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Multicomponent Sensor K6D / F6D / K3R

Instruction manual

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Function of the K6D Multicomponent Sensors

The set of K6D Multicomponent Sensors comprises six independent force sensors equipped with strain gauges.

Using the six sensor signals, a calculation rule is applied to calculate the forces within three spatial axes and the three moments around them.

The measurement range of the multicomponent sensor is determined:

- by the measurement ranges of the six independent force sensors, and
- by the geometrical arrangement of the six force sensors or via the diameter of the sensor.

The individual signals from the six force sensors cannot be directly associated with a specific force or moment by multiplying with a scaling factor.

The calculation rule can be precisely described in mathematical terms by the cross product from the calibration matrix with the vector of the six sensor signals.

This functional approach has the following advantages:

- Particularly high rigidity,
- Particularly effective separation of the six components ("low cross-talk").

Calibration matrix

The calibration matrix $\underline{A}$ describes the connection between the indicated output signals $\underline{U}$ of the measurement amplifier on channels 1 to 6 (u1, u2, u3, u4, u5, u6) and components 1 to 6 (Fx, Fy, Fz, Mx, My, Mz) of the load vector $\underline{L}$.

Measured value: output signals u1, u2, ...u6 on channels 1 to 6	output signal $\underline{U}$
Calculated value: forces Fx, Fy, Fz; moments Mx, My, Mz	Load vector $\underline{L}$
Calculation rule: Cross product	$\underline{L} = \underline{A} \times \underline{U}$

The calibration matrix $\underline{Aij}$ includes 36 elements, arranged in 6 rows (i=1..6) and 6 columns (j=1..6).

The unit of the matrix elements is N/(mV/V) in rows 1 to 3 of the matrix.

The unit of the matrix elements is Nm/(mV/V) in rows 4 to 6 of the matrix.

The calibration matrix depends on the properties of the sensor and that of the measurement amplifier.

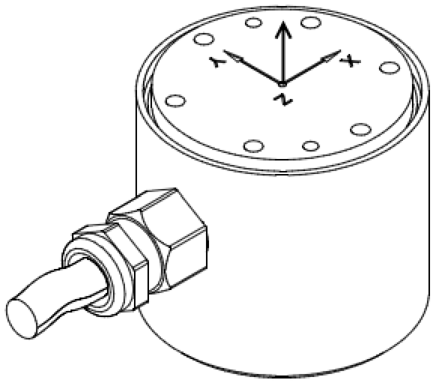
It applies for the GSV-8 measurement amplifier and for all amplifiers, which indicate bridge output signals in mV/V.

The matrix elements may be rescaled in other units by a common factor via multiplication (using a "scalar product").

The calibration matrix calculates the moments around the origin of the underlying coordinate system.

The origin of the coordinate system is located at the point where the z-axis intersects with the facing surface of the sensor.1) The origin and orientations of the axes are shown by an engraving on the facing surface of the sensor.

1) The position of the origin may vary with different K6D sensor types. The origin is documented in the calibration sheet. E.G the origin of K6D68 is in the center of the sensor.



Example of a calibration matrix (K6D, F6D)

	u1 in mV/V	u2 in mV/V	u3 in mV/V	u4 in mV/V	u5 in mV/V	u6 in mV/V
Fx in N / mV/V	-217.2	108.9	99.9	-217.8	109.2	103.3
Fy in N / mV/V	-2.0	183.5	-186.3	-3.0	185.5	-190.7
Fz in N / mV/V	-321.0	-320.0	-317.3	-321.1	-324.4	-323.9
Mx in Nm / mV/V	7.8	3.7	-3.8	-7.8	-4.1	4.1
My in Nm / mV/V	-0.4	6.6	6.6	-0.4	-7.0	-7.0
Mz in Nm / mV/V	-5.2	5.1	-5.1	5.1	-5.0	5.1

The force in the x-direction is calculated by multiplying and totalling up the matrix elements of the first row a1j with the rows of the vector of the output signals uj.

```
Fx =   -217.2 N/(mV/V) u1+ 108.9 N/(mV/V) u2 + 99.9 N/(mV/V) u3
       -217.8 N/(mV/V) u4+ 109.2 N/(mV/V) u5 +103.3 N/(mV/V) u6
```

