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DEVELOPMENT OF A FLAT-SURFACE TEST STAND FOR INVESTIGATIONS ON DRIVING DYNAMICS

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Abstract

Road-test research on braking dynamics led to the knowledge of global and local system behaviour and to the wish to investigate local effects under defined and repeatable, but still real conditions. To meet all these requirements the quarter-car flat-surface test stand 'EFA' with the ability to simulate vehicle dynamics of a quarter-car three-dimensionally was developed and built by the Institute of Automotive Engineering (*fzd*) of the Technical University of Darmstadt (THD). Based on the principle of kinematic inversion a flexible power-drive belt made of polyamide coated with elastomer simulates the moving road surface with a μ-slip characteristic like dry asphalt up to a maximum speed of 100 km/h. Realistic vertical excitation of the quarter-car with real suspension, body mass and ABS is possible by moving the wheel support under the belt with frequencies up to 25 Hz and amplitudes up to 40 mm. This concept enables to measure dynamic wheel load up to 15.000 N directly in the road. The research work presented here shows the necessity and advantage of a flat-surface test stand for investigations on braking dynamics under real conditions and describes the concept for these investigations for the future.

Keywords: driving dynamics, test stand.

1. General

Experimental investigations of the dynamic behaviour of tyre/road contact in terms of driving comfort and safety show that the use of suitable laboratory test stands is highly desirable. In particular, investigations of the combined effect of wheel suspension and brake on uneven roads, of wheel unbalance, tyre non-uniformity and brake judder require the use of laboratory test stands with realistic simulation of road surfaces. During field tests, it is often difficult to obtain reproducible measurements if certain defined parameters vary. Moreover, the characteristics of the various components required for simulation calculations, such as the elasticity and damping characteristics of the rolling tyre, the rubber elements in the wheel suspension, etc., are frequently not available.

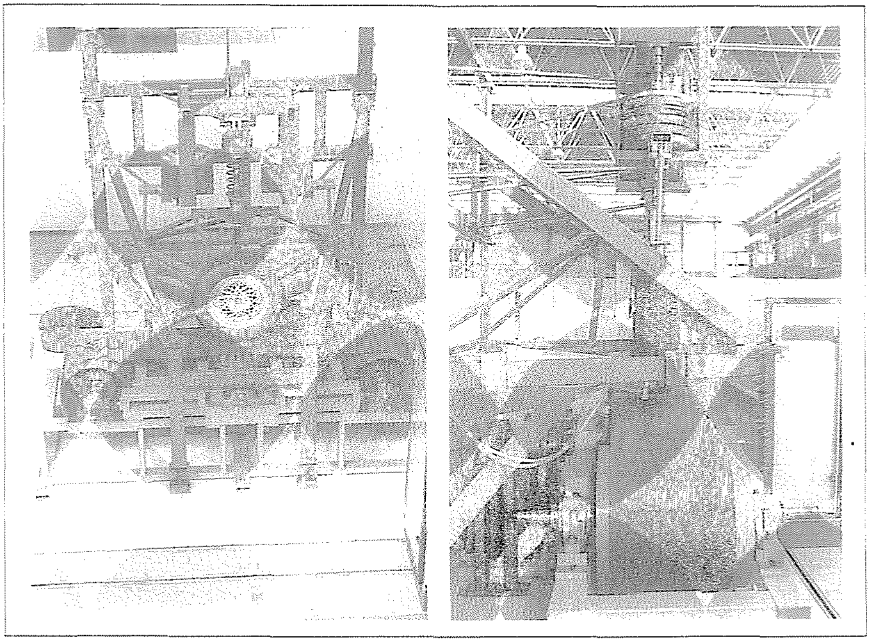

Fig. 1. Flat-surface quarter-car test stand EFA

2. Development and Description of the Test Stand

The following 10 basic rules for the specification of a suitable testing device are the result of the experience gathered by *fzd* during tests on actual roads (motorcycles, cars, commercial vehicles and agricultural or forestry vehicles) carried out to investigate driving, braking and tyre behaviour:

- Measurement in a conditioned environment,
- Consideration of all important parameters (including all forces acting on wheel and tyre),
- Movement of the wheel free from disturbances and side effects,
- Defined, reproducible vertical road excitation,
- Simulation of 3-dimensional driving dynamics,
- Real-life tyre/road force transmission,
- Flat tyre/road contact area,
- Realistic spring/elasticity and damping properties (vertical and horizontal),
- Wheel braking and driving ability (suitable for ABS/TCS),
- Relevant parameters variable for all sizes of cars, from the smallest models to luxury limousines.

