

Calibration Matrices for Force/Torque Sensors

Many applications require that only one axis of the force/torque sensor be utilized to 50% to 100%, while the remaining axes of the sensor are only used to 10% or even just 1% of their measuring range. Figure 1 shows an example.

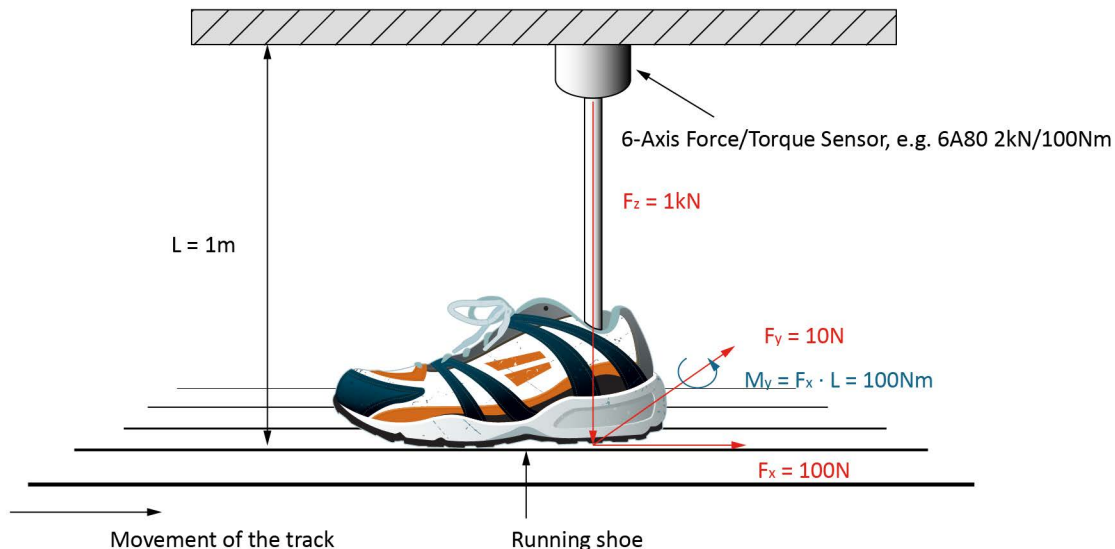


Figure 1: Example of an application of 6A sensors in Tribology

Interface offers support for special measuring ranges

- Calibration with partial loads between 10% ... 50% of the rated load,
- a special calibration procedure "Matrix-Plus".

Both methods make it possible to ensure optimal accuracy in these application-specific load cases.

The tasks of the calibration matrix are:

- a) Minimizing the measurement error in the loaded measurement axis and,
- b) Minimizing crosstalk in the remaining (unloaded) 5 axes.

Standard Calibration

With low utilization of some measuring axes, the error due to crosstalk in these axes can have a relatively large impact, even though it is well below 1% when considering 100% of the measuring range.

Extended Calibration "Matrix-Plus"

Interface has developed a new calibration procedure that improves the display in

The measurement of the loaded axis and the display in the unloaded axes are optimized. The characteristic curves of the 6-axis sensor are represented by two matrices. Matrix A describes the linear relationships, and Matrix B describes the nonlinear relationships.

Matrix-Plus with "Standard Constraints"

Specific conditions are defined when determining the matrices to minimize measurement errors even with low utilization of the measuring range. Mathematically, loads of 100%, 80%, 60%, 40%, and 20% are optimized.

Matrix-Plus with "Calibration at the Operating Point"

Alternatively, calibration at the application's operating point is also possible. Customer-specific calibration uses the actual loads and leverage ratios of the customer's application. In this case, accuracies of 0.5% to 0.1% of the actual value can be achieved.

For calibration, suitable fixtures may need to be manufactured to replicate the application's specific leverage ratios. This may result in additional costs and delivery times in certain 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 rated load is the best choice. Due to the excellent linearity of the 6A sensors, especially in the measuring ranges up to 1 kN and up to 100 Nm, a quadratic solution approach with MatrixPlus does not offer a significant improvement for universal use.

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

The advantage of the linear approach with standard calibration is that the BX8 measuring amplifier can automatically calculate forces and moments and display analog voltages or currents at the analog output. Calculations for the quadratic approach are (currently) only performed in the BlueDAQ software or by the customer's data acquisition system using the provided formula set.

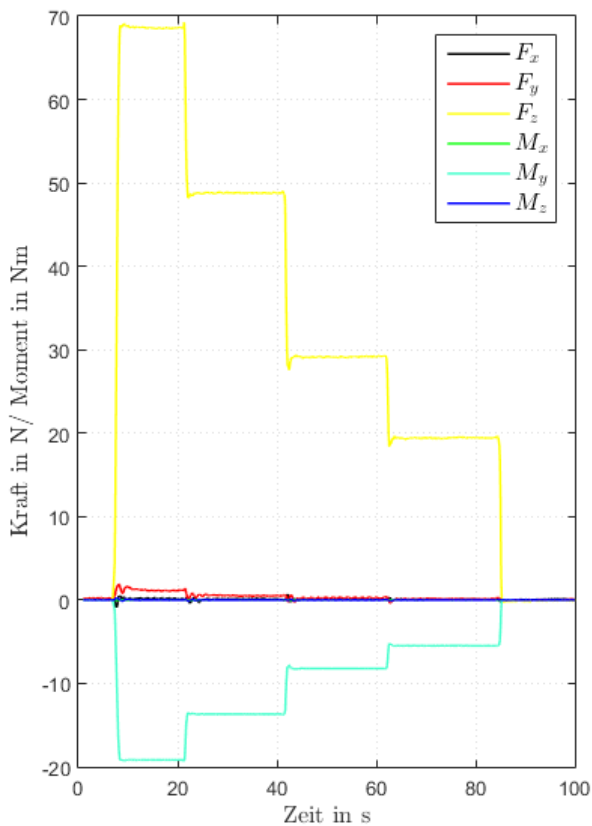


Figure 2: 6A40 200N/20Nm: Standard calibration at 100% rated load; test load -19.233Nm, +68.69N; display at 100%, 75%, 50% and 25% of the test load.

