Calibration of a force vector sensor with a multicomponent calibration system

collaborative research project of PTB together wih:

Gassmann Testing and Metrology GmbH

encouraged by:

Projektträger AiF Otto von Guericke

Bundesministerium für Wirtschaft und Technologie

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State of the Art

- Conventional precision force transducers measure forces only as scalar size.
- Transfer-standards for multi-component force and torque test stands do not exist.
- Nowadays multi-component force transducers have an uncertainty within a range of 0.5% and higher, they do not achieve the requirements of all customers in industry (tire development, aviation).
- No calibration procedures in deadweight force standard machines with lowest uncertainty in the realization of force exist

Prototype of the new multi-component transducer

Constructive design of the prototype:

Axial force: 100 kN

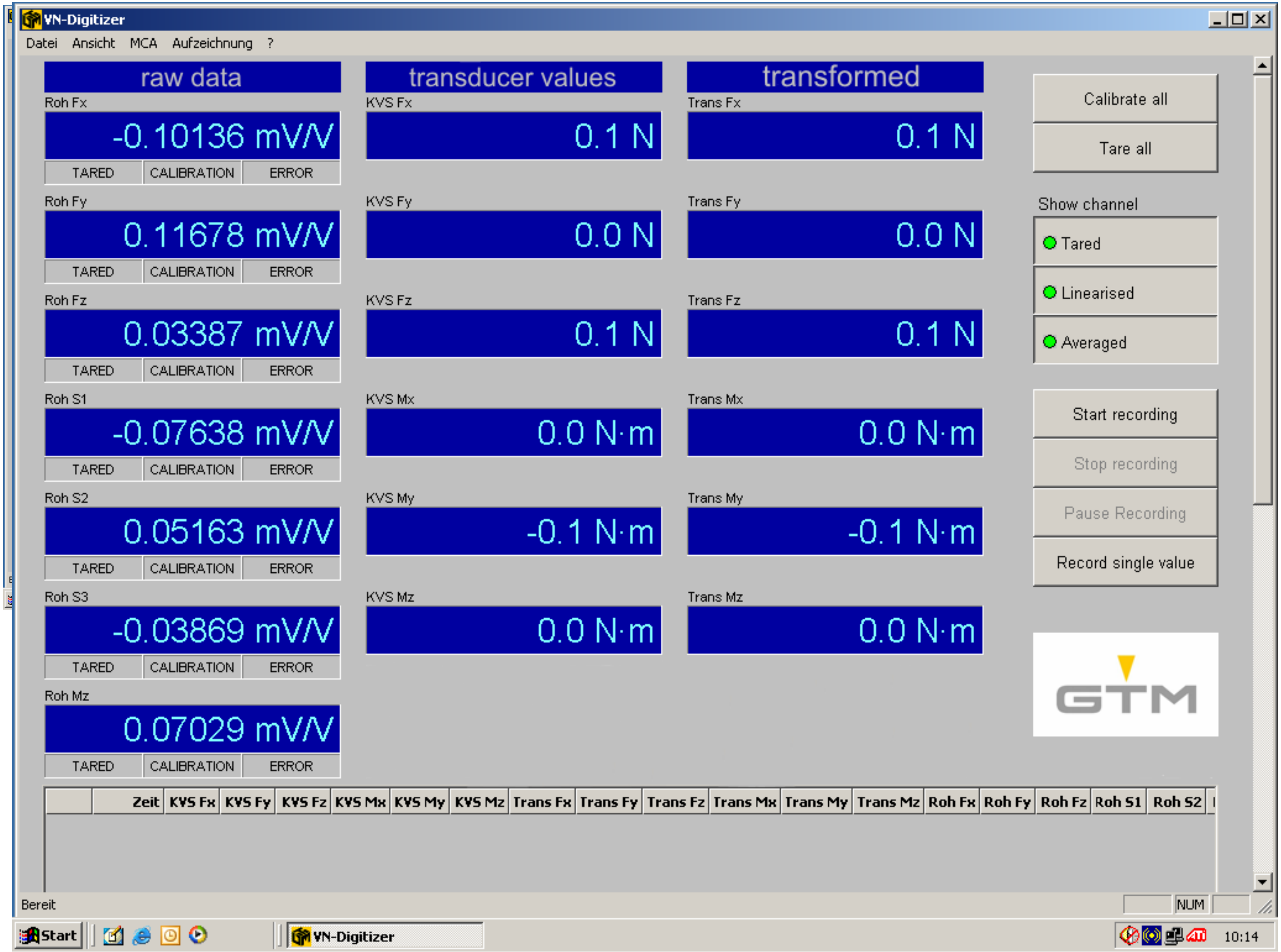
Sideway forces: 10 kN

Torque : 500 Nm

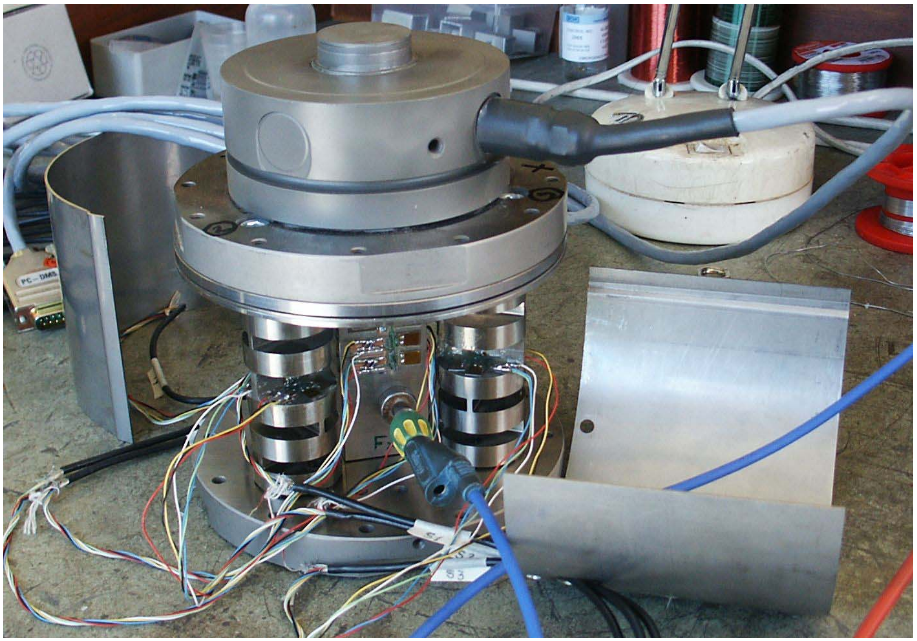
Uncertainty: < 0,01%

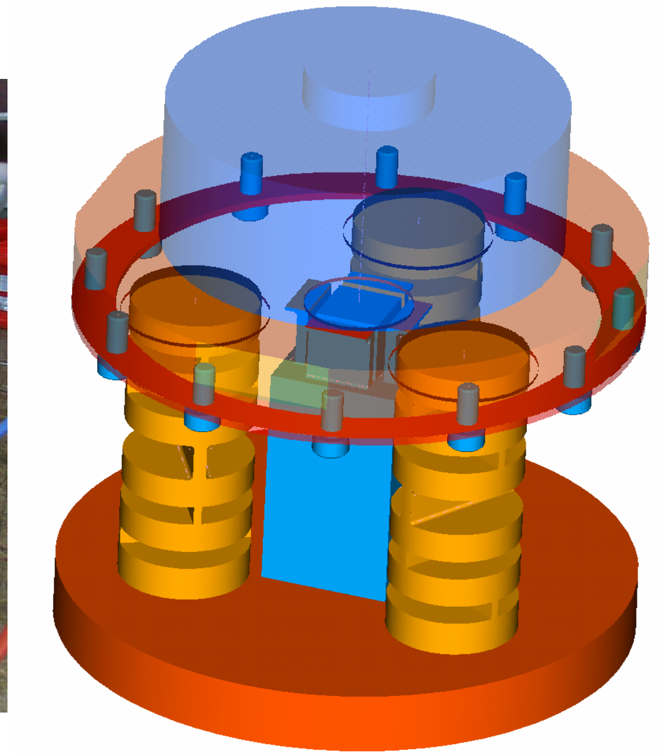
Force vector sensor mounted in a force standard machine

