Calibration matrices for force/torque sensors

A lot of applications require that only one axis of a force/torque sensor is used from 50% to 100% of the nominal load, while the other axis of the sensor are used only up to 10% or even only up to 1% of the measuring range. An example shows Figure 1.

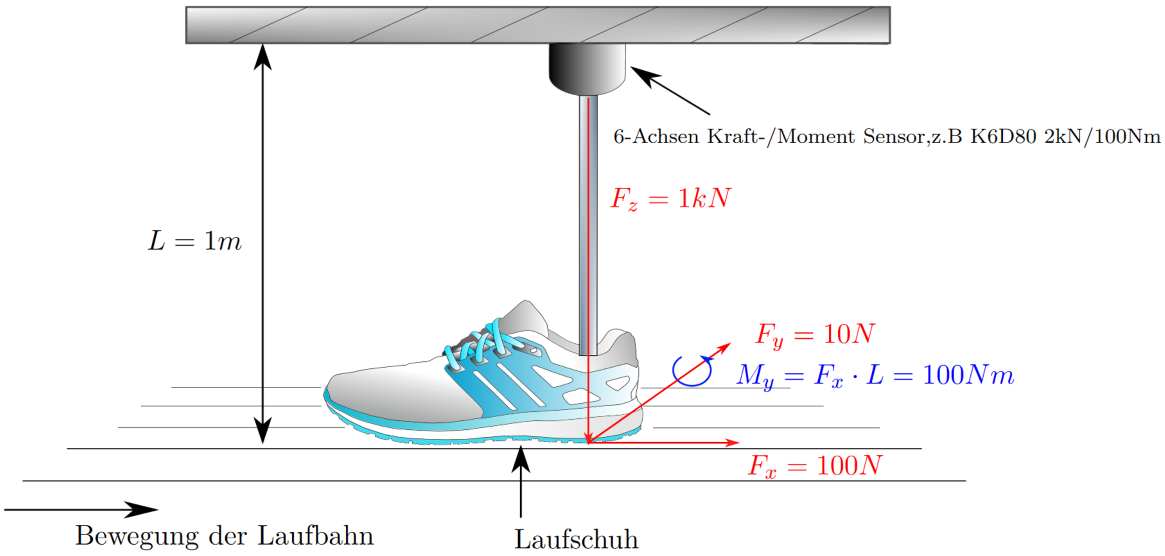

Figure 1: example of an application of K6D sensors in tribology

- ME-Meßsysteme GmbH offers for the support of special measuring ranges calibration with partial loads between 10% ... 50% of the nominal load,
- a special calibration procedure "Matrix-Plus".

With both methods it is possible to guarantee optimum accuracy in these application-specific load cases.
The tasks of the calibration matrix are
a) Minimizing the measurement error in the loaded measuring axis and
b) Minimizing the crosstalk in the remaining (unloaded) 5 axes.

Standard calibration

In the case of low utilization of some measuring axes, the error can have a relatively strong effect in these measurement axes due to crosstalk, although it is significantly less than 1% based on 100% of the measuring range.

Advanced calibration "Matrix-Plus"

ME-Systems has developed a new calibration method, which optimizes the display in the

loaded measuring axis and in the unloaded measuring axes.
The characteristic field of the 6-axis sensor is represented by two matrices. Matrix A describes the linear relationships, matrix B describes the non-linear relationships.

Matrix Plus with "standard constraints"

Special conditions are defined in the determination of the matrices so that the measurement errors are minimized even at low forces and torques.
Loads of 100%, 80%, 60%, 40% and 20% are mathematically optimized.

Matrix Plus with "Calibration in the operating point"

Alternatively, a calibration is also possible at the operating point of the application.
Customer-specific calibration uses the actual loads and lever ratios of the customer-specific application.
In this case, accuracies of 0.5% to 0.1% of the actual value can be achieved.
Suitable devices may have to be produced for the calibration in order to display the special lever ratios of the application. This can result in additional costs and delivery times in individual cases.

