cumputing simulations which put into consideration vertical, lateral and longitudinal dynamics of vehicles or vehicle combinations a numerical tyre model is needed. This must reproduce the interrelations between lateral and longitudinal forces, longitudinal slip, slip angle, wheel load and friction value.

The University of Hannover is working on this subject. As far as possible the results are already used for a reseach program about braking characteristics of retarder-equipped HGV on road surfaces with different friction values as well as on μ-split or sudden changes of μ.

The aim is to know more about the problems and the driving qualities when retarder-brakes will be integrated into the normal braking systems of vehicles.

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