

Multi-Axis Sensor 6A / 6ADF / 5AR
Instruction Manual

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Function of the 6A Multi-Axis Sensors

The set of 6A Multi-Axis 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 Multi-Axis 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 ($u_1, u_2, u_3, u_4, u_5, u_6$) and components 1 to 6 ($F_x, F_y, F_z, M_x, M_y, M_z$) of the load vector $\underline{L}$.

Measured value: output signals $u_1, u_2, \dots, u_6$ on channels 1 to 6	output signal $\underline{U}$
Calculated value: forces F_x, F_y, F_z ; moments M_x, M_y, M_z	Load vector $\underline{L}$
Calculation rule: Cross product	$\underline{L} = \underline{A} \times \underline{U}$

The calibration matrix $\underline{A}_{ij}$ 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.

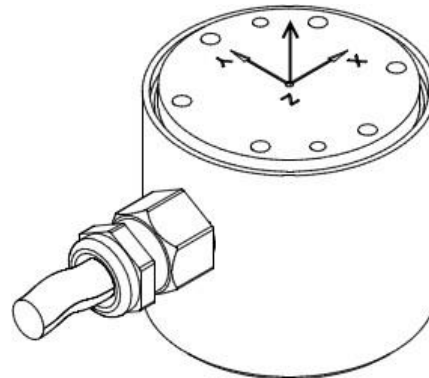
It applies for the BX8 measurement amplifier and for all amplifiers, which indicate bridge output signals in mV/V.

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 6A sensor types. The origin is documented in the calibration sheet. E.G the origin of 6A68 is in the center of the sensor.



Example of a calibration matrix (6A, 6ADF)

	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 a_{1j} with the rows of the vector of the output signals u_j.

$$F_x = -217.2 \text{ N/(mV/V)} u_1 + 108.9 \text{ N/(mV/V)} u_2 + 99.9 \text{ N/(mV/V)} u_3 \\ -217.8 \text{ N/(mV/V)} u_4 + 109.2 \text{ N/(mV/V)} u_5 + 103.3 \text{ N/(mV/V)} u_6$$

For example: on all 6 measurement channels is $u_1 = u_2 = u_3 = u_4 = u_5 = u_6 = 1.00 \text{ mV/V}$ displayed. Then there is a force