Chapter 12

Tire Steady-State and Dynamic Test Facilities

At various automotive and tire industrial companies and at a number of universities and institutes, test facilities are available for performing full-scale tire measurements to assess the tire force and moment generation properties. The test installation may be built on a truck or trailer that is equipped with a special wheel suspension and guidance system to which a measuring hub is attached. Typically, with such an over the road testing equipment, moderate speeds up to ca. 120 km/h can be reached. The frequencies with which the steer angle can be varied are relatively low. The camber angle is changed mechanically or through a hydraulic cylinder. The vertical load may be set at a desired average level; the load variations caused by road unevennesses may be filtered out. Commonly, the longitudinal slip results from the controlled application of the brake pressure. In very few cases, the wheel angular velocity is controlled through a hydraulic motor that acts relative to the vehicle's road wheel speed of revolution. In such a way, the test wheel drive and brake slip can be varied in a controlled manner. In some devices, water can be sprayed in front of the test wheel to create wet road conditions. The measuring hub contains strain gauge or piezo-electric force measuring elements. With these test facilities, usually measurements are conducted at quasi-steady-state conditions. Typically, a side-slip or brake-slip sweep may be imposed at a low rate. After processing, correcting and averaging the signals, the steady-state force and moment slip characteristics are obtained.

The large indoor test stands usually operate along similar lines. These rigs are based on an imitated road surface provided by the surface of a drum or by that of a flat track (endless belt). Somewhat higher frequencies of changing vertical axle position and yaw angle can usually be achieved (up to ca. 2–8 Hz). Drum test stands have been built with diameters ranging from 2 to ~4–5 m. With the larger drums, the tire usually runs or can also be run on the inner surface. This configuration makes it possible to mount realistic road surface segments and to maintain a layer of water on the inner surface, thereby enabling testing at wet or icy (and even snowy) conditions. External drums of 2.5–3 m diameter are more often encountered. Also, flat bed and flat plank test rigs are

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used. Typically, but not always, these machines operate at very low speed of travel of either the plank or the wheel axle. Also, turn table or swing arm devices exist which are constructed to measure turn slip properties.

On the drum test stand, a measuring tower or a special wheel guidance system with a force measurement platform or hub can be positioned. For dynamic higher frequency tire tests, very stiff rigs are required (or very soft seismic systems). Special equipment is used that is often limited to a specific application to allow the system to become light and sufficiently rigid, that is: high first natural frequency. Devices exist dedicated to specific tasks such as systems with: axle fixed (but adjustable in height) to assess tire non-uniformity, cleat response, or response to brake pressure variations; axle forced to perform only vertical axle oscillations to assess the vertical dynamic stiffness and the response of the longitudinal force; and axle to perform only yaw angle variations to assess the tire dynamic steer response.

The original TU-Delft Tire Test Trailer, cf. Eldik Thieme (1960), later owned and operated by TNO-Automotive, Helmond, the Netherlands, has been replaced by a newly constructed semi-trailer (cf. Figure 12.1), and is equipped with the two original measuring stations. One for passenger car size tires and e.g., F1 tires limited to not so large camber angles and on the other side a new device specially designed for motorcycle tires that can handle also large camber angles, cf. Figure 12.2.

The car wheel can be subjected to a fixed or sweeping steer angle (−18 to +18 deg.) and the camber angle can be mechanically set at given values

FIGURE 12.1 The new TNO Tire Test Semi-Trailer.

FIGURE 12.2 The large camber measuring device of TNO here mounted in the old test trailer.

from −5 up to 30 deg., cf. Sec.4.3.6 for example test results. At the motorcycle test side, the wheel camber angle can be swept from −20 to 70 deg. or set at a fixed angle, cf. Sec.4.3.6. The wheels can be braked up to wheel lock. The three forces and two moments (that is: except the brake torque) are measured with measuring hubs: a large strain gauge based and a compact piezo-electric based system respectively. Water can be sprayed at a controlled rate in front of the test tire.

