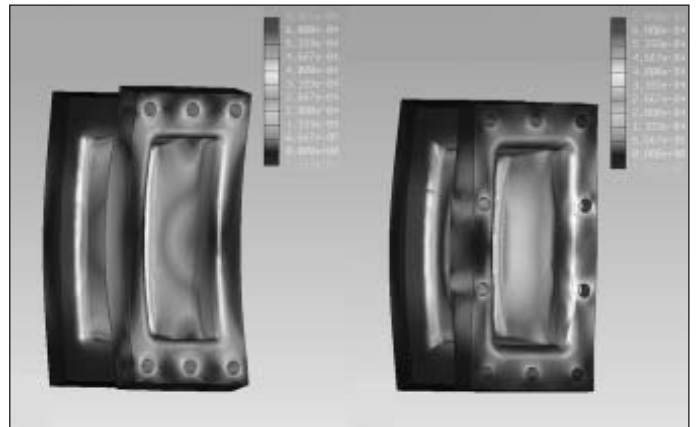


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# Force Measurements on a Trailer Drawbar

*Measuring the forces acting on the link between tractor and trailer is necessary to evaluate the interaction. Basically, there are various quantifying approaches with specific advantages and disadvantages. This article describes the development of a force-measurement-device designed to solve the crosstalk and lack of sensitivity problems in one of the three directions of force.*

Fig. 1: Results of FEM-modelling before (left) and after (right) modification



The last decades have shown a growing trend in rising transport speeds and payload. In 1972 [1] envisioned a payload of 8 to 10 tons and a maximum transport speed of 36 km/h, whereas today one can already find agricultural trailers with 33 tons gross weight and 40 km/h maximum legal speed on a regularly basis. Moreover, recent years have shown a trend towards low linkage points (in Germany, already common in other countries). The newer hitches include the Piton-Fixe and especially the ball-type coupling 80 and are preferred due to increased vertical load and comfort [2]. With a given maximum permissible weight of the tractor-trailer-combination, payload can only be increased by diminishing tractor weight which, in an off-road-context, leads to traction problems and renders the application of propelled trailers to be a sensible alternative [3].

Taking this into account, the measuring of forces at the linking point of tractor and trailer becomes very interesting. As many methods of measurement have been described before it is only possible to cite a few, exemplary ones without being exhaustive. Differing demands for precision, dynamic and space led to quite different solutions. Specific demands were driving the development and construction of these gauges. One can distinguish motivations by the main focus of the measurement, namely vehicle dynamics [4], investigation of draught and traction [5], implications of distributing drive power among tractor and propelled trailer [6], and

acquisition of collective load [7]. Equally different are the methods of measuring. The clearest distinction lies between setups with several single gauges in contrast to a single member with wire strain gauges (WSG) applied. Not necessarily all directions of force are measured.

## Problem statement

Taking the complexity of the different setups into consideration it becomes obvious that for setups with single gauges (usually these are load cells) precautions have to be taken to avoid lateral forces. A typical setup is one load cell on each axis of force which by means of swivelling bearings is kept free of lateral forces. A moment of friction in these bearings - linearly rising with longitudinal force - on the one hand diminishes the measured force in the respective direction and on the other hand generates a significant hysteresis. One-piece multi-component measuring devices are completely free of (outer) friction, even though hysteresis can occur. A force can only act on the gauge itself, which leads to a more precise measurement, but there still is the problem of crosstalk common to all gauges of this type which - nevertheless - can lead to false measurement. If multi-component gauges have to be dimensioned for highly differing forces in the directions to be measured, a conflict of goals arises between the necessary strength in one direction and the desired strain in another. For the specific purpose of the coupling of

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Dedicated to Prof. Dr. Ing. Dr. h.c. H. D. Kutzbach on occasion of his 65th anniversary.

## Keywords

Tractors, trailers, force-measurement, development, FEM

agricultural trailers one has to expect high draft forces (x-axis) comparably small lateral forces (y-axis) as well as vertical forces (z-axis) in between the other two as far as the amount of force is concerned.