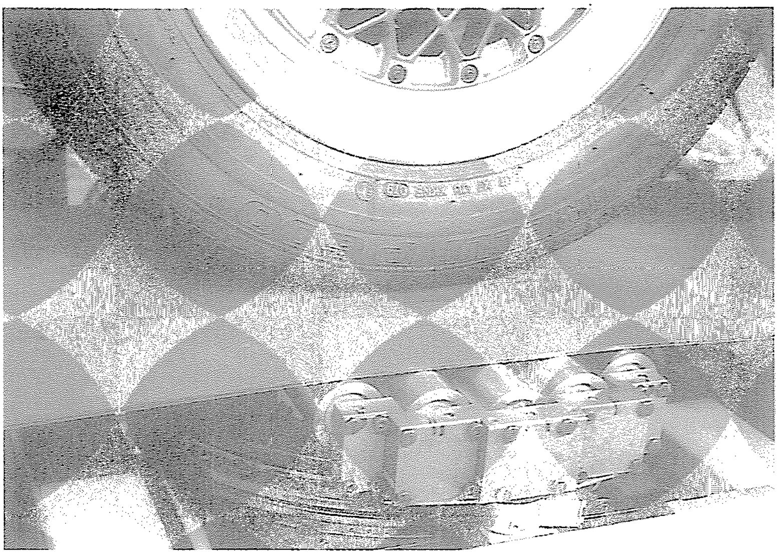

Fig. 2. Wheel support

The flat-surface driving dynamics test stand EFA built in accordance with these rules permits a complete simulation of the driving dynamics of a quarter-car, *Fig. 1.* It is based on the principle of kinematic inversion, i.e. driving speed and vehicle mass are integrated into the rotating 'road', the 'vehicle' being stationary while the wheel rotates [1]. Center of the design is a conventional heavy-duty flat belt made of polyamide with elastomer coating on both sides and driven by means of crowned drums with high initial tension [4].

In the region of tyre contact area the belt is supported by a number of very closely spaced pulleys. In conjunction with the high initial tension and the inherent stiffness of the belt, this provides an almost perfectly even 'road' surface, *Fig. 2.*

Measurements carried out at fzd confirm that the μ-slip characteristic of the belt is virtually identical to that of a real asphalt road, *Fig. 3.*

A track rod adjusts the slip angle. For operation with high lateral forces the excursion of the belt is compensated for by a defined and predetermined skew of the pulleys under the tyre contact area in the opposite direction.

Road surface irregularities are simulated by a sinusoidal vertical excitation whose frequency can be varied as a function of travel and time as well as randomly by computer control. The vertical stroke is adjustable from 0 to 80 mm. The vertical excitation is limited by the maximum ac-