Figure 12.3 depicts the flat track machine (TIRF, 1973) constructed and operated by Calspan, Buffalo. The upper structure can be steered about a vertical axis. With respect to this part, the wheel axle can be tilted about a line that forms the line of intersection of the wheel center plane and the belt that imitates the road surface. Through this configuration, a pure camber or wheel inclination angle can be created also at nonzero steer angle. The belt is supported by two drums and underneath the tire by a flat air bearing surface. The lateral stabilization of the belt is accomplished by letting one of the drums tilt against a stiff spring. The test wheel can be driven and braked in a slip-controlled manner. The facility can also handle larger truck tires. For some test results, cf. Sec.4.3.6, Figures 4.31 and 4.32. MTF Systems Corporation has developed and produces a similar device but with the steer axis inclining with camber variations, cf. Figure 4.30 for a test result.

Figures 12.4 and 12.5 show the layout of two internal drum test stands, cf. Bröder, Haardt, Paul (1973), and Krempel (1967). The drum of Figure 12.4 can also be used on its outer surface with a maximum speed of 250 km/h.

These large rigs are operated at the Karlsruhe University of Technology. The arrangement of the wheel loading, tilting, and steering system enables

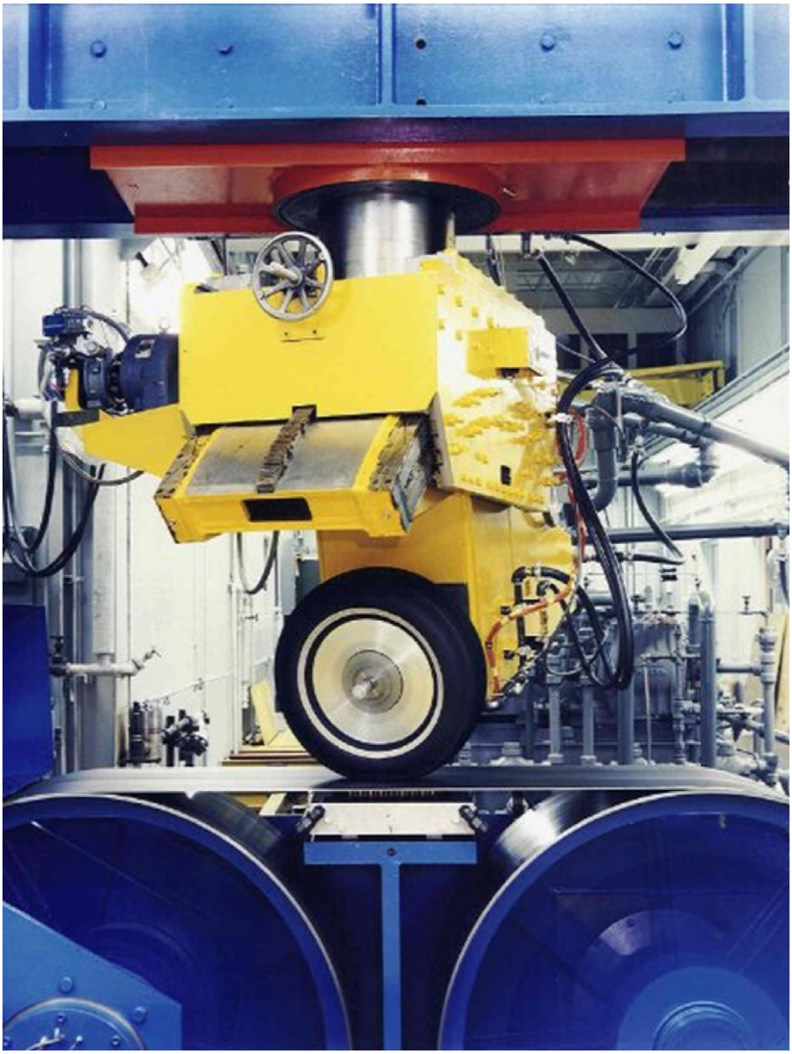

FIGURE 12.3 The flat track machine (TIRF) of Calspan.