Software of Force Vector Sensor Data Evaluation

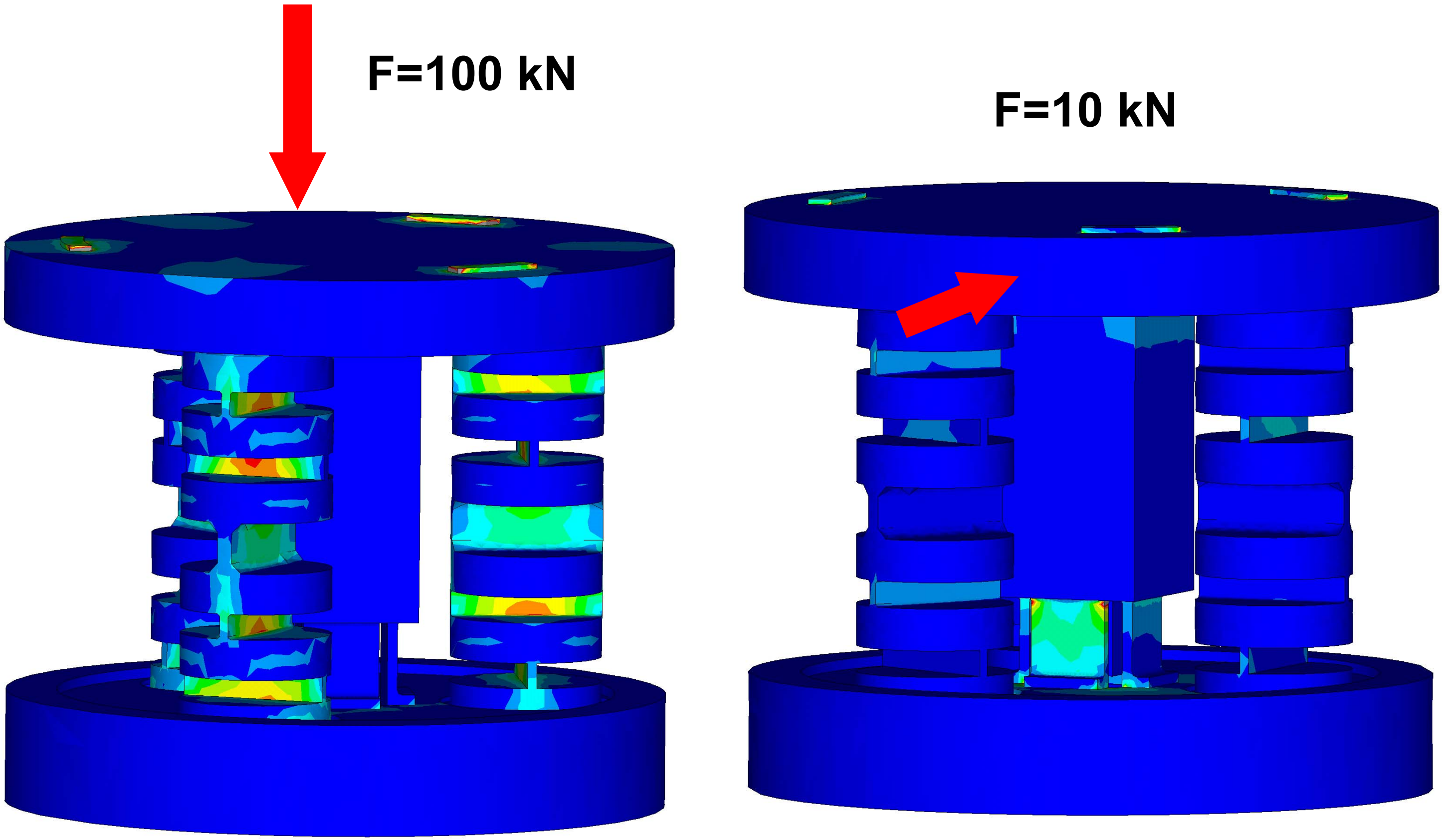


Internal structure of the new multi-component transducer





Numeric Simulation of Force Vector Sensor



Field for use of multi-component transducers

tire test stands

tests in aviation industry

wheel load sensor

Field for use of multi-component transducers

first multi-component calibration facility accredited in DKD

Mehrkomponenten Kraft und Moment Mehrkomponentenaufnehmer	250 N bis 1,2 MN 5 N·m bis 5kN·m	


Deutscher Kalibrierdienst (DKD)
Akkreditierungsstelle bei der
Physikalisch-Technischen Bundesanstalt (PTB)
vertreten im
Deutschen AkkreditierungsRat

Akkreditierung

Die Akkreditierungsstelle des **Deutschen Kalibrierdienstes** akkreditiert hiermit das Kalibrierlaboratorium für mechanische Messgrößen

bei

GTM Gassmann Theiss Messtechnik GmbH
Philipp-Reis-Straße 6
64404 Bickenbach

als Kalibrierlaboratorium nach DIN EN ISO/IEC 17025 für Kalibrierungen in den Bereichen:

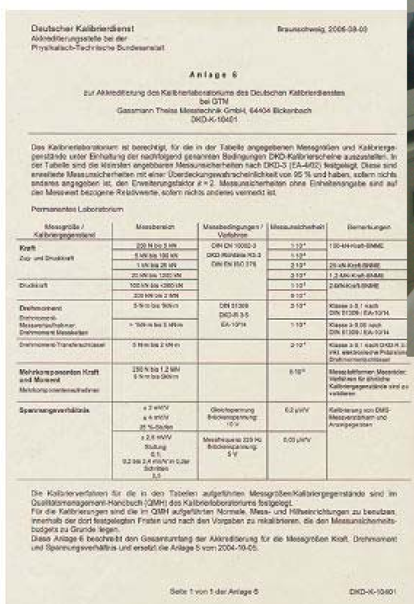
Kraft, Drehmoment, Spannungsverhältnis

Bestandteil der Urkunde ist: Anlage 06 (1 Seite), 2005-08-03

DAR-Registriernummer: DKD-K-10401-06
Akkreditiert im DKD seit: 1993-03-01

Braunschweig, 2005-08-03

Dr.-Ing. Wolfgang Bosch
Leiter der Akkreditierungsstelle


Deutscher Kalibrierdienst
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Physikalisch-Technische Bundesanstalt

Braunschweig, 2005-08-03

Anlage 6

zur Akkreditierung des Kalibrierlaboratoriums des Deutschen Kalibrierdienstes
bei GTM
Gassmann Theiss Messtechnik GmbH, 64404 Bickenbach
DKD-K-10401

Permanentes Laboratorium

Seite 1 von 1 der Anlage 6

DKD-K-10401

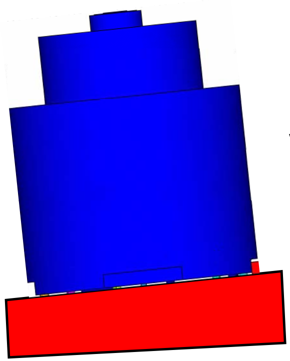
Methods for generating force and moment vectors

a) additional equipment for force standard machines to generate sideway forces and moments

b) inclined mounting of the force transducer in dead weight machines generates combination of axial load and additional components

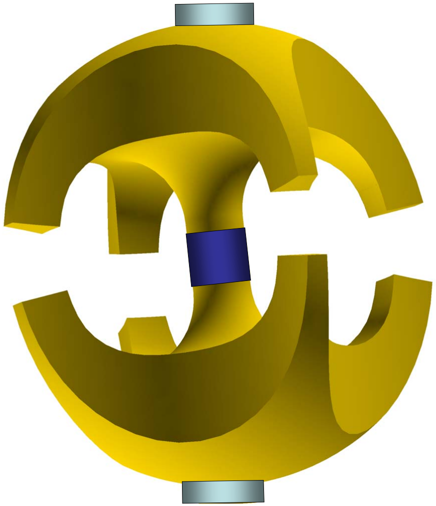
c) multi-component calibration device for generating arbitrary force and moment vectors