For example: on all 6 measurement channels is u1 = u2 = u3 = u4 = u5 =u6 = 1.00mV/V displayed. Then there is a force Fx of -13.7 N.
The force in the z direction is calculated accordingly by multiplying and summing the third row of the matrix a3j with the vector of the indicated voltages uj:

```
Fz =   -321.0 N/(mV/V) u1 -320.0 N/(mV/V) u2 -317.3 N/(mV/V) u3
       -321.1 N/(mV/V) u4 -324.4 N/(mV/V) u5 -323.9 N/(mV/V) u6.
```

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Matrix Plus for K6D / F6D sensors

When using the "Matrix Plus" calibration procedure, two cross products are calculated: matrix A x U + matrix B x U *

Measured values: output signals u1, u2, ... u6 at channels 1 to 6	output signals **U**
Measured values are output signals as mixed products: u1u2, u1u3, u1u4, u1u5, u1u6, u2u3 of channels 1 to 6	output signals **U***
Calculated value: Forces Fx, Fy, Fz; Moments Mx, My, Mz	Load vector **L**.
Calculation rule: Cross product	L = A x U + B x U*

Example: example-calculation-16101424-k6d68.pdf

Example of a calibration matrix "B"

	u1·u2 in (mV/V)²	u1·u3 in (mV/V)²	u1·u4 in (mV/V)²	u1·u5 in (mV/V)²	u1·u6 in (mV/V)²	u2·u3 in (mV/V)²
Fx in N / (mV/V)²	-0.204	-0.628	0.774	-0.337	-3.520	2.345
Fy in N /(mV/V)²	-0.251	1.701	-0.107	-2.133	-1.408	1.298
Fz in N / (mV/V)²	5.049	-0.990	1.453	3.924	19.55	-18.25
Mx in Nm /(mV/V)²	-0.015	0.082	-0.055	-0.076	0.192	-0.054
My in Nm / (mV/V)²	0.050	0.016	0.223	0.036	0.023	-0.239
Mz in Nm / (mV/V)²	-0.081	-0.101	0.027	-0.097	-0.747	0.616

The force in the x-direction is calculated by multiplying and summing the matrix elements A of the first row a1j with the rows j of the vector of the output signals uj
plus matrix elements B of the first row a1j with the rows j of the vector of the mixed-quadratic output signals:

Example of Fx

```
Fx =   -217.2 N/(mV/V) u1 + 108.9 N/(mV/V) u2 + 99.9 N/(mV/V) u3
       -217.8 N/(mV/V) u4 + 109.2 N/(mV/V) u5 +103.3 N/(mV/V) u6
       -0.204 N/(mV/V)² u1u2 - 0.628 N/(mV/V)² u1u3 + 0.774 N/(mV/V)² u1u4
       -0.337 N/(mV/V)² u1u5 - 3.520 N/(mV/V)² u1u6 + 2.345 N/(mV/V)² u2u3
```

Example of Fz

```
Fz =   -321.0 N/(mV/V) u1 -320.0 N/(mV/V) u2 -317.3 N/(mV/V) u3
       -321.1 N/(mV/V) u4 -324.4 N/(mV/V) u5 -323.9 N/(mV/V) u6.
       +5.049 N/(mV/V)² u1u2 -0.990 N/(mV/V)² u1u3 +1.453 N/(mV/V)² u1u4
       +3.924 N/(mV/V)² u1u5 +19.55 N/(mV/V)² u1u6 -18.25 N/(mV/V)² u2u3
```

Attention: The composition of the mixed quadratic terms may change depending on the sensor.

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Offset of the origin

Forces which are not applied in the origin of the coordinate system are shown by an indicator in the form of Mx, My and Mz moments based on the lever arm.

Generally speaking, the forces are applied at a distance z from the facing surface of the sensor. The location of the force transmission may also be shifted in x- and z- directions as required.

If the forces are applied at distance x, y or z from the origin of the coordinate system, and the moments around the offset force transmission location need to be shown, the following corrections are required:

Corrected moments Mx1, My1, Mz1 following a shift in force transmission (x, y, z) from the origin	Mx1 = Mx + y*Fz - z*Fy My1 = My + z*Fx - x*Fz Mz1 = Mz + x*Fy - y*Fx

Note: The sensor is also exposed to the moments Mx, My and Mz, with moments Mx1, My1 and Mz1 displayed. The permissible moments Mx, My and Mz must not be exceeded.