center point steering and tilting about a line that touches the inner drum surface and lies in the wheel center plane. The order of changing the wheel attitude angles – first steering about the always vertical axis and then tilting about the new (still horizontal) x-axis – ensures that each of the angles, defined about and with respect to the vertical, remains unchanged when the other is varied. Of course, this principle also holds for the system of Figure 12.1 but not for the flat track machine of Figure 12.3. The configuration of Figure 12.5 exhibits

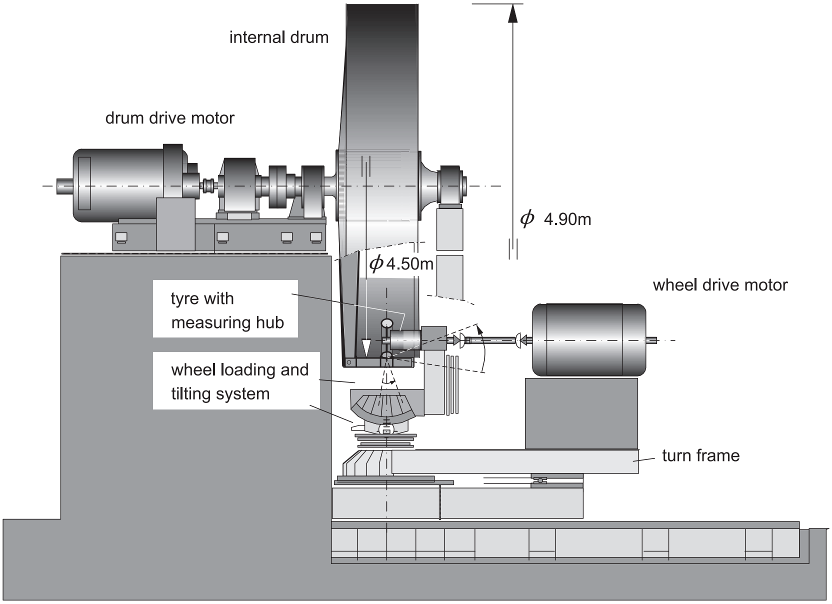

FIGURE 12.4 Internal drum test stand originally possessed and operated by Porsche.

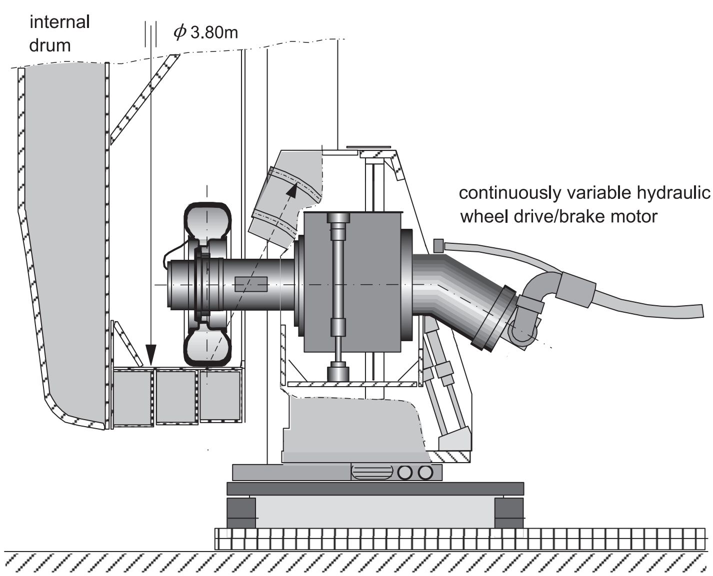

FIGURE 12.5 The Karlsruhe University internal drum test stand.

a hydraulic wheel drive motor with which the wheel slip ratio can be controlled. Here, the force-measuring unit rotates together with the wheel. This avoids the otherwise necessary constructional measure to suppress parasitic forces and cross-talk such as the brake torque interaction with aligning torque that arises due to slight misalignment.

With a stationary measuring hub, a double Cardan coupling drive shaft (including a length change compensation element) is an example of such a measure which ensures that practically only the drive/brake torque is transmitted to the wheel. Instead of a pair of these couplings, a set of two membranes (thin flexible discs) or other devices (see Figure 12.7) may be used. Accurate alignment remains necessary.

