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# The influence of the tyre pressure on the lateral response characteristic of agricultural tyres

Due to many possible fields of application of agricultural tractors, the agricultural tyres are used with inflation pressures varying between 0.8 bar and 2 bar. However, the inflation pressure has an influence on the transfer behaviour of the tyres in all three dimensions and subsequently on driving dynamics. The Hohenheim Tyre Model enables the calculation of the three-dimensional transfer behaviour of agricultural tyres, considering the influence of the tyre inflation pressure by using different stiffness and damping coefficients. In this article, the influence of the tyre inflation pressure on the steady state and transient lateral tyre behaviour of agricultural tyres is shown and the corresponding parameters for the Hohenheim Tyre Model are determined.

**Keywords**
Tyre pressure, lateral force, tyre model, driving dynamics, multibody simulation

**Abstract**
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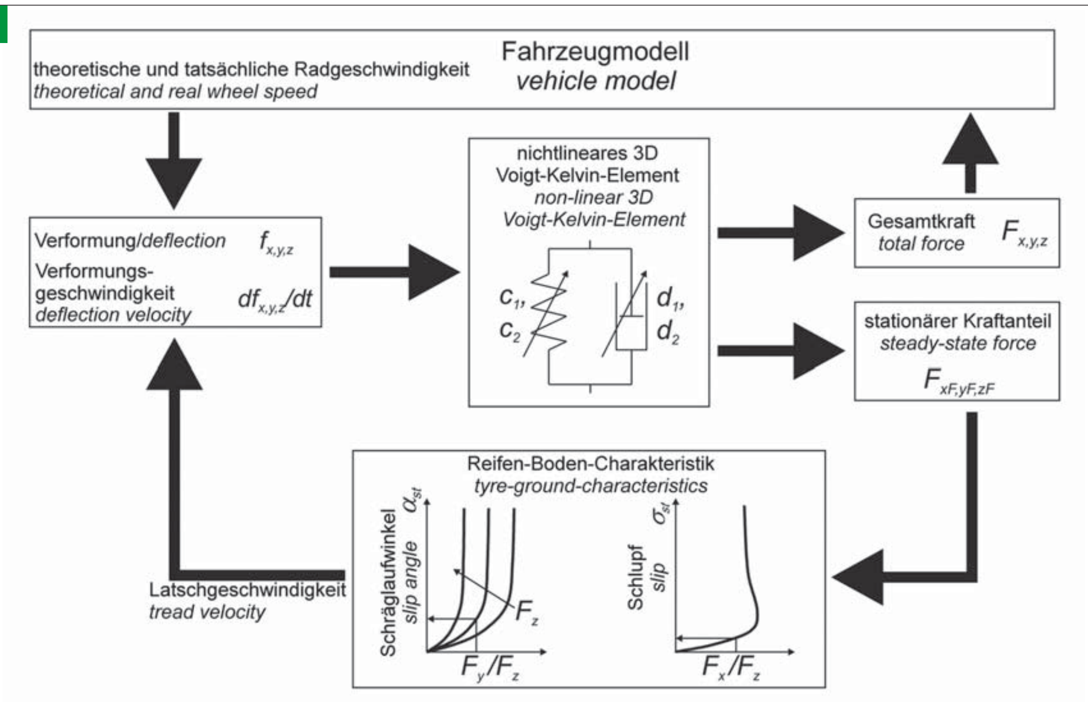
With the Hohenheim Tyre Model, a model capable of reproducing the three-dimensional dynamic behaviour of agricultural tyres is established and allows driving dynamics simulation of agricultural tractors [1; 2]. The tyre tests in [1; 2] were accomplished with a tyre inflation pressure of 1.2 bar. However, the tyre inflation pressure has a strong influence on the tyre behaviour in all three directions in space, thus affecting the driving dynamics. Measurements on the vehicle do not allow a determination of the influence of the tyre inflation pressure on the transfer behaviour in a certain direction in space, since the forces on the wheel affect each other strongly. Therefore, the single wheel tester of the University of Hohenheim was used [3]. In contrast to measurements with a vehicle, the single wheel tester allows lateral force measurements at a constant wheel load, eliminating the influence of wheel load oscillations.

## Lateral force calculation in the Hohenheim Tyre Model

In the Hohenheim Tyre Model, the forces in all three dimensions are calculated using non-linear Voigt-Kelvin-Elements, **figure 1**.