Methods for generating force and moment vectors



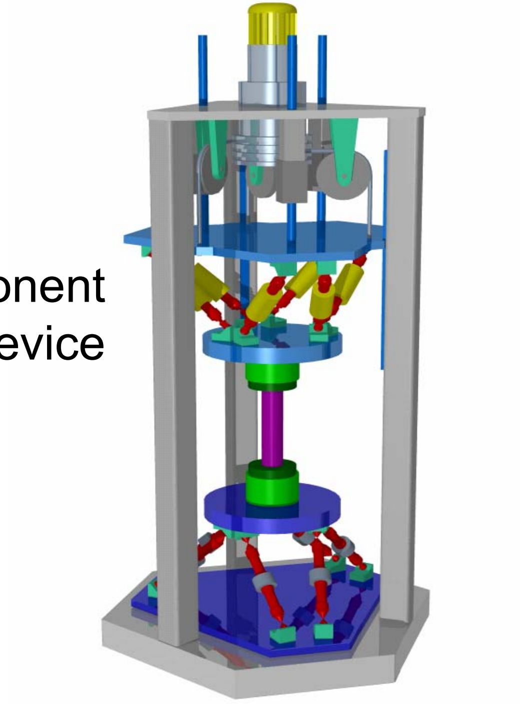
wedge

load-frame for the 100-kN-FSM to generate sideway forces



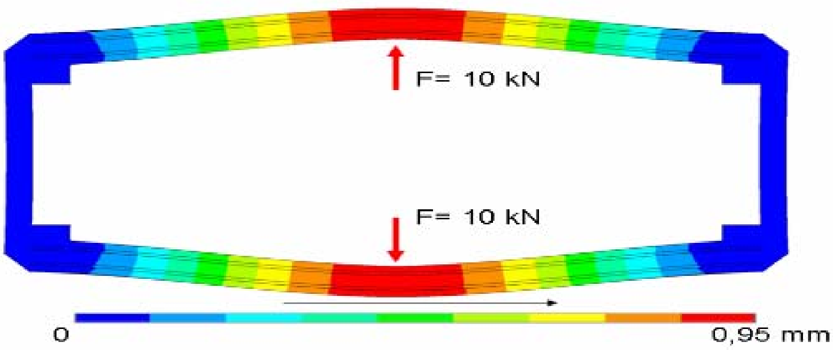
spherical calibration facility

multi-component calibration device

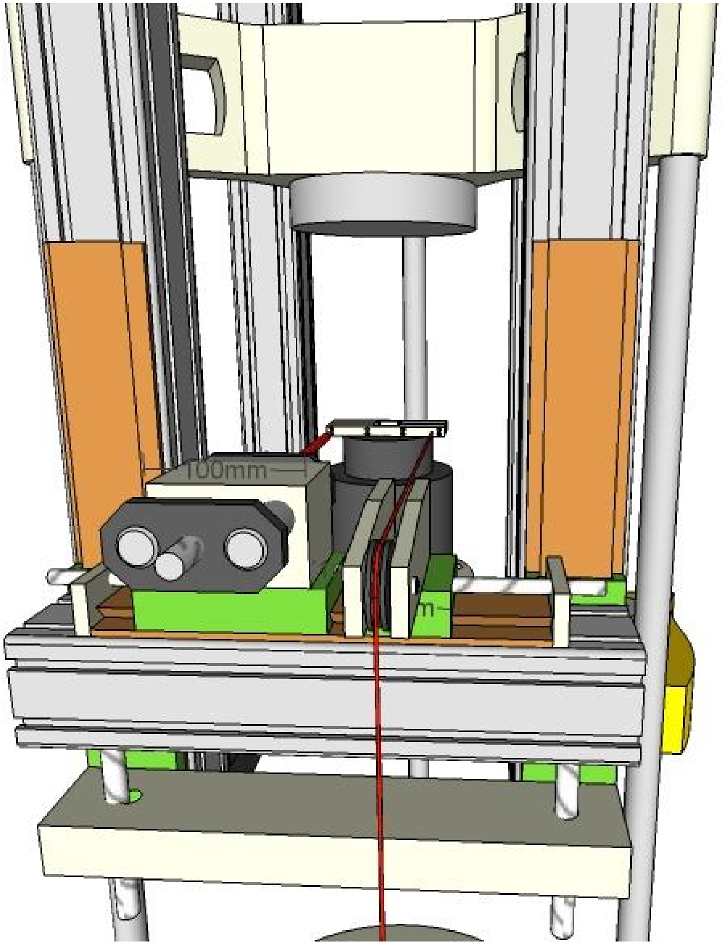


a) Additional equipment

frame for generating sideway forces which is clamped around the cross heads of the 100-kN-force-standard-machine