Scaling of the calibration matrix

By referring the matrix elements to the unit mV/V, the calibration matrix can be applied to all available amplifiers.

The calibration matrix with the N/V and Nm/V matrix elements applies to the GSV-1A8USB measuring amplifier with an input sensitivity of 2 mV / V and an output signal of 5V with a 2 mV/V input signal.

Multiplication of all matrix elements by a factor of 2/5 scales the matrix from N/(mV/V) and Nm/(mV/V) for an output of 5V at an input sensitivity of 2 mV/V (GSV-1A8USB).

By multiplying all matrix elements by a factor of 3.5/10, the Matrix is scaled from N/(mV/V) and Nm/(mV/V) for an output signal of 10V at an input sensitivity of 3.5 mV/V (eg GSV-8DS)

The unit of the factor is (mV/V)/V
The unit of the elements of the load vector (u1, u2, u3, u4, u5, u6) are voltages in V

Example of Fx

Analog output with GSV-8DS, input sensitivity 3.5 mV / V, output signal 10V:

```
Fx =  3.5/10 (mV/V)/V
      (-217.2 N/(mV/V) u1 + 108.9 N/(mV/V) u2 + 99.9 N/(mV/V) u3
       -217.8 N/(mV/V) u4 + 109.2 N/(mV/V) u5 +103.3 N/(mV/V) u6
      ) +
      (3.5/10)² ( (mV/V)/V )²
      (-0.204 N/(mV/V)² u1u2 - 0.628 N/(mV/V)² u1u3 + 0.774 N/(mV/V)² u1u4
       -0.337 N/(mV/V)² u1u5 - 3.520 N/(mV/V)² u1u6 + 2.345 N/(mV/V)² u2u3
      )
```

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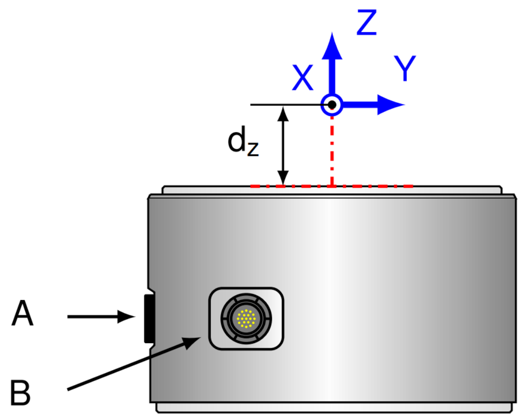
Matrix 6x12 for K6D sensors

With the sensors K6D150, K6D175, K6D225, K6D300 it is possible to use a 6x12 matrix instead of a 6x6 matrix for error compensation.

The 6x12 matrix offers the highest accuracy and the lowest crosstalk, and is recommended for sensors from 50kN force.

In this case, the sensors have a total of 12 measuring channels and two connectors. Each connector contains an electrically independent force-torque sensor with 6 sensor signals. Each of these connectors is connected to its own measuring amplifier GSV-8DS.

Instead of using a 6x12 matrix, the sensor can also be used exclusively with connector A, or exclusively with connector B, or with both connectors for redundant measurement. In this case, a 6x6 matrix is supplied for connector A and for connector B. The 6x6 matrix is supplied as a standard.



The synchronization of the measured data can be e.g. with the help of a synchronization cable. For amplifiers with EtherCat interface a synchronization via the BUS lines is possible.

The forces Fx, Fy, Fz and moments Mx, My, Mz are calculated in the software GSVmulti. There the 12 input channels u1...u12 are multiplied by the 6x12 matrix A to get 6 output channels of the load vector L.

The channels of connector "A" are assigned to channels 1...6 in the GSVmulti software..

The channels of connector "B" are assigned to channels 7...12 in the GSVmulti software.

After loading and activating the matrix 6x12 in the GSVmulti software, the forces and moments are displayed on channels 1 to 6.