Selection criteria for the calibration procedure

For universal use of the force sensor in various applications and with all load combinations, standard calibration at 100% of the nominal load is the best choice. Due to the excellent linearity of the K6D sensors, especially in the measuring ranges up to 1 kN and up to 100 Nm, a quadratic solution approach with MatrixPlus offers no significant improvement for universal use.

In a defined application with a largely constant load vector, both the standard calibration with partial loads and the calibration with partial load plus quadratic approach offer an improvement of the accuracies up to 0.1% of the actual value (quadratic approach) or 0.2% (linear approach) including crosstalk.

The advantage of the linear approach with a standard calibration is that the GSV-8 amplifier can automatically calculate the forces and moments and display analog voltages or currents at the analog output. The calculations for the quadratic approach are (so far) only carried out in the GSVmulti software or by the customer's data acquisition department using the "formula set" provided.

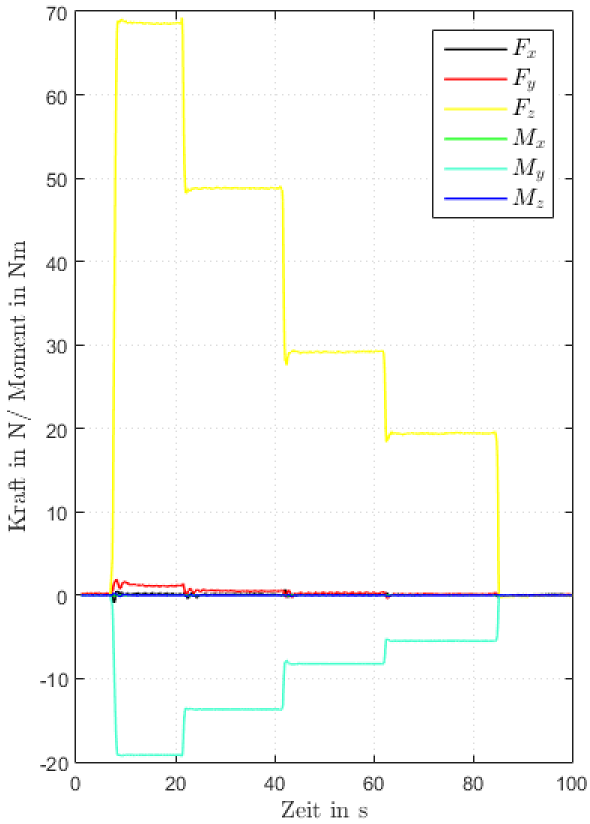

Figure 2: K6D40 200N/20Nm: standard calibration at 100% of rated load; test load -19,233Nm, +68,69N; display at 100%, 75%, 50% and 25% of the test load.