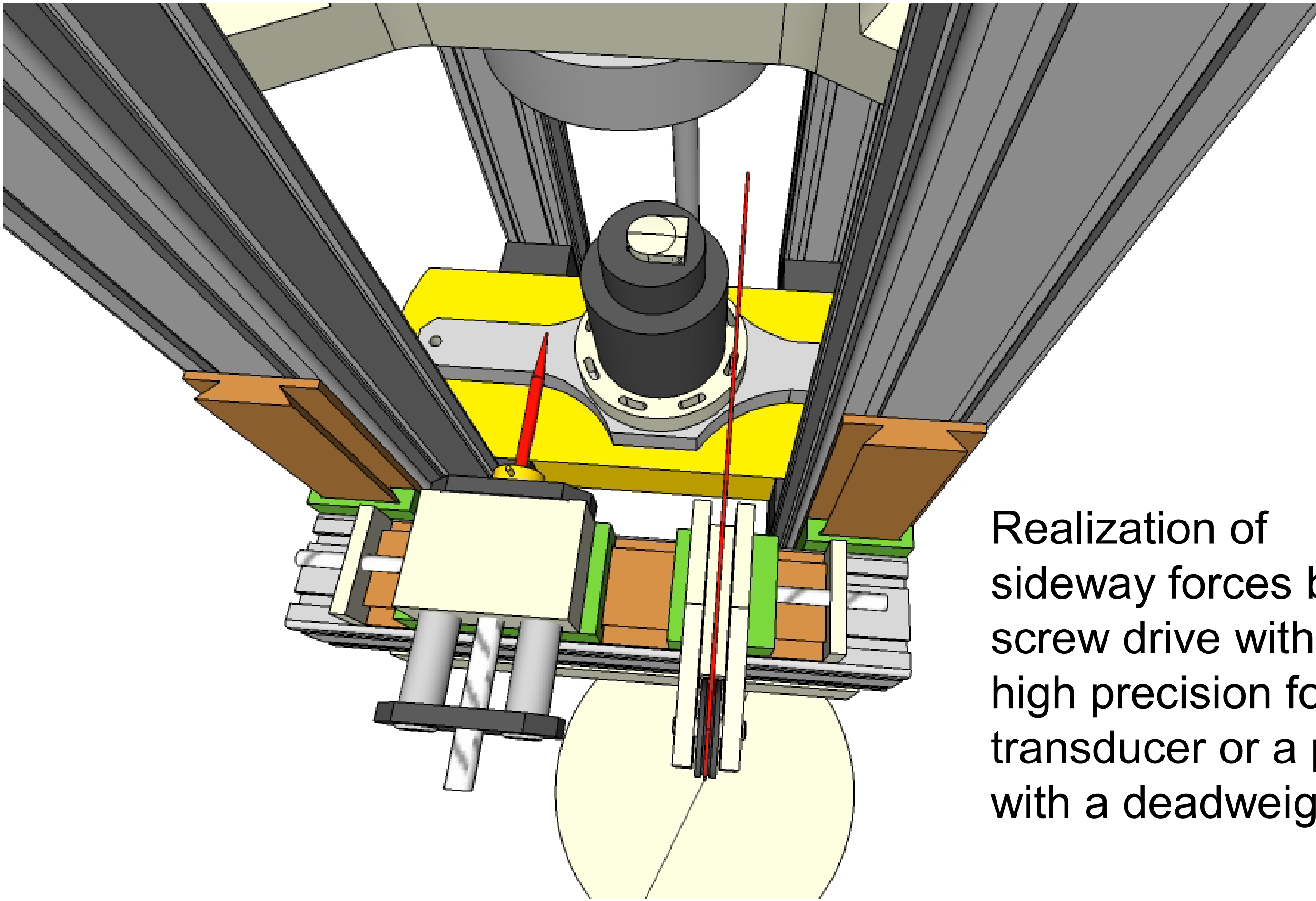


a) Additional equipment



Vertically and horizontally movable crosshead at the load frame with loading facilities

a) Additional equipment



Realization of sideway forces by a screw drive with a high precision force transducer or a pulley with a deadweight

b) Inclined mounting

Realization of sideway force by mounting the vector sensor on a wedge inside the FSM.

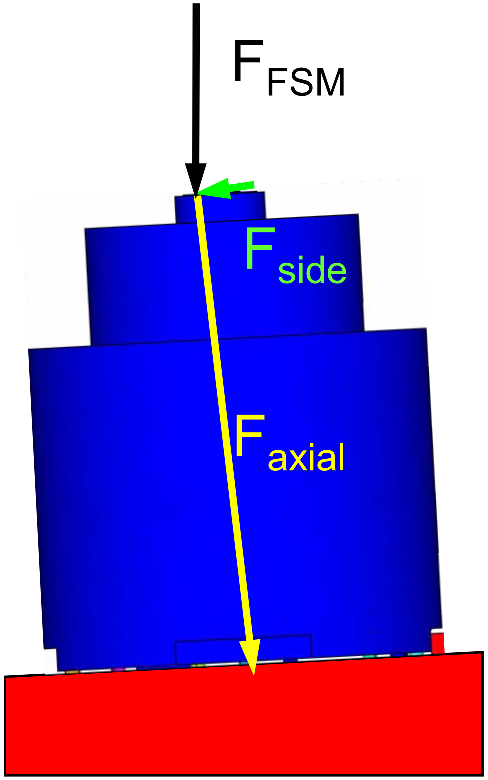
Disadvantages:

-uncertainties in centering

-no arbitary angles

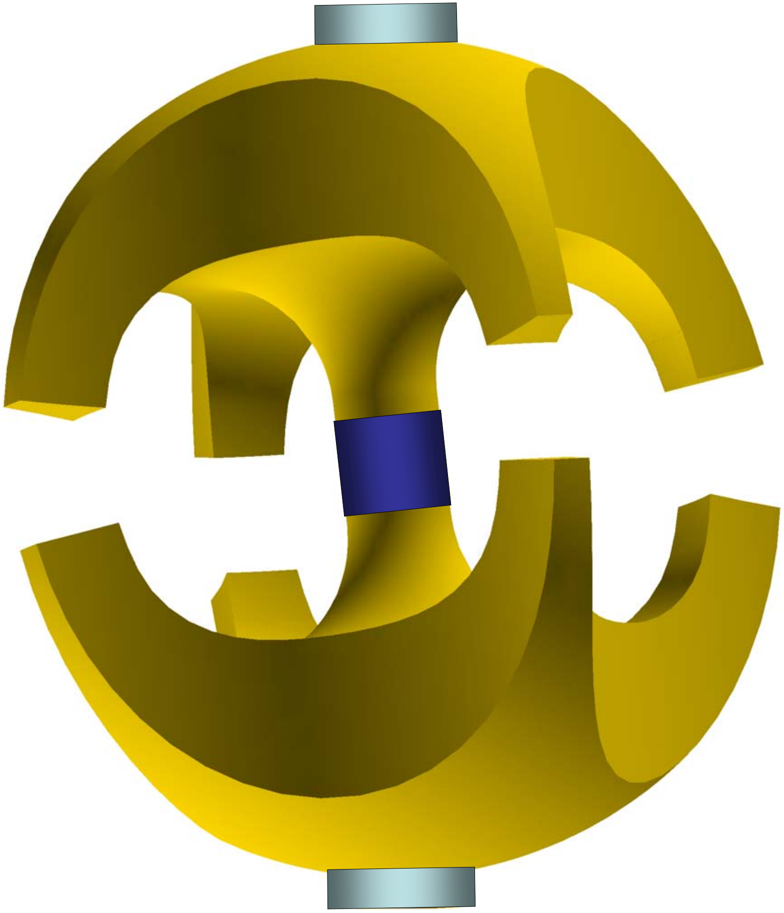
Solution:

Development of a so called spherical calibration body

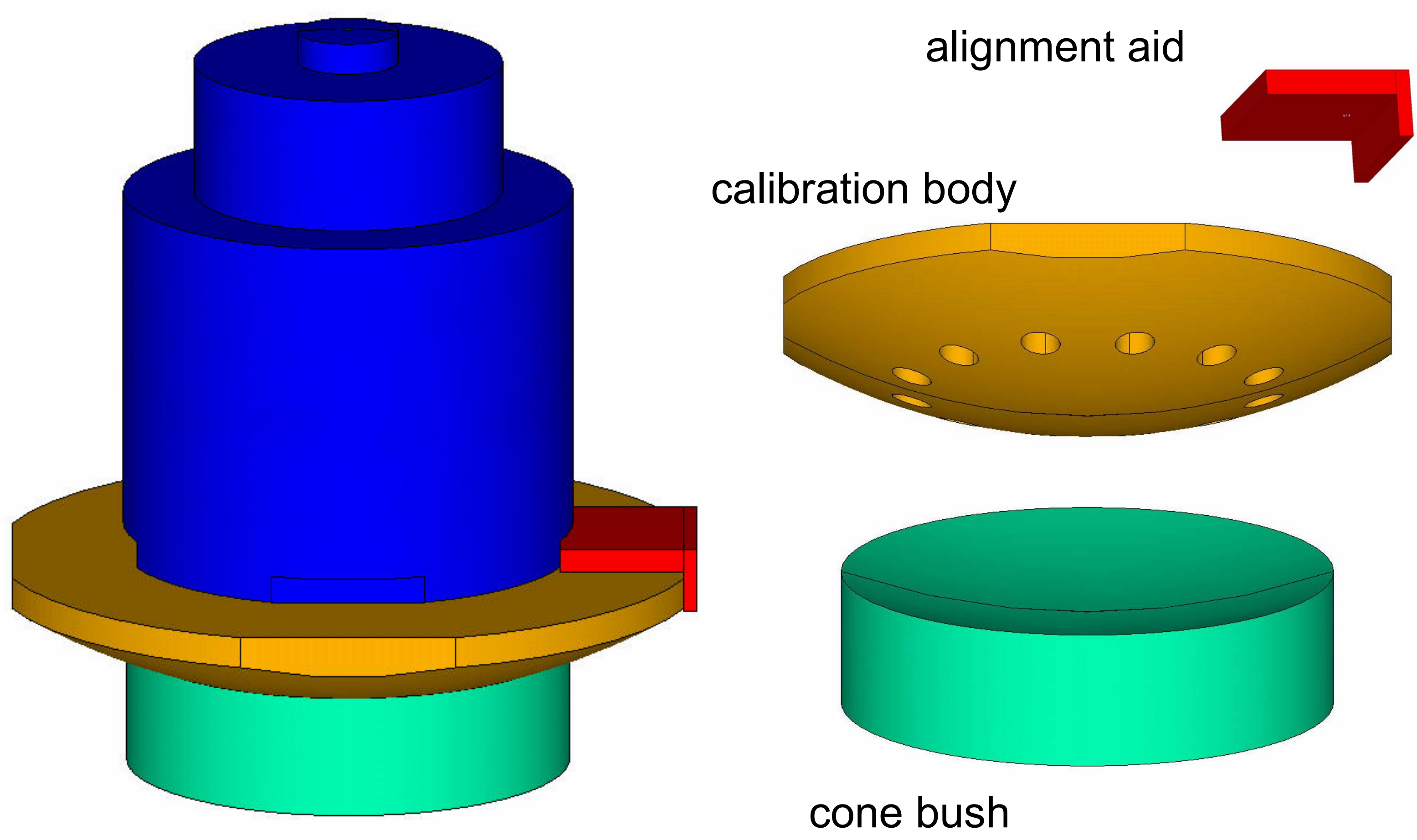


b) spherical calibration body

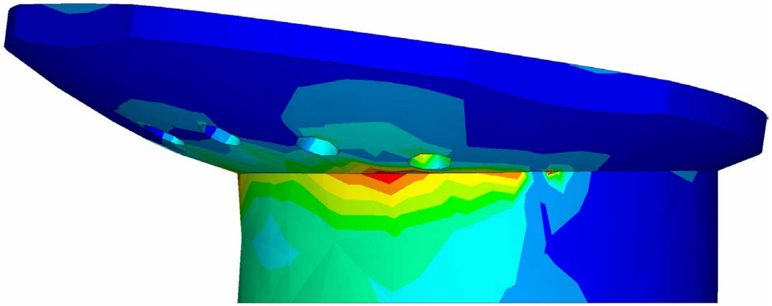
- Only one cantering for measurement in different rotational positions
- Arbitrary angles
- Centre of the sensor is not moved by turning



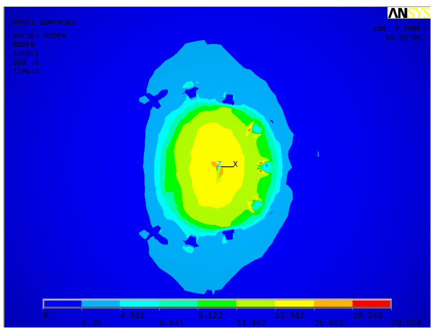
b) spherical calibration body - optimisations



b) spherical calibration body - optimisations



Numerical simulation to analyse maximum stress at the maximum gear angle and to analyse the influence of the mounting boreholes