Channels 7...12 contain the raw data of connector B and are not relevant for further evaluation. These channels (with the designation "dummy7") to "dummy12") can be hidden from the display and the recording via the function "Channel"--> "Hide".

When using the 6x12 matrix, the forces and moments are calculated exclusively by software, since it is composed of data from two separate measuring amplifiers.

Tip: When using the GSVmulti software, the configuration and linking to the 6x12 matrix can be done by "Save Session". and "Open Session" is pressed. so that the sensor and channel configuration only has to be carried out once.

Stiffness Matrix

The stiffness matrix is defined by:

$$\underline{f} = \underline{S} * \underline{u}$$

With the load vector f: $\underline{f} = \begin{bmatrix} F_x \\ F_y \\ F_z \\ M_x \\ M_y \\ M_z \end{bmatrix}$, the shifts vector u: $\underline{u} = \begin{bmatrix} u_x \\ u_y \\ u_z \\ \varphi_x \\ \varphi_y \\ \varphi_z \end{bmatrix}$

and with the stiffness matrix S: $\underline{S} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} & c_{15} & c_{16} \\ c_{21} & c_{22} & c_{23} & c_{24} & c_{25} & c_{26} \\ c_{31} & c_{32} & c_{33} & c_{34} & c_{35} & c_{36} \\ c_{41} & c_{42} & c_{43} & c_{44} & c_{45} & c_{46} \\ c_{51} & c_{52} & c_{53} & c_{54} & c_{55} & c_{56} \\ c_{61} & c_{62} & c_{63} & c_{64} & c_{65} & c_{66} \end{bmatrix}$

The forces F_i have the unit N or kN
The moments M_i have the unit kNm, or Nm or Nmm
The shifts u_i have the unit m or mm
The angle φ_i are expressed in radians

The stiffness matrix is symmetric: $c_{ij} = c_{ji}$

Example of a stiffness matrix

K6D130 5kN/500Nm

93,8 kN/mm	0,0	0,0	0,0	3750 kN	0,0
0,0	93,8 kN/mm	0,0	-3750 kN	0,0	0,0
0,0	0,0	387,9 kN/mm	0,0	0,0	0,0
0,0	-3750 kN	0,0	505,2 kNm	0,0	0,0
3750 kN	0,0	0,0	0,0	505,2 kNm	0,0
0,0	0,0	0,0	0,0	0,0	343,4 kNm

When loaded with 5kN in x-direction, a shift of 5 / 93.8 mm = 0.053 mm in the x direction, and a twist of 5 kN / 3750 kN = 0.00133 rad results in the y-direction

When loaded with 15kN in z-direction, a shift of 15 / 387.9 mm = 0.039 mm in the z direction (and no twist).

When Mx 500 Nm a twisting of 0,5kNm / 505,2kNm = 0.00099 rad results in the x-axis, and a shift from 0,5kNm / -3750 kN = -0,000133m = -0,133mm.

When loaded with Mz 500Nm a twisting results of 0,5kNm / 343.4 kNm = 0.00146 rad about the z-axis (and no shift).

Calibration Matrix for K3R Sensors

The sensors of the type K3R allow the measurement of the force Fz and the moments Mx and My.

The sensors K3R may be used for displaying 3 orthogonal forces Fx, Fy, and Fz, when the measured torques are divided by the lever arm z (distance of force application Fx, Fy of the origin of the coordinate system).

	ch1	ch2	ch3	ch4
Fz in N / mV/V	100,00	100,00	100,00	100,00
Mx in Nm / mV/V	0,00	-1,30	0,00	1,30
My in Nm / mV/V	1,30	0,00	-1,30	0,00
H	0,00	0,00	0,00	0,00

The force in the z direction is calculated by multiplying and summing the matrix elements of the first row A1J with the lines of the vector of the output signals uj

Fz = 100 N/mV/V u1 + 100 N/mV/V u2 + 100 N/mV/V u3 + 100 N/mV/V u4

Example: on all 6 measurement channels is u1 = u2 = u3 = u4 = 1.00 mV/V displayed. Then a force Fz results of 400 N.