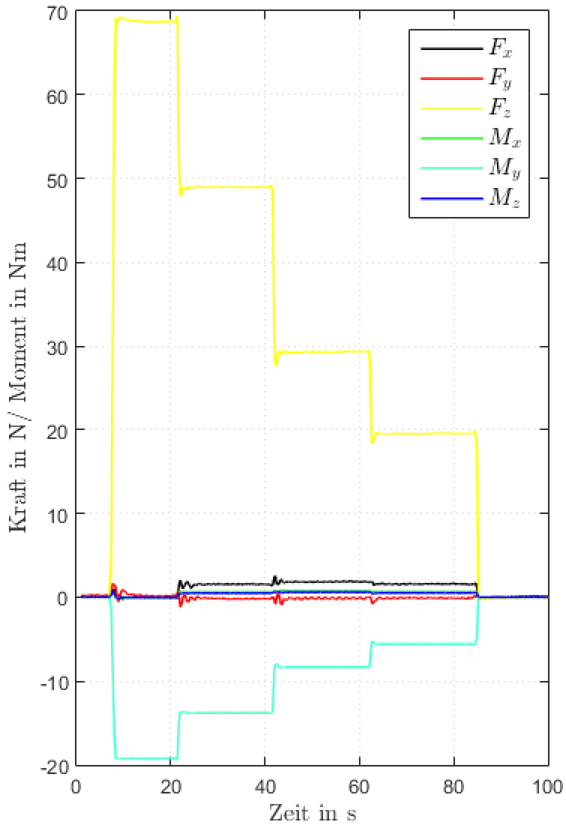

Figure 3: K6D40 200N/20Nm: Calibration Matrix Plus at 100% of rated load (no constraints). Test load -19,233Nm, +68,69N; Display at 100%, 75%, 50% and 25% of the test load.

The Figure 2 shows the result of the standard calibration. At a rated load of 100%, the measurement uncertainty is due to crosstalk up to 1% of the rated load. The crosstalk decreases with lower loads.
By applying the Matrix-Plus for the non-linear connections, the measuring errors are minimized at 100% of nominal load (Figure 3).

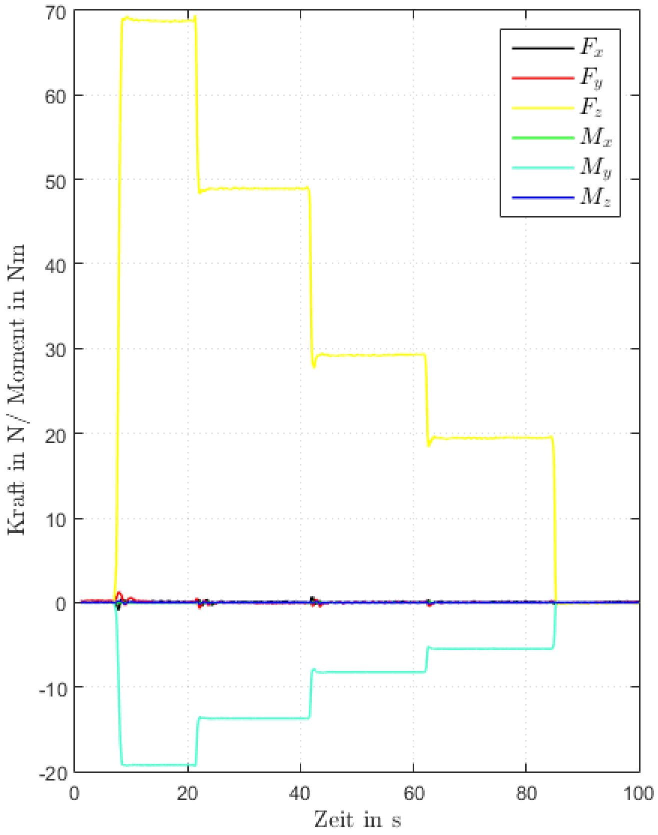

Figure 4: K6D40 200N/20Nm: Calibration Matrix Plus with standard constraint at 100% of the rated load. Test load -19,233Nm, +68,69N; Display at 100%, 75%, 50% and 25% of the test load.

The Figure 4 shows the result of "Matrix Plus" application with standard constraints. The crosstalk is minimized at all load stages. The measurement uncertainty due to crosstalk is about 0.2% of the rated load in all load stages.

The Figure 5 also shows the result of the application of „Matrix-Plus "with standard constraint at 100% of rated load (or 50% rated load for Fz). The display in N or Nm and the deviation from the test load in % are indicated for each test load. Three repetition measurements are performed for each load vector. The extended measurement uncertainty with k = 2 is 0.31% for the display of the moment My.