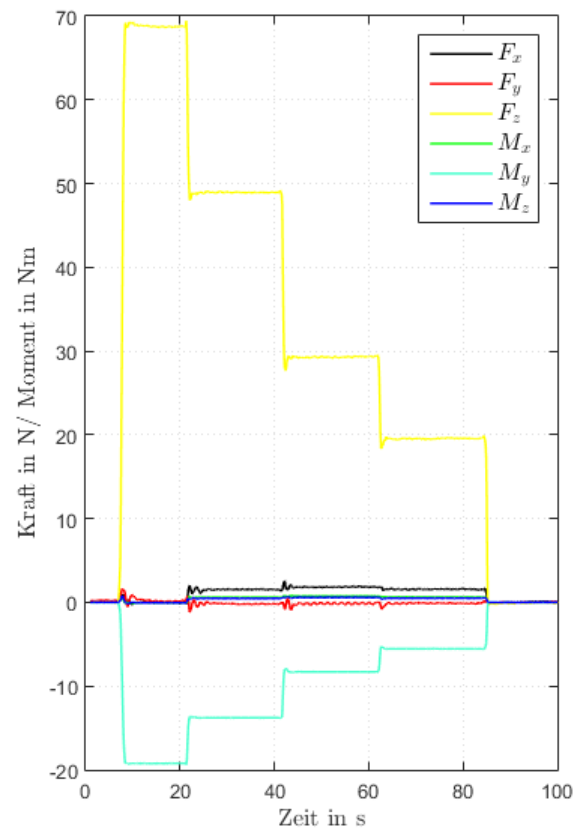


Figure 3: 6A40 200N/20Nm: Matrix Plus calibration at 100% rated load (no secondary conditions). Test load: -19.233Nm, +68.69N; readings at 100%, 75%, 50%, and 25% of the test load.

Figure 2 shows the result of the standard calibration. At 100% rated load, the measurement uncertainty due to crosstalk is up to 1% of the rated load. Crosstalk decreases with lower loads.

By applying Matrix-Plus for the nonlinear relationships, the measurement errors at 100% rated load are minimized (Figure 3).

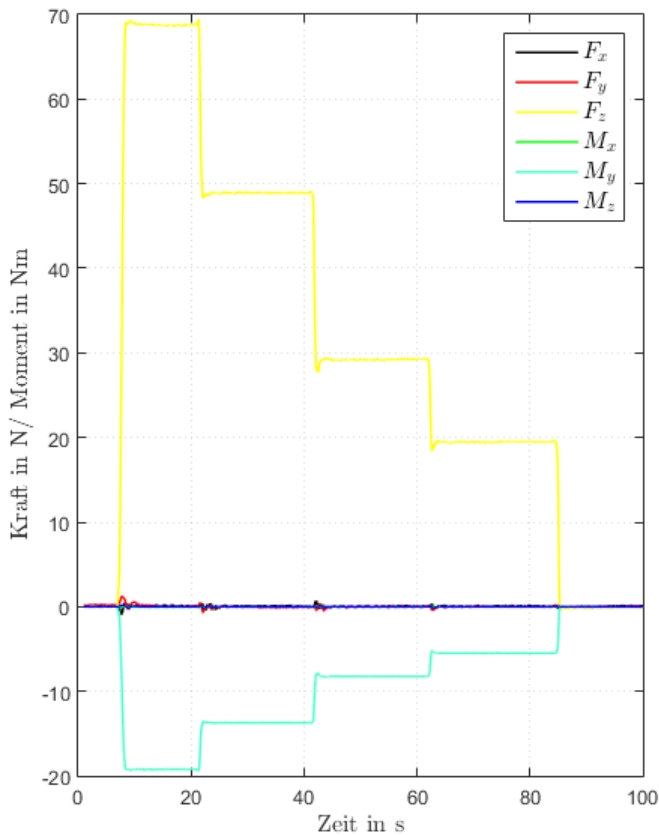


Figure 4: 6A40 200N/20Nm: Matrix Plus calibration with standard constraint at 100% rated load. Test load -19.233Nm, +68.69N; readings at 100%, 75%, 50% and 25% of the test load

Figure 4 shows the result of applying "Matrix-Plus" with standard constraints. Crosstalk is minimized at all load levels. The measurement uncertainty due to crosstalk is approximately 0.2% of the rated load at all load levels.

Figure 5 also shows the result of applying "Matrix-Plus" with standard constraints at 100% rated load (or 50% rated load for F_z). For each test load, the reading in N or Nm and the deviation from the test load in % are given. Three repeat measurements are performed for each load vector. The expanded measurement uncertainty with $k=2$ is 0.31% for the reading of the torque M_y .

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

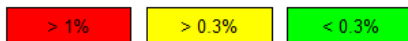


Figure 5: 6A27 50N/1Nm: Matrix Plus calibration with standard constraint at 100% rated load.