The calibration matrix A of K3R sensor has the dimensions 4 x. 4
The vector u of the output signals of the measuring amplifier has the dimensions 4 x. 1
The result vector (Fz, Mx, My, H) has the dimension of 4 x. 1
At the outputs of ch1, ch2 and ch3 after applying the calibration matrix, the force Fz and the moments Mx and My are displayed. On the Channel 4 output H is constantly displayed 0V by the fourth line.

Commissioning of the sensor

The “GSVmulti” software is used to show the measured forces and moments. The GSVmulti software and related manuals can be downloaded from the website.

Schritt	Beschreibung
1	Installation of the GSVmulti software
2	Connect the measuring amplifier GSV-8 via USB port; Connect the sensor K6D to the measuring amplifier. Switch on the measuring amplifier.
3	Copy directory with calibration matrix (supplied USB stick) to suitable drive and path.
4	Start GSVmulti software
5	Main window: Button AddChannel;

Schritt	Beschreibung
	Select device type: GSV-8 Select interface: for example COM3 Select channel 1 to 6 to open Button Connect
6	main window: Button Spezial Sensor Select six axis sensor
7	Window "Six-axis sensor settings: Button Add Sensor
8	a) Button Change Dir Select the directory with the files Serial number.dat and Serial number.matrix. b) Button Select Sensor and select Seial number c) Button Auto Rename Channels d) if necessary. Select the displacement of the force application point. e) Button OK Enable this Sensor
9	Select Recorder Yt" window, start measurement;

Commissioning of the 6x12 sensor

When commissioning the 6x12 sensor, channels 1 to 6 of the measuring amplifier at connector "A" must be assigned to components 1 to 6.

Channels 7...12 of the measuring amplifier at connector "B" are assigned to components 7 to 12.

When using the synchronization cable, the 25-pin SUB-D female connectors (male) on the back of the amplifier are connected to the synchronization cable.

The synchronization cable connects the ports no. 16 of the measuring amplifiers A and B with each other.

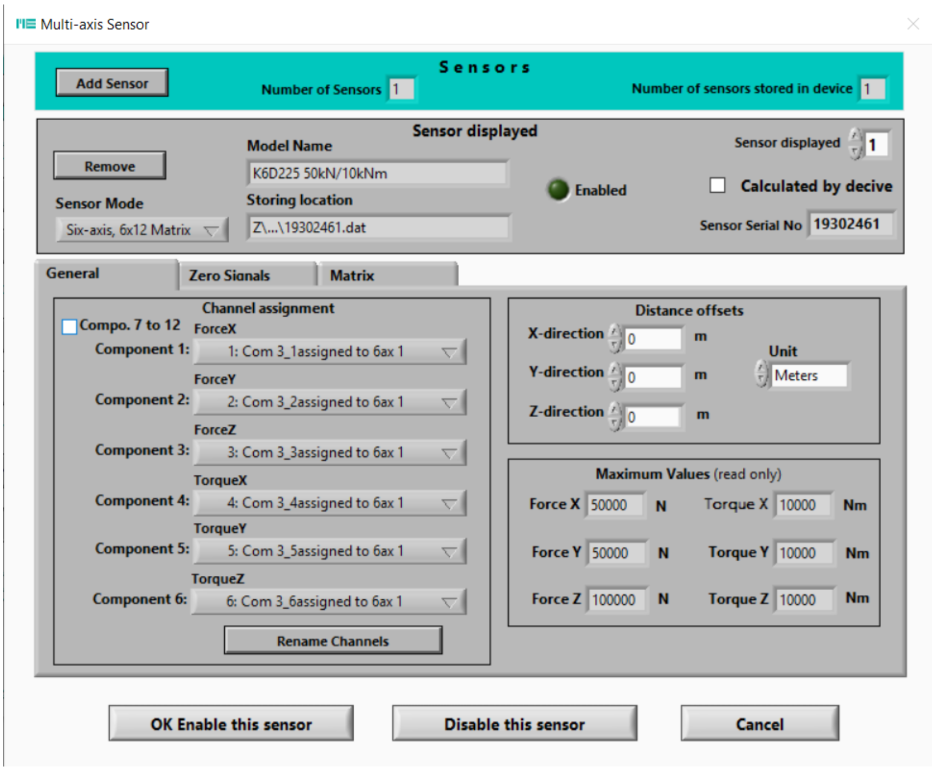
For amplifier A port 16 is configured as output for the function as master, for amplifier B port 16 is configured as input for the function as slave.