Soll-Last	Fx (N)	Fx (%)	Fy (N)	Fy (%)	Fz (N)	Fz (%)	Mx (Nm)	Mx (%)	My (Nm)	My (%)	Mz (Nm)	Mz (%)
Fz=98.126 N;	-0.01	0.02 %	0.03	0.06 %	98.10	-0.03 %	0.00	0.00 %	0.01	0.54 %	0.00	0.01 %
Fz=98.126 N;	0.01	0.02 %	0.03	0.07 %	98.16	0.04 %	0.00	0.13 %	-0.00	0.46 %	0.00	0.02 %
Fz=98.126 N;	0.01	0.01 %	0.02	0.04 %	98.20	0.07 %	-0.00	0.38 %	0.00	0.05 %	0.00	0.02 %
Fx=-49.063 N;	-49.04	-0.04 %	-0.01	0.03 %	-0.03	0.03 %	-0.00	0.04 %	0.00	0.01 %	-0.00	0.14 %
Fx=-49.063 N;	-49.07	0.01 %	0.01	0.02 %	-0.04	0.04 %	0.00	0.01 %	0.00	0.04 %	0.00	0.01 %
Fx=-49.063 N;	-49.05	-0.02 %	-0.00	0.01 %	-0.04	0.04 %	-0.00	0.02 %	-0.00	0.16 %	0.00	0.13 %
Fx=49.063 N;	49.04	-0.04 %	0.01	0.03 %	-0.06	0.06 %	-0.00	0.01 %	0.00	0.01 %	-0.00	0.06 %
Fx=49.063 N;	49.08	0.03 %	-0.00	0.01 %	-0.04	0.04 %	-0.00	0.03 %	-0.00	0.08 %	0.00	0.01 %
Fx=49.063 N;	49.09	0.05 %	-0.01	0.03 %	-0.03	0.03 %	-0.00	0.03 %	-0.00	0.04 %	0.00	0.05 %
Fy=49.063 N;	0.02	0.04 %	49.06	-0.01 %	-0.06	0.07 %	-0.00	0.13 %	-0.00	0.02 %	0.00	0.12 %
Fy=49.063 N;	0.02	0.03 %	49.08	0.03 %	-0.02	0.02 %	-0.00	0.06 %	-0.00	0.03 %	-0.00	0.13 %
Fy=49.063 N;	-0.00	0.00 %	49.09	0.05 %	-0.04	0.05 %	-0.00	0.11 %	-0.00	0.01 %	-0.00	0.01 %
Fy=-49.063 N;	0.01	0.01 %	-49.03	-0.06 %	-0.04	0.04 %	-0.00	0.08 %	-0.00	0.01 %	-0.00	0.02 %
Fy=-49.063 N;	0.00	0.00 %	-49.05	-0.04 %	-0.05	0.05 %	-0.00	0.10 %	-0.00	0.01 %	-0.00	0.04 %
Fy=-49.063 N;	0.02	0.05 %	-49.08	0.03 %	-0.02	0.02 %	-0.00	0.12 %	-0.00	0.04 %	0.00	0.06 %
Fz=14.7189 N; Mx=1.045 Nm;	0.01	0.03 %	-0.01	0.03 %	14.69	-0.03 %	1.04	-0.10 %	-0.00	0.13 %	-0.00	0.02 %
Fz=14.7189 N; Mx=1.045 Nm;	-0.00	0.00 %	-0.01	0.02 %	14.70	-0.02 %	1.04	-0.09 %	0.00	0.05 %	-0.00	0.01 %
Fz=14.7189 N; Mx=1.045 Nm;	-0.01	0.01 %	-0.00	0.01 %	14.69	-0.03 %	1.04	-0.02 %	-0.00	0.06 %	0.00	0.00 %
Fz=14.7189 N; Mx=-1.045 Nm;	0.01	0.01 %	0.01	0.02 %	14.68	-0.04 %	-1.05	0.23 %	-0.00	0.03 %	0.00	0.01 %
Fz=14.7189 N; Mx=-1.045 Nm;	0.01	0.03 %	0.03	0.06 %	14.69	-0.03 %	-1.05	0.33 %	0.00	0.00 %	-0.00	0.01 %