Fig. 1




*Functional diagram of the Hohenheim Tyre Model [1]*

The equation for the lateral force calculation reads as follows:

$$F_y(t) = c_{1y} \cdot f_y(t)^{c_{2y}} + d_y \cdot \frac{d}{dt} f_y(t) \qquad \text{(Eq. 1)}$$

where:
$c_{1y}$ and $c_{2y}$ – lateral stiffness coefficient,
$d_y$ – lateral damping coefficient,
$f_y$ – lateral tyre deflection.

According to [1] the lateral deflection for pure lateral slip is calculated as follows:

$$f_y(t) = \int [-v_y(t) - |v_x(t)| \cdot \tan(\alpha_{st}(\mu_y(t)))]dt \qquad \text{(Eq. 2)}$$

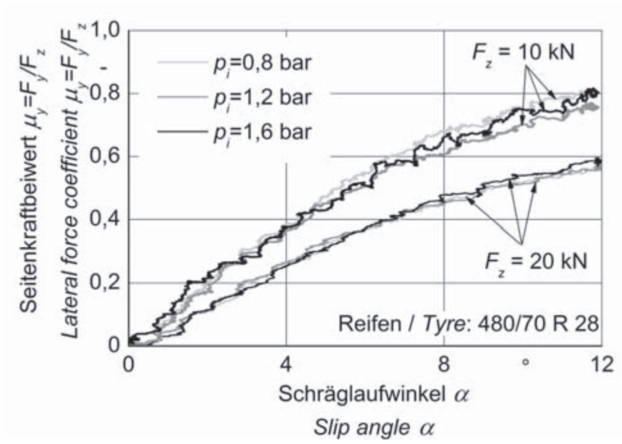
where:
$v_y$ – lateral velocity of the wheel hub,
$v_x$ – longitudinal velocity of the wheel hub,
$\alpha_{st}$ – steady state slip angle as a function of the lateral force,
$\mu_y$ – lateral force coefficient.

The stiffness coefficients $c_{1y}$ and $c_{2y}$ depend on the tyre inflation pressure and can be determined with the single wheel tester. Due to the test rig restrictions, the maximum reachable lateral deflection velocity is relatively low, so the damping coefficient dy can not be measured with the single wheel tester. Thus, in this article an estimated value of $d_y$ = 2700 Ns/m is used, which corresponds to the values of the vertical stiffness. The relationship between the lateral force and the slip angle is represented by $\alpha_{st}$ and can be determined with the single wheel tester.

### Influence of the wheel load and of the tyre inflation pressure on the steady state lateral force

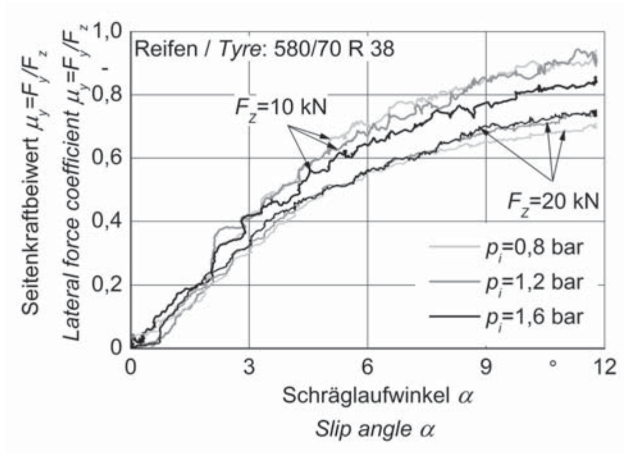
The steady state lateral force generated by the tyre plays an important role in the driving dynamics of vehicles. It determines the slip angle of the respective wheel and thereby the slip angle and the yaw rate of the entire vehicle. Usually, for the lateral force calculation the steady state lateral force coefficient is used. **Figure 2** and **figure 3** show the lateral force coefficient $\mu_y$ from the **Equation (2)** at a slip angle rate of 0.3°/s, which is considered quasi-stationary. The driving speed of the single wheel tester was 2 km/h for all following figures. For both tyre dimensions shown here, no explicit connection between the tyre inflation pressure and the steady state lateral force coefficient is observed, as already established by Schlotter [4]. The lateral force coefficient decreases with increasing stationary wheel load. In the Hohenheim Tyre Model, this relationship is taken into account by a characteristic diagram with an interpolation between the characteristic curves for 10 and 20 kN and an extrapolation up to 40 kN [1].