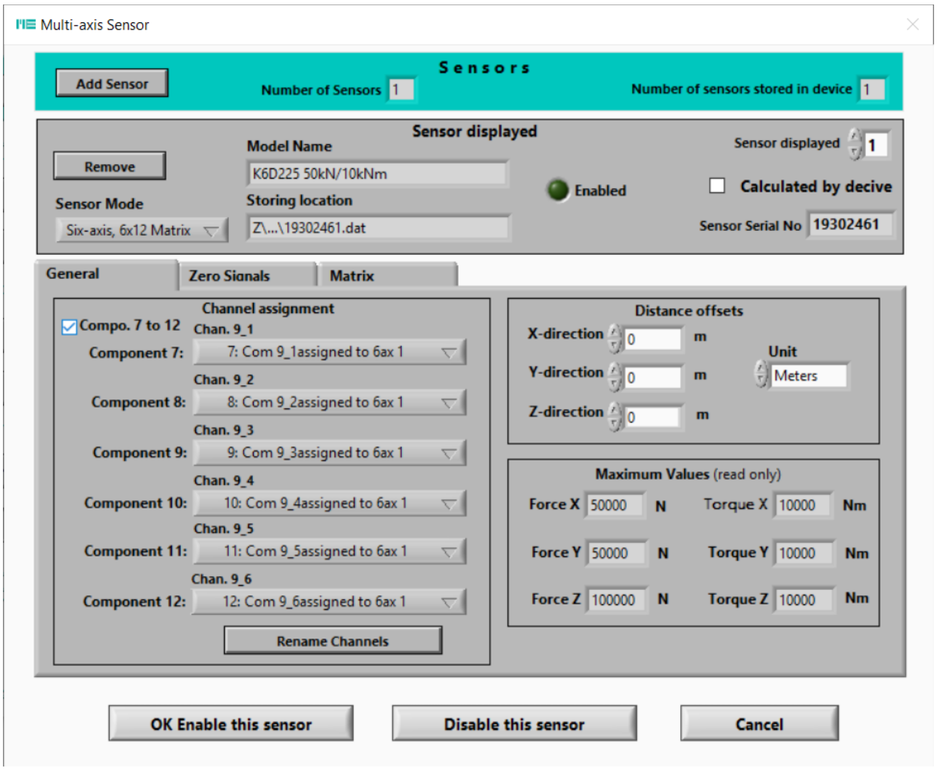
The settings can be found under "Device" →Advanced Setting" →Dig-IO.

Hint: The configuration of the data frequency must be done at the "Master" as well as at the "Slave". The measuring frequency of the master should never be higher than the measuring frequency of the slave.