With the UMTRI configuration (University of Michigan), cross-talk has been prevented by positioning the brake system between the nonrotating, stationary measuring system and the wheel. One of the drawbacks of rotating measuring systems is the fact that the sensitivity about the vertical axis (for the small aligning torque) cannot be chosen larger than the sensitivity about the horizontal longitudinal axis about which the moment may become relatively large.

Figure 12.6 shows the Delft flat plank machine, cf. Eldik Thieme (1960) and Higuchi (1997), now operated by the Eindhoven University of Technology. With this rig, accurate measurements can be conducted at a low speed of 2.3 cm/s. The plank has a maximum stroke of 7.5 m and can be tilted about the longitudinal center line on the test surface. Hereby, pure camber step responses can be established. The wheel axle, equipped with a measuring hub, can be steered, cambered, and the wheel can be braked. The vertical axle position or the vertical tire load can be adjusted. Cleats can be mounted on the plank surface. Typically, tire static stiffness tests (vertical, longitudinal, lateral, yaw, and camber), transient (step) side slip and camber tests (relaxation lengths and nonlagging part), impulse turning, and low speed cleat tests are performed on this machine, cf. Figure 5.12, Figures 7.5–7.10 and Figure 10.24 and Pacejka (2004).

The indoor drum test facility of the Delft University of Technology is based on two coupled drums with a diameter of 2.5 m that can run up to a maximum speed of 300 km/h. On top of one of the drums, a measuring tower (for low or moderate frequency yaw and brake experiments, cf. Figure 9.37) can be installed (not shown). This rig, cf. Eldik Thieme (1960) and Maurice (2000), can be turned about a vertical axis that passes through the tire contact center and through the top of the drum surface.

On the other drum, a rig can be mounted that is designed for measuring in-plane tire dynamics, Figure 12.7, cf. Zegelaar (1998). Much care has been taken to make the rig sufficiently rigid. This resulted in a lowest natural frequency of just over 100 Hz which allows the use of test data up to ca. 70 Hz. In addition, to avoid force and moment cross-talk, the brake shaft is connected with the wheel shaft through an intermediate shaft with two flexible couplings. These

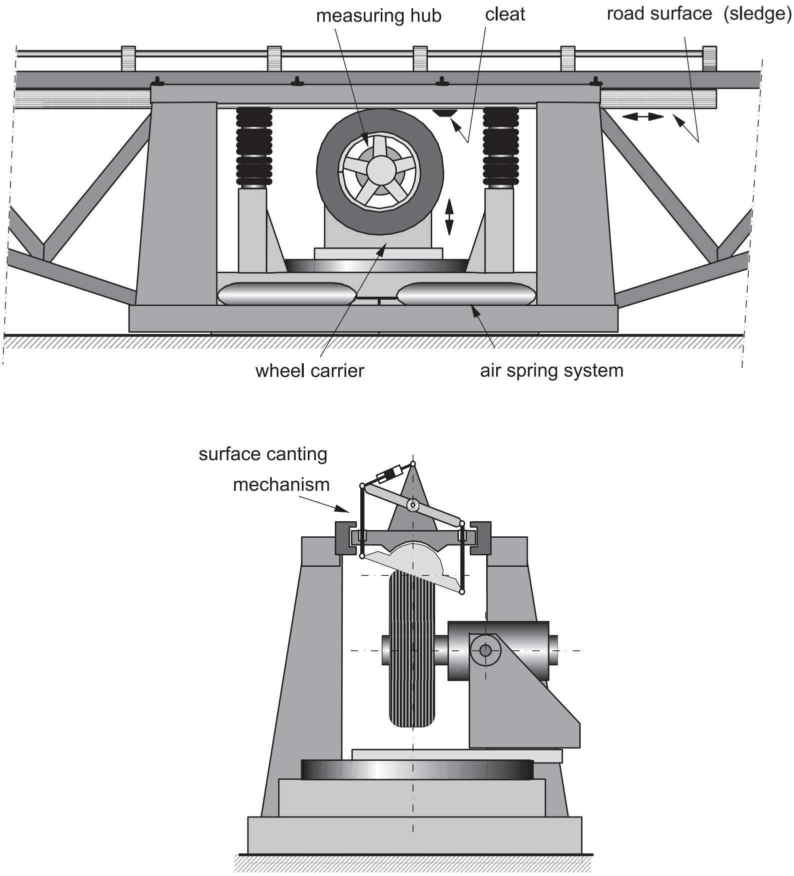

FIGURE 12.6 The flat plank machine with road canting system.