Fig. 2



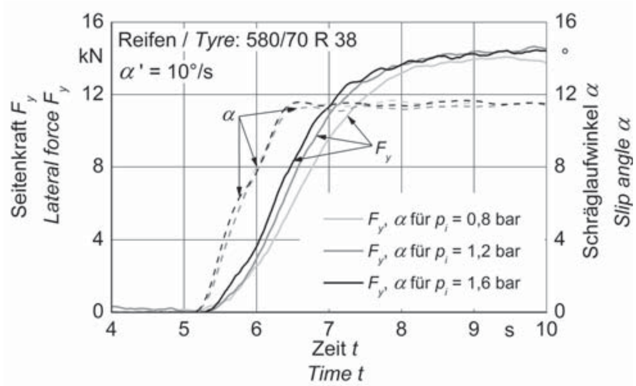

*Quasi steady-state lateral force coefficient at different stationary loads and tyre pressures for a 480/70 R 28 tyre on asphalt*

Fig. 3




*Quasi steady-state lateral force coefficient at different stationary loads and tyre pressures for a 580/70 R 38 tyre on asphalt*

Fig. 4




*Measured slip angle and the corresponding lateral forces for a 580/70 R 38 tyre at different tyre pressures and a stationary wheel load of 20 kN*

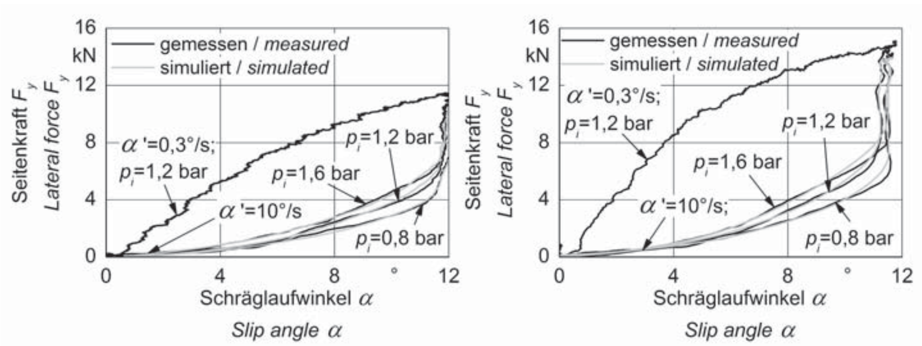
## Influence of the dynamic slip angle change on the lateral force at different tyre inflation pressures

Dynamic change of the slip angle at a constant wheel load results in a clear dependency of the lateral force on the tyre inflation pressure, figure 4. Thereby, the slip angle was modified with slip angle rate of 10°/s up to a maximum value of 12°. According to figure 1 respectively equation 2, the lateral force is generated by the tyre deflection with a maximum force given by the steady state characteristic curve. Increasing tyre inflation pressure leads to an increasing lateral stiffness and thus to smaller deflections and faster force build up, figure 4. A force vs. slip angle diagram shows the deviation of the dynamic lateral force from the steady state force, figure 5. However, the difference between the dynamic forces is small for slip angles up to approximately 5°. In **figure 5**, the calculation results of the Hohenheim Tyre Model are also presented, together with corresponding measurements. The model parameters used for the calculations are listed in table 1.

## Conclusions

The tyre inflation pressure has a major influence on the transfer behaviour of tyres. This influence on the lateral transfer behaviour was investigated on a single wheel tester at a constant

Fig. 5




*Measured and simulated lateral forces on a 480/70 R 28 tyre (left) and a 580/70 R 38 tyre (right) under different tyre pressures, slip angle rates (0,3°/s and 10°/s) and a constant vertical load of 20 kN on asphalt*

Table 1

*Stiffness coefficients as a function of tyre pressure*

| Reifen-innendruck *Tyre pressure* | Reifen/*Tyre* 580/70 R 38 | | Reifen/*Tyre* 480/70 R 28 | |
|---|---|---|---|---|
| [bar] | $c_{1y}$ [N/m] | $c_{2y}$ | $c_{1y}$ [N/m] | $c_{2y}$ |
| 0.8 | 80 000 | 1.15 | 70 000 | 1.17 |
| 1.2 | 100 000 | 1.11 | 85 000 | 1.12 |
| 1.6 | 120 000 | 1.11 | 105 000 | 1.12 |

wheel load. No explicit connection between the tyre inflation pressure and the steady state lateral force coefficient was observed, confirming prevailing scientific findings. This leads to the conclusion that changes in the driving dynamics behaviour due to different tyre inflation pressures are mainly caused by different lateral stiffness coefficients of the tyre. The lateral stiffness increases with the inflation pressure and can be quantified with the Hohenheim Tyre Model. It was also shown that the Hohenheim Tyre Model is able to reproduce the lateral transfer behaviour very well and is thus suitable for driving dynamics simulations.

## Literature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