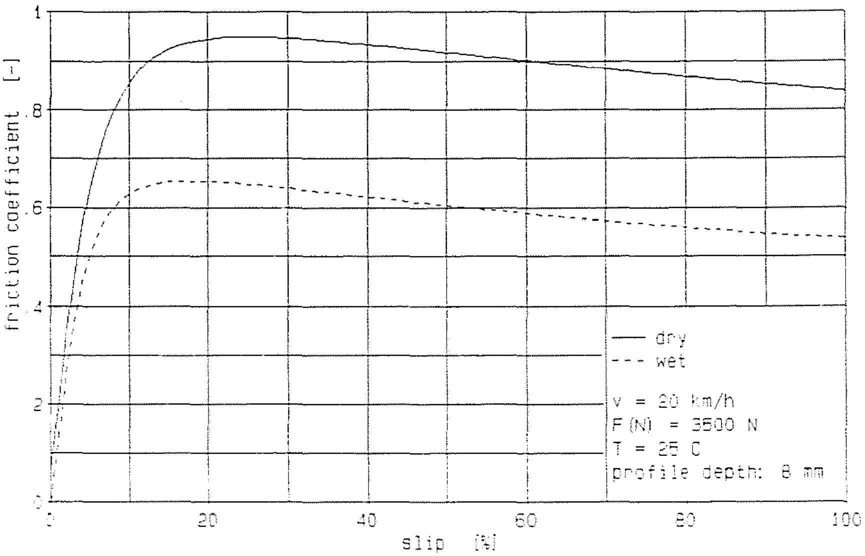

Fig. 3. μ-slip characteristic of the belt

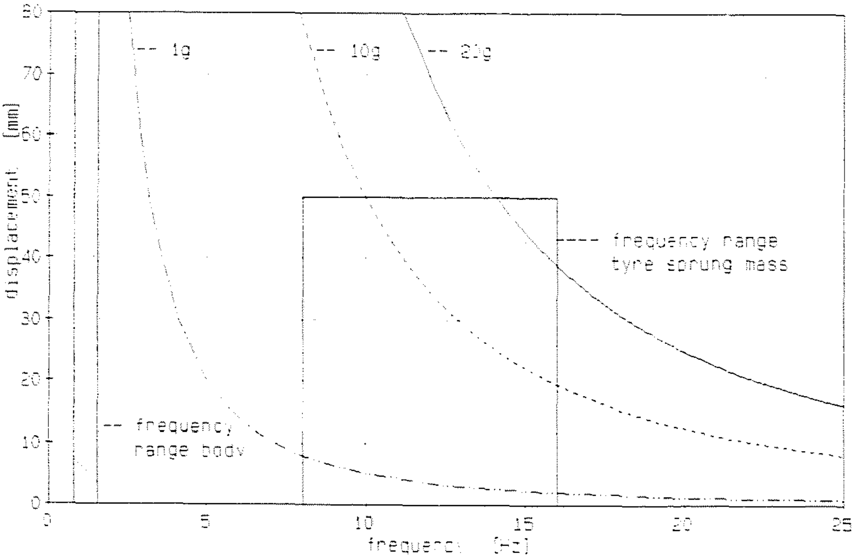

Fig. 4. Stroke and frequency range of vertical excitation

celeration of $200\,\mathrm{m/s^2}$ of the wheel support. The adjustable combinations of stroke and frequency are shown in *Fig. 4*.

A specially developed double-wishbone wheel suspension prevents additionally induced longitudinal, lateral and vertical forces as a result of shifts of the tyre contact area during movement of the wheel. Camber, caster, toe-in and kingpin inclination can be infinitely varied. Prominent features of the wheel suspension include low weight and low friction.

The basic specifications of the flat-surface quarter-car test stand are listed in *Table 1*. They meet the requirements stipulated above.

Table 1

Specifications of EFA

1. Longitudinal dynamics	$v_{\max} = 100\,\mathrm{km/h}$ $F_{x,\max} = \pm 10.000\,\mathrm{N}$ $P_{M,L} = 10\,\mathrm{kW}$ $\mu - s$-curve = asphalt Elasticity/damping: presently rigid, adjustability planned
2. Lateral dynamics	Slip angle: $-10^\circ \ldots 0^\circ \ldots +10^\circ$ Camber angle: $-10^\circ \ldots 0^\circ \ldots +5^\circ$ $F_{y,\max} = \pm 10.000\,\mathrm{N}$ Elasticity/damping: presently rigid, adjustability planned
3. Vertical dynamics	sinusoidal as a function of travel and time: $f_{e,\max} = 25\,\mathrm{Hz}$ $A_{\max} = 40\,\mathrm{mm}$ $a_{a,max} = 20\,\mathrm{g}$ $F_{z,\max} = 15.000\,\mathrm{N}$ $P_{M,V} = 47\,\mathrm{kW}$ Spring/elasticity and damping variable
4. Combinations	1. + 3.: no limitation 1. + 2.: presently limited by $P_{M,L}$ 1. + 2. + 3.: presently limited, see above
5. Other	Further wheel settings: Caster: 0 … 24 mm/0° … 5° Kingpin inclination: $-2^\circ \ldots 0^\circ \ldots +2^\circ$ Dimensions: $H \times L \times W$: $3000 \times 3000 \times 2500\,\mathrm{mm}$ Weight: approx. 9600 kg

3. Measuring System

In *Fig. 5* the presently used measured variables and measuring points are shown. The innovative digital MGC system from Hottinger Baldwin Messtechnik GmbH, Darmstadt, is used as measuring amplifier [2].