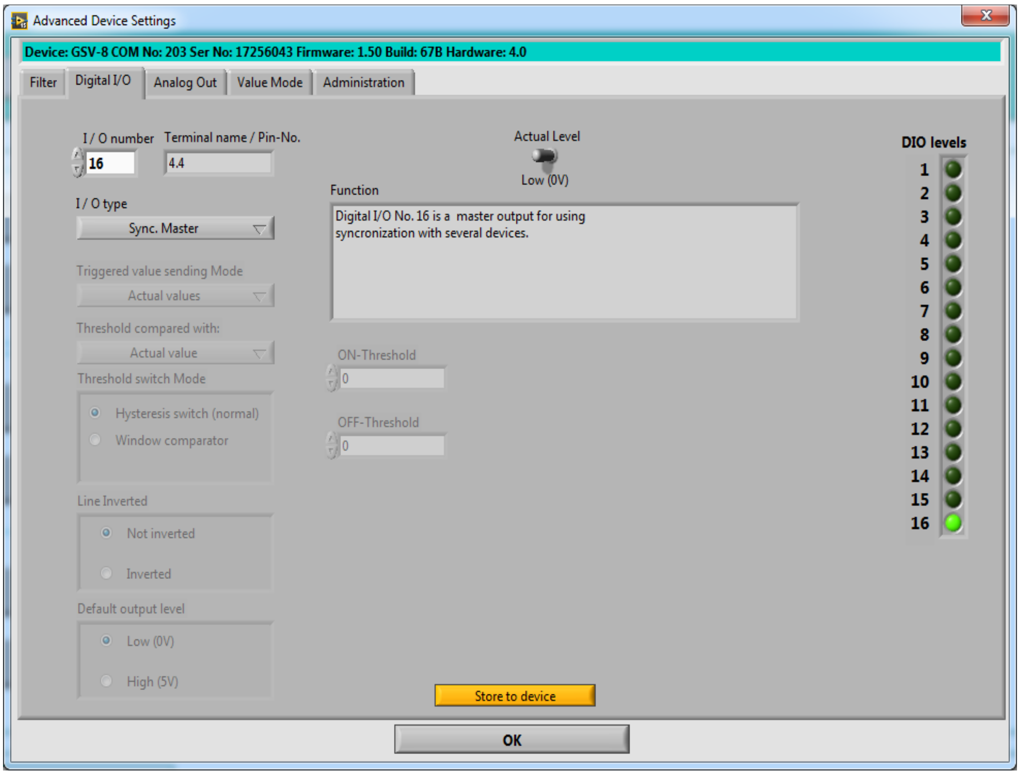
Screenshots

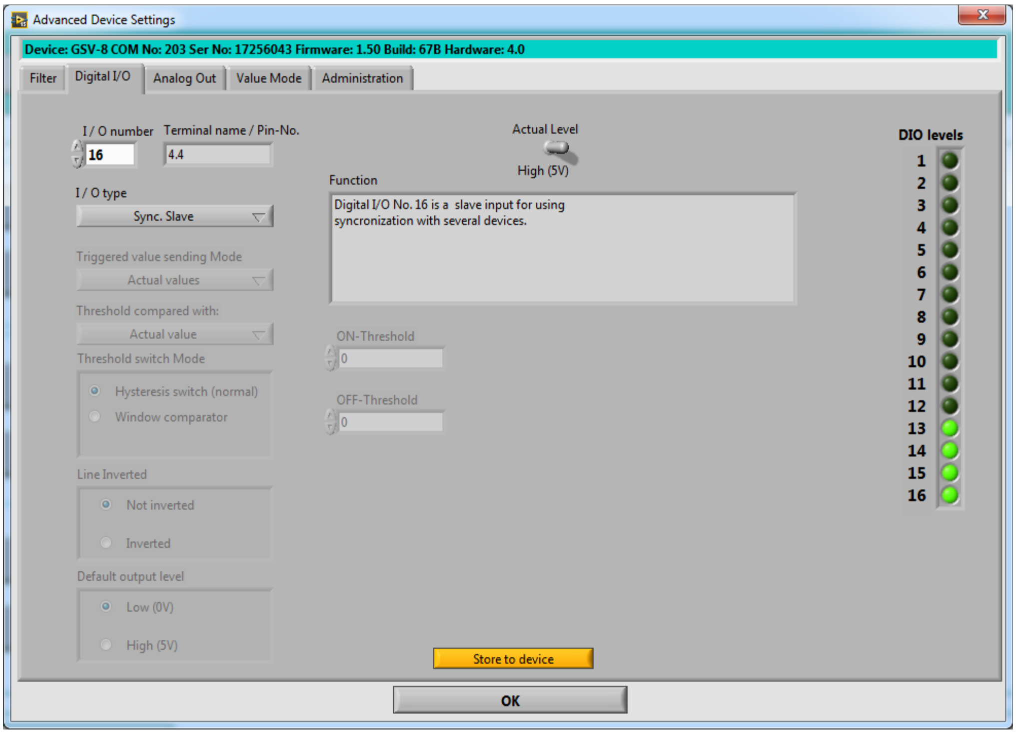
Adding a force / moment sensor





Configuration as Master / Slave





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Changelog

Version	Datum	Änderungen
ba-k6d-v1.0.odt	17.08.16	first Version
ba-k6d-v1.1.odt	15.11.17	including Matrix Plus; Scaling Elements from (mV/V) to V;
Ba-k6d-v1.2odt	11.09.19	Incl. Section Matrix 6x12; Sync Cable
ba-k6d-v1.3.odt	07.10.19	Sync cable: DIO connection designation, Save Session Tip, DIO Screenshots etc.