couplings represent an alternative solution for the double Cardan coupling of Figure 12.4. They are flexible in all directions except about the axis of rotation. If properly aligned, this ensures that only the brake torque is transmitted to the wheel and that other parasitic forces and moments are largely suppressed. The brake torque is measured with strain gauges attached to the intermediate coupling shaft. A hydraulic servo system is used to control the brake pressure fluctuations (bandwidth up to ca. 60 Hz). Piezo-electric load cells placed on top of the bearings of the wheel shaft provide the signals from which the forces and moments that act on the wheel (except the brake torque) can be derived. With this machine, dynamic brake tests (Figures 9.42 and 9.45) and cleat tests (Figures 10.25–10.32) have been conducted. In a different setup, the machine may be used for response measurements to vertical axle oscillations (<20 Hz), cf. Figure 8.6.

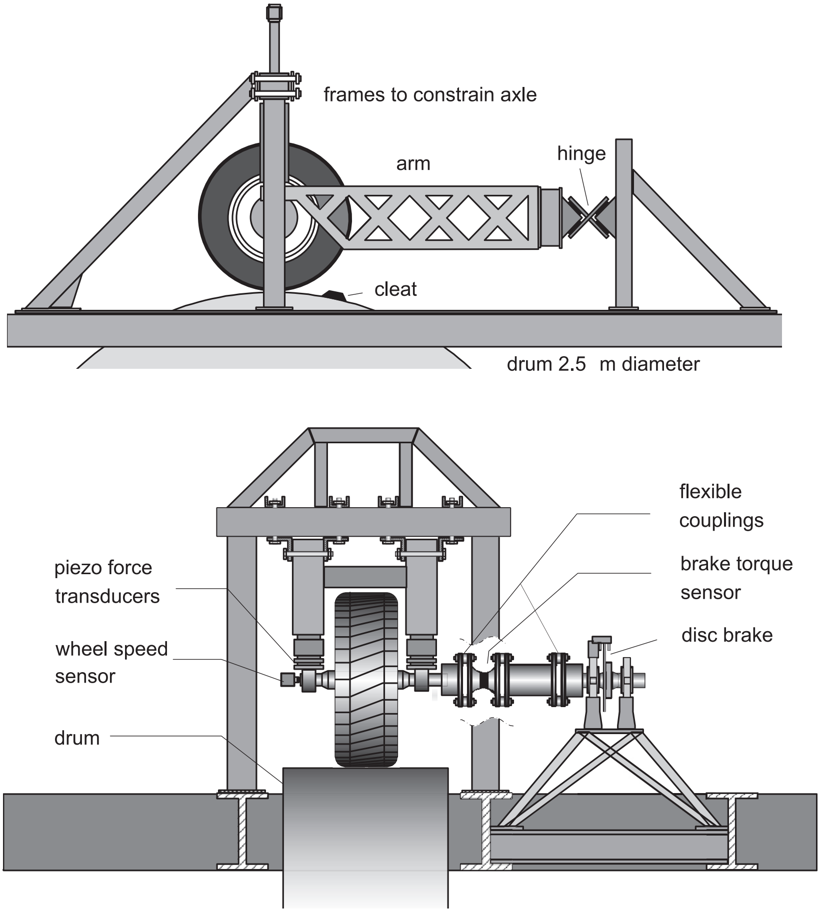

FIGURE 12.7 Dynamic brake and cleat test facility in side and front view. Tests may be conducted up to ca. 65 Hz enabling the assessment of tire/wheel in-plane inertia and stiffness parameters including residual stiffnesses and rigid modes of vibration.