### Concept

The obvious conclusion of the facts mentioned above is that a single gauge with a solid member is not suited for the given ratio of forces for e.g. a solid beam has an - in this case - unfavourable ratio of cross-section to section modulus. For reasons of space, complexity, costs, and last but not least the predicted measuring inaccuracy, concepts, which utilised load-cells, were dropped at an early stage. Due to these circumstances, it soon became clear that a hollow section with differing section moduli for each axis looked like the most promising concept. At the same time, the cross-section should remain as small as possible thus enabling the measurement of small draft forces which generate only a fractional strain compared to the strain under maximum force. The cross-section can be further minimised by the use of heat-treated steel (42CrMo4) which can withstand a significantly higher stress compared to standard carbon steel.

Therefore, the objective of development is a minimal cross-section providing for good measurement of x-forces. A quick consideration of space shows that the member will become by far shorter than high which means the constraint of the simple bending beam is not fulfilled. By using the FEM-tool Pro/MECHANICA it was possible to model the behaviour of different drafts under load. The maximum loads were defined for a 22 to trailer according to *table 1*.

The models taken out of Pro/ENGINEER can be easily and quickly modified and these modifications can be validated in a following loop. *Figure 1* shows a modification with additional holes for screw connections of the sensing element itself with an adapter plate at the tip of the trailer drawbar.

The deflection of the element is scaled in this figure which simplifies the search for improvement potential. A more harmonic progress of strain in the side-walls of the element is obvious. Apart from helping to modify the element itself, the FEM models also provide the possibility to search for suitable

places to apply the WSGs. A further (though expected) result of the FEM calculations was that maximised rounding-radii are especially advantageous. The use of a hollow section provides for another advantage as well. Not only is it possible to apply the WSGs inside the hollow section at a secure spot but also to incorporate the measuring amplifiers for all three directions of force. If the sensing element is then connected with the adapter plate, a dust- and water-proof unit evolves. Moreover, cabling between the amplifiers and the WSG-bridge is extremely short and the measuring electronics is well screened. Integrating the amplifiers also means that only supply voltage, 3 signals and ground have to have an outside connection which is achieved by a single socket at the backside of the adapter plate where also 3 switches for zeroing are built in under a dust- and water-proof cover.

### Results

As presented above, a very compact three-components-gauge was designed. It features a high degree of integration of the measuring equipment and can be described as quite robust. *Figure 2* shows a Pro/ENGINEER-model of the assembled sensing element and the adapter plate attached to the drawbar and fitted with a ball-type coupling 80. The ball-type coupling has an additional advantage in this context. Because it is a coupling virtually without play, the point of force-application remains at the same distance, making the use of edges such as in [7] unnecessary.

The sensing element combined with the adapter plate measures  $\sim 220 \cdot 160 \cdot 350$  mm and can be mounted on the drawbar using the standard hole pattern. Therefore, it can be assumed that neither utilisability nor vehicle behaviour will be suffering significantly.

At this point of time only a few preliminary calibration tests could be finished after the completion of the design and manufacturing. The results are satisfying, although slight crosstalk of z- into x-force has to be noted. This phenomenon had already been suspected based on the FEM-calculations. Nevertheless, this crosstalk can be easily compensated by a simple correction algorithm. Solving the crosstalk by means of design would lead to excessive additional effort and would also mean accepting other disadvantages.

### Conclusion

The result of the described design process is a sensing element which can measure all three forces acting on the link between tractor and trailer. Additionally, by the integration of the electronics it can endure the rough

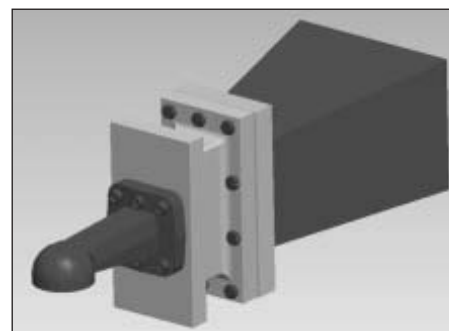


Fig. 2: Pro/E-model of the force-measuring-unit

environment agricultural vehicles are operating in. A diminished utilisability of neither tractor nor trailer in practise is not to be feared. As far as calibration and crosstalk is concerned, a final conclusion is only possible after pending tests on a correspondingly equipped test stand.

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Table 1: Given maximum loads

Axis	Force	Amount [kN]
x	draft / push-	150
y	lateral	50
z	vertical	100