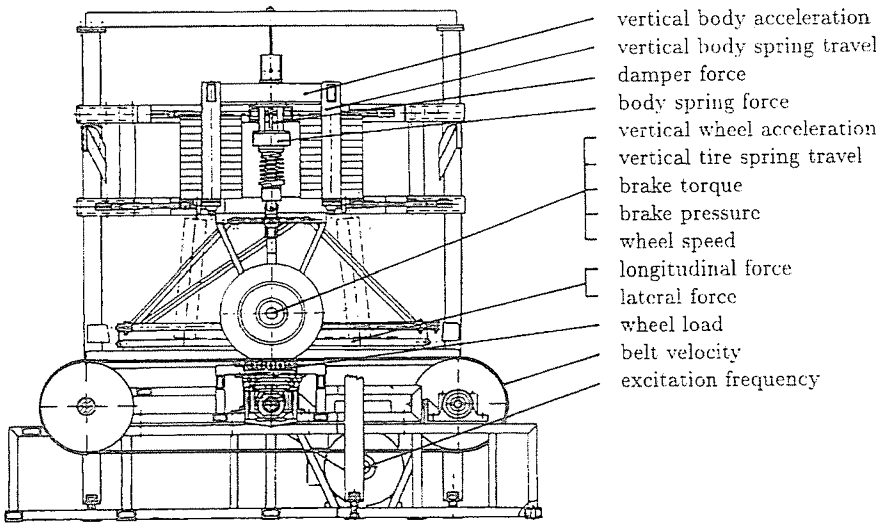

Fig. 5. Measuring parameters and points

Here, 10 × MC 30 (for sensors operating on the WSG principle) and 2 × MC 50 (for inductive sensors) are available as amplifiers. This measuring system is the first to permit a quick adjustment of all necessary parameters (such as calibrating curves, type and cut-off of filters, physical units and the like). The processed measuring signals are transmitted to a conventional IBM-PC and stored on data carriers (hard disk, floppy disk, video screen, printer/plotter) or subjected to further processing. The amplifier unit can also be operated from the PC. The amplifier settings can be stored as parameters and re-entered at any time. This makes it particularly easy to use the measuring system for different applications.

4. Conclusions

To solve the problems mentioned in the introduction, a flat-surface driving dynamics test stand for simulating real-life driving dynamics under laboratory conditions was developed, built and commissioned at the Technical University of Darmstadt, Institute of Automotive Engineering (*fzd*) in cooperation with Alfred Teves GmbH, Frankfurt/Main, as part of a research project sponsored by the German Ministry of Research and Technology (BMFT). This test stand permits the complete driving dynamics of a quarter-car with real tyre/road contact to be simulated in the laboratory with simultaneous superposition of longitudinal, lateral and vertical dynamics, thereby opening up new potential for the investigation of car safety, comfort and economy.

As far as known, this test stand is the only one permitting braking dynamics (e.g. ABS-braking operations) to be fully simulated physically and under real-life conditions in the laboratory.

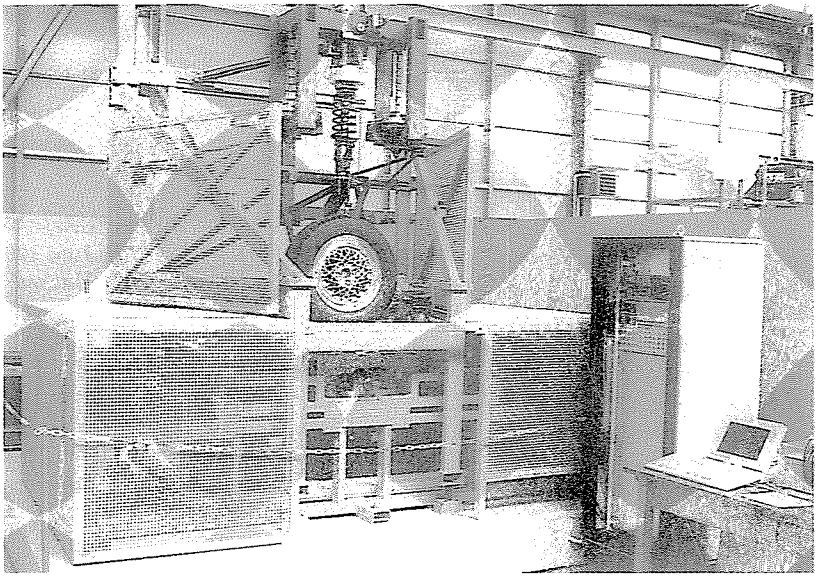

Fig. 6. Flat-surface test stand for investigations on braking dynamics

As shown above, local effects on the dynamic behaviour of tyre, brake and suspension can be investigated under defined and repeatable conditions. In connection with the knowledge out of road-test research prediction of global system behaviour is possible.

5. Future Activities

Future measurements focus on tyre/road friction monitoring inbeneath the tyre, tyre elasticity/damping behaviour at different speeds, excitation frequencies and tyre pressure, the influence of tyre- and brake-induced vibrations (e.g. judder) on riding comfort, and on measurements of rolling resistance. Real-road tests are carried out on defined even and uneven roads to validate the test-stand measurements [3, 5, 7].

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