On the other drum, rigs may be mounted for out-of-plane tire dynamic experiments. One is the trailing arm 'pendulum' test stand, cf. Vries et al. (1998a) and Maurice (2000), with at one end a vertical hinge and at the other the steering head (for adjusting the average slip angle) with piezo-electric measuring hub (cf. Figure 12.8). At that point, the arm is excited laterally up to ca. 25 Hz by means of a hydraulic actuator. The wheel load is adjusted by tilting the vertical hinge slightly forward. The arm length is 1.65 m and the tire is subjected to an almost purely lateral slip variation. The rig is useful to assess the overall relaxation length and the gyroscopic couple parameter. The idea of the pendulum concept originates from

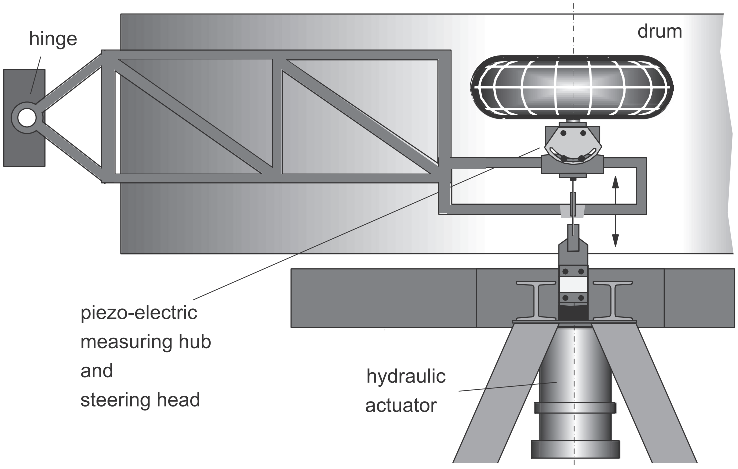

FIGURE 12.8 The trailing arm 'pendulum' test rig exciting the tire almost purely laterally. Frequencies up to ca. 25 Hz adequate for assessing the tire relaxation length and gyroscopic couple parameter.

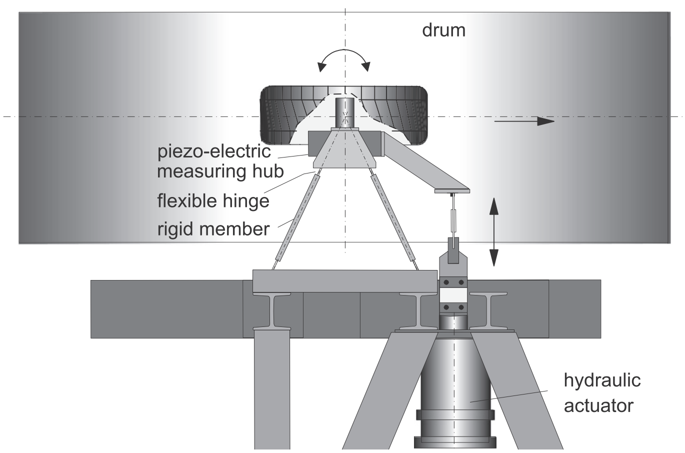

FIGURE 12.9 The yaw oscillation test rig featuring center point steering. Frequencies up to ca. 65 Hz enable the assessment of tire out-of-plane inertia and stiffness parameters including residual stiffnesses and rigid modes.

Bandel et al. (1989). They designed and used an actual freely swinging pendulum rig.

In Figure 12.9, the so-called yaw oscillation test stand, Maurice (2000), is depicted that can be used for tests around an average steer angle that can be set at a value between -5 and $+5$ degrees. The structure is light and very stiff.

The two guiding members with flexible hinges intersect in the vertical virtual steering axis that is positioned in the wheel center plane (center point steering). A hydraulic actuator is mounted to generate the yaw vibration (typically random with a bandwidth of 65 Hz). The wheel axle is provided with a piezo-electric measuring hub. The tire is loaded by mechanically adjusting the axle height above the drum surface. Test results have been presented in Figures 9.43, 9.44 and Figure 9.46.