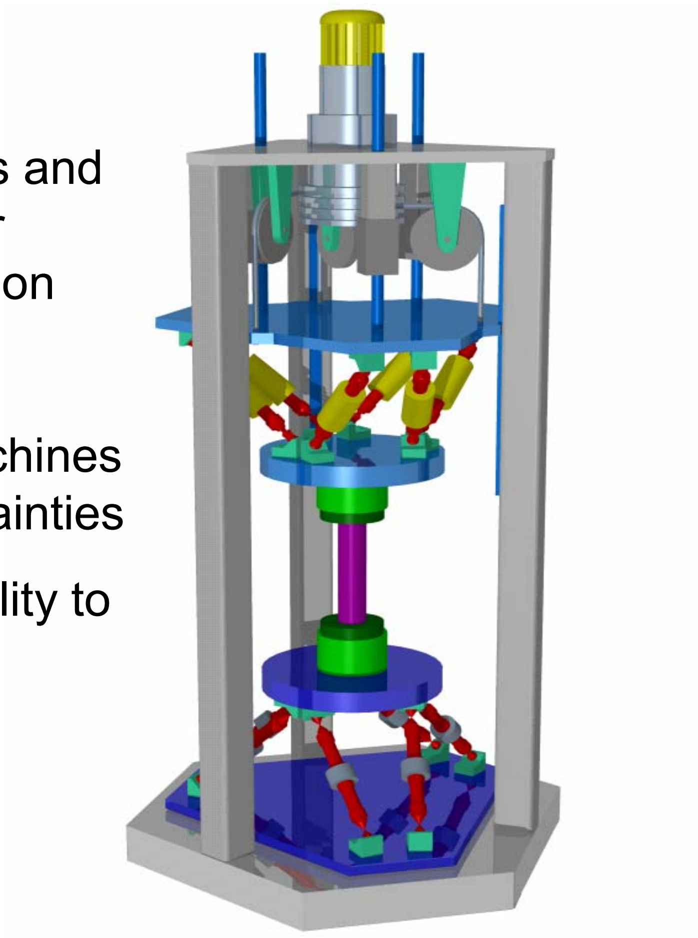
c) multi-component calibration device

Realization of all directions of forces and moments and their arbitrary combination

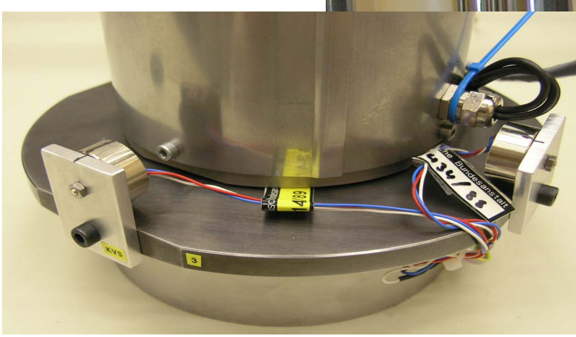
But:

- Dead weight machines have lower uncertainties

- No direct tractability to the standards



For calibration of the force vector sensor the spherical calibration artefact method was chosen because of the low uncertainty achievable by using dead weight force standard machines.