Fz=14.7189 N; Mx=-1.045 Nm;	0.01	0.02 %	0.02	0.05 %	14.70	-0.01 %	-1.05	0.09 %	-0.00	0.04 %	0.00	0.00 %
Fz=14.7189 N; My=1.045 Nm;	-0.01	0.01 %	0.01	0.02 %	14.67	-0.05 %	-0.00	0.07 %	1.04	-0.47 %	0.00	0.03 %
Fz=14.7189 N; My=1.045 Nm;	0.00	0.01 %	0.02	0.05 %	14.72	-0.00 %	-0.00	0.00 %	1.05	0.28 %	-0.00	0.02 %
Fz=14.7189 N; My=1.045 Nm;	-0.00	0.01 %	0.02	0.04 %	14.69	-0.03 %	-0.00	0.10 %	1.05	0.14 %	-0.00	0.02 %
Fz=14.7189 N; My=-1.045 Nm;	-0.00	0.00 %	-0.00	0.01 %	14.68	-0.04 %	0.00	0.02 %	-1.04	-0.01 %	0.00	0.01 %
Fz=14.7189 N; My=-1.045 Nm;	-0.01	0.02 %	0.01	0.03 %	14.69	-0.03 %	0.00	0.04 %	-1.05	0.00 %	0.00	0.00 %
Fz=14.7189 N; My=-1.045 Nm;	0.01	0.01 %	0.00	0.01 %	14.70	-0.02 %	-0.00	0.13 %	-1.05	0.08 %	-0.00	0.03 %
Fy=14.7189 N; Mz=1.045 Nm;	-0.00	0.00 %	14.73	0.03 %	-0.08	0.08 %	0.00	0.01 %	-0.00	0.06 %	1.04	-0.06 %
Fy=14.7189 N; Mz=1.045 Nm;	0.03	0.05 %	14.71	-0.02 %	-0.05	0.06 %	-0.00	0.07 %	0.00	0.02 %	1.05	0.03 %
Fy=14.7189 N; Mz=1.045 Nm;	-0.00	0.01 %	14.72	-0.00 %	-0.01	0.01 %	0.00	0.03 %	-0.00	0.02 %	1.04	-0.03 %
Fy=14.7189 N; Mz=-1.045 Nm;	0.01	0.02 %	14.74	0.04 %	-0.05	0.05 %	-0.00	0.17 %	-0.00	0.01 %	-1.04	-0.08 %
Fy=14.7189 N; Mz=-1.045 Nm;	0.02	0.04 %	14.75	0.07 %	-0.03	0.03 %	-0.00	0.05 %	0.00	0.06 %	-1.05	0.14 %
Fy=14.7189 N; Mz=-1.045 Nm;	0.00	0.00 %	14.76	0.09 %	-0.04	0.04 %	-0.00	0.19 %	-0.00	0.01 %	-1.04	-0.02 %
Max		0.05		0.09		0.08		0.38		0.54		0.14
Min		-0.04		-0.06		-0.05		-0.10		-0.47		-0.08
Mittelwert		0.01		0.03		0.01		0.08		0.06		0.03
Standardabweichung		0.02		0.03		0.04		0.10		0.16		0.05
Messunsicherheit (k=2)		0.04		0.06		0.08		0.20		0.31		0.10

> 1% > 0.3% < 0.3%

Figure 5: K6D27 50N/1Nm: calibration Matrix Plus with standard constraint at 100% of rated load

Stand:	30.10.19
Version	kb-kalibriermatrix_en-v1.1
Bearbeiter	Holger Kabelitz
Herausgebende Stelle	Vertrieb
Freigabe durch:	Holger Kabelitz, 30.10.2019
Änderungen	Changelog Seite 6

Changelog

Version	Datum	Änderungen
kb-kalibriermatrix.odt	23.05.18	first version
Kb-kalibriermatrix_en-v1.1.odt	30.10.19	incl. Matrix Plus