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Sensor wheel for recording wheel forces at the tractor rear axle

In a German Research Society supported project for determining the forces acting on tractor bodies the forces at the drive wheels have great importance. The recording of these forces based on axle housing deformation is often difficult or impossible to carry out. A sensor wheel delivered more exact results and also enabled the recording of lateral and drive forces. The working principle of a self-built sensor wheel is presented as well as specialties in the constructional design. Also explained are the non-contact transmission of energy and signals and finally the method of calibration.

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In the German Research Society supported project „Tractor Body Collective" load collectives acting on the tractor chassis were determined. Alongside forces at implement mounting points, knowledge of wheel forces is of critical importance. Recording of such forces is partly possible through measurement of axle housing deformations [1]. However, this is not always possible and does not cover all force components. For this reason a sensor wheel was designed and constructed with the capabilities of measuring wheel load, draught and lateral forces on a tractor rear wheel reliably and with enough precision (*fig. 1*).

The ground principle of the measurement instrument here described was applied in the past in the determination of forces between tractor and implement [2]. For its application as a sensor wheel, however, the exact angle position of the wheel must also be established.

Measurement principle

Wheel load and draught force

Main component of the sensor wheel is a four-spoke cross. The spoke ends are attached into the wheel rim in a way which is friction-free and jointed and axially movable, construction which is of critical importance to the measurement principle (*fig. 2*)

With a force in z-direction the flexible membrane allows the spoke pair 2 to react by moving axially. This leaves almost all the load on spoke pair 1 which bends under the load with the reaction very precisely recorded by deformation measuring strips (DMS). The maximum deformation moment applies at the spoke foot and this is where the DMS are applied.

A force applied in the x-direction means the load lies on spoke pair 2, spoke pair 1 moves axially as a reaction. With simultaneous application of forces in x and y directions, the reactions occur parallel to, and independently of, each other.

In that the sensor wheel revolves during travel, its exact position must be determined at measurement. Depending on the angle of rotation α and the forces applying on the spoke pairs F_{SP1} and F_{SP2}, wheel load and draught force can be established thus:

Fig. 1: Instrumented wheel with tire 520/70 R 38

$$\text{Wheel load} = \cos\alpha \cdot F_{SP1} + \sin\alpha \cdot F_{SP2}$$
$$\text{Draught force} = \sin\alpha \cdot F_{SP1} + \cos\alpha \cdot F_{SP2}$$

The drive moment is fully compensated through the switching of the DMS to Wheatstone Bridge and had with that no influence on the measurement results.

Lateral force

Measurement of lateral force took place on all four spokes, eight DMS (two per spoke) were switched to a full bridge. The lateral force signal is independent of the angle of rotation in that the DMS is so switched that a disturbing influence from steering and plunge moments are completely balanced.

Drive, plunge and steering moments

The recording of these forces was not conducted on the presented wheel but is basically possible with additional DMSs applied. For the drive moment, switching must be carried out in such a way to allow the equal bending of all spokes on the y-axis to be totalled (no influence of angle of rotation). It is also possible in this way to determine the plunge and steering forces with extent of lateral bending of both spoke pairs measured separately for this. With the information of the angle of rotation, the plunge and steering forces can then be calculated.

Construction

The sensor wheel is designed for the rear axle of a standard tractor (tyres 520/70 R 38)

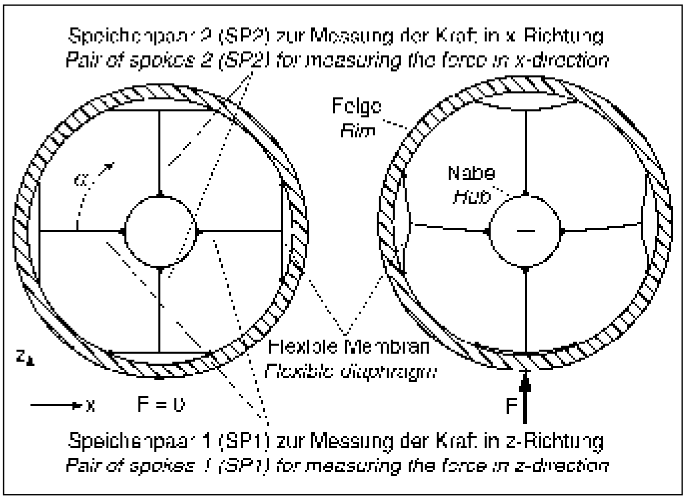

Fig. 2: Principle demonstrated by measuring the wheel load

and a maximum wheel load of ~ 100 kN. The extreme special case of a simultaneously occurring maximum draught force of ~ 100 kN with corresponding drive moment (whilst ignoring rolling resistance) still does not lead to plastic flowing in the extremely stressed components. With these load assumptions was expected a safe and reliable operation of the trial tractor Fendt Favorit 509C (net weight 5400 kg) and this was confirmed by the first recordings.