CALIBRATION OF THE FORCE VECTOR SENSOR

$$f_i = \sum_{j=x}^{z} a_{ij} F_j \qquad i = x; y; z \qquad (a_{ij}) = A$$

$$A = \begin{pmatrix} 0{,}34 & 5{,}2 \cdot 10^{-3} & 1{,}0 \cdot 10^{-4} \\ 3{,}7 \cdot 10^{-3} & -0{,}34 & -1{,}2 \cdot 10^{-4} \\ -2{,}4 \cdot 10^{-5} & -2{,}1 \cdot 10^{-5} & 2{,}0 \cdot 10^{-2} \end{pmatrix}$$

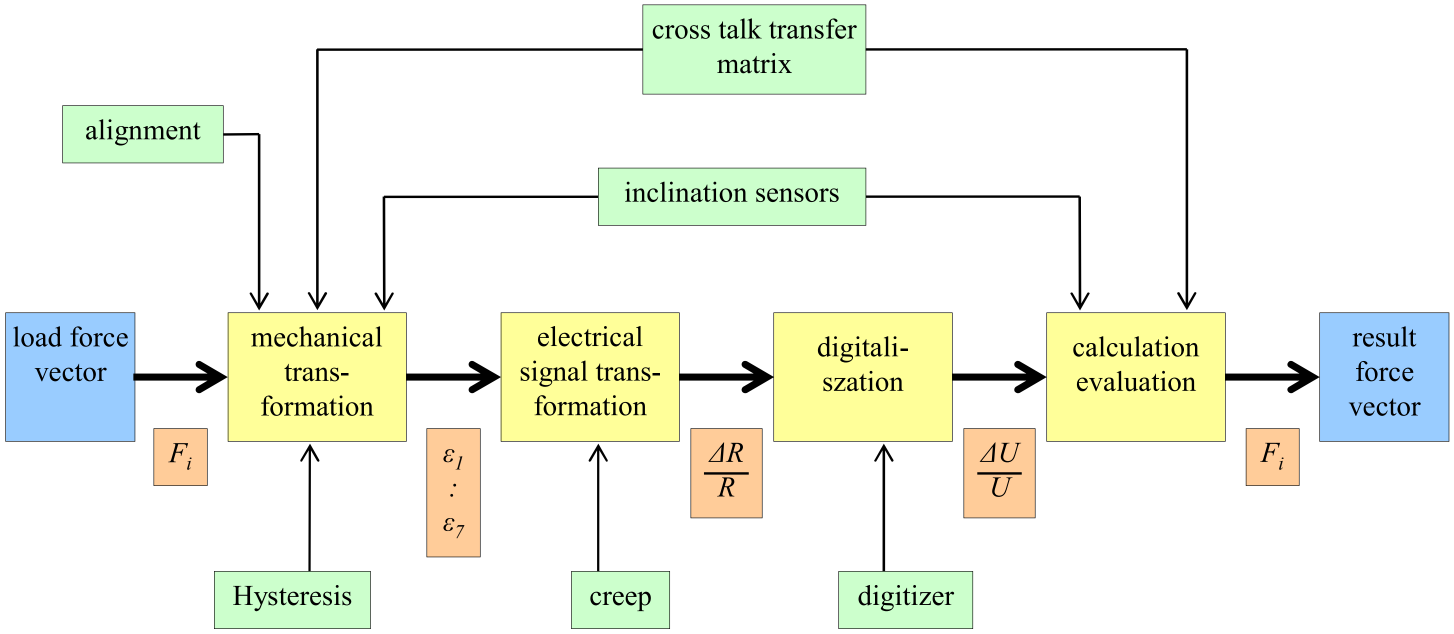
$$F_i = \sum_{j=x}^{z} b_{ij} f_j \qquad i = x; y; z \qquad A^{-1} = (b_{ij})$$

$$A^{-1} = \begin{pmatrix} 3{,}0 & 4{,}6 \cdot 10^{-2} & -1{,}5 \cdot 10^{-2} \\ 3{,}2 \cdot 10^{-2} & -3{,}0 & -1{,}8 \cdot 10^{-2} \\ 3{,}5 \cdot 10^{-3} & -3{,}0 \cdot 10^{-3} & 49{,}9 \end{pmatrix}$$

Components of Uncertainty, regarding side forces *Fx* *and Fy* and axial force *Fz*

component	$u_i \rightarrow (F_x, F_y)$	$u_i \rightarrow (F_z)$
alignment	$7 \cdot 10^{-4}$ mV/V	$4 \cdot 10^{-4}$ mV/V
digitizer	$5{,}2 \cdot 10^{-5}$ mV/V	
hysteresis	$6 \cdot 10^{-3}$ mV/V	$5 \cdot 10^{-5}$ mV/V
creep	$4 \cdot 10^{-5}$ mV/V	
inclination sensor	$4 \cdot 10^{-2}°$	
response matrix	$8 \cdot 10^{-4}$ mV/V	$4 \cdot 10^{-8}$ mV/V

Uncertainty Model of the force vector sensor calibration



Uncertainty Result

component	$\rightarrow (F_x, F_y)$	$\rightarrow (F_z)$
alignment	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$
digitizer	$1{,}5 \cdot 10^{-5}$	$2{,}6 \cdot 10^{-5}$
hysteresis	$1{,}8 \cdot 10^{-3}$	$1{,}5 \cdot 10^{-5}$
creep	$1{,}2 \cdot 10^{-5}$	$2 \cdot 10^{-5}$
inclination sensor	$7{,}2 \cdot 10^{-3}$	$8 \cdot 10^{-6}$
response matrix	$2{,}4 \cdot 10^{-4}$	$9{,}9 \cdot 10^{-7}$
combined uncertainty	**$7{,}4 \cdot 10^{-3}$ kN**	**$1{,}1 \cdot 10^{-4}$ kN**

CONCLUSIONS

The results of investigation show that the new force vector sensor achieves lower uncertainties in multi-component force measurement. This will allow to use the sensor in precision measurements for instance as transfer standard for calibrating multi-component force measuring stands and for investigating parasitic effects in high precision force standard machines. As the sensor is also capable of measuring moments analogue methods for calibration will be developed so all six components of a force and moment vector can be measured with lower uncertainty.