The design of the sensor wheel is presented in *figure 3*. The hub was mounted on the tractor rear axle (275 mm hole circle). The recording spokes were fitted onto the hub, each with 12 screws. For an improved deformation performance, a spacer sleeve, which also simultaneously served as mechanical protection for the DNS, was fitted over the screws. On the outside the spokes were fitted into a round diaphragm (no-play fitting, axial attachment with screw nut). Attachment of the diaphragm to its mounting is by screws through the strengthened outer edge of the diaphragm. The mounting is welded directly to the rim ring. To avoid latent stresses building up, the height of the diaphragm frame was adjusted exactly by removing surplus during assembly. For increasing rim stiffness (no rim plate) two stiffening rings were welded on.

Important sensor wheel data are brought together in *table 1*.

Jointed and axially-movable attachment of spoke ends in the wheel

The sensor spokes can react by moving longitudinally and with that almost the total load is presented as deformation on the other

Table 1: Wheel data

Weight (incl. Tyre)	443 kg
Rim size	DW 18 L x 38
Max. wheel load	100 kN
Max. draught load	100 kN
Max. lateral load	60 kN

spoke pair in each case. With the jointed attachment of the spoke ends, the spokes can be looked upon as solidly fixed on one side.

This sort of attachment during trial recording should not, as far as possible, take place with joints associated with friction (e.g. ball joints and linear channelling). The friction would lead to hysteresis of the receivers and would be subject to additional scattering.

For this reason a flexible diaphragm was constructed for the jointed and axially-movable attachments (min. wall strength 3 mm). On the level of the diaphragm these must withstand the largest forces and exhibit greatest stiffness. In that these loads can only be taken-up through forces in the membrane level, both requirements are well met. Vertical stiffness and loadings are small.

Recessed bottom of spokes

The recessed bottom of the spokes is vulnerable to maximum demands. The form of the spoke was optimised through FEM calculations [3]. Through this, the recession affect could be substantially reduced and simultaneously the area of maximum tension enlarged. This is advantageous for the reception of signals through the DMS applied in this area (e.g. constant tension under the measurement grid of the DMS).

Material selection

For the highly-stressed spokes, the diaphragms and the spacer sleeves, was used 42 CrMo 4 V stainless steel. These semi-finished products was fully tempered on fitting (tensile strength 900 Mpa) and processed in this condition. The hub material does not have to stand high strength demands and availability was the main point here. The diaphragm frame for attachment of the diaphragm to the rim was of St 52-3 (good welding suitability and strength). The stiffening rings were formed from simple construction steel.

Transmission of energy and signals

The non-contact transmission of energy and signals worked best via a so-called sensor-telemetry offered as a complete system from various manufacturers. The electricity supply for the DMS and for the signal transmissions came via inductive coupling (high frequency, here 13.56 MHz) independent of setting and revolutions.

For transmitting the signals from both spoke pairs and the lateral forces a three-channel Multiplex system was used.

Calibration

The completed sensor wheel and tyre was mounted on a tractor and placed on wheel load scales. Above the rear lifting arms and a fixed point on the floor a linear relationship between wheel load and starting signal of the DMS amplifier – without crosstalk affecting other wheel measurement factors – could be determined. The calibration of lateral force took place on the lying wheel with weights laid on the hub. Here too, a linear progression without crosstalk could be established.

Literature

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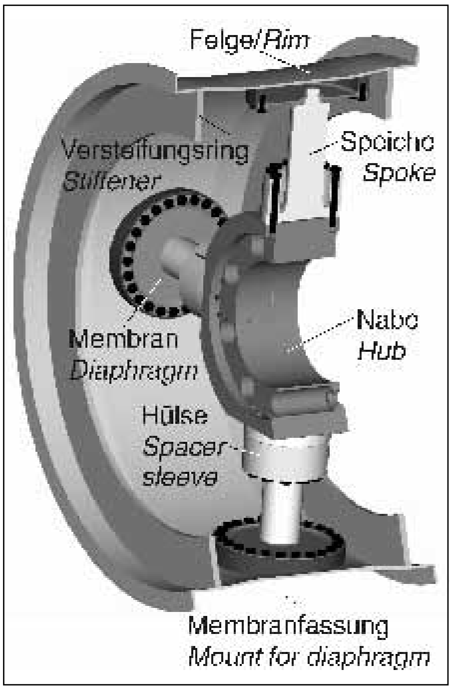

Fig. 3: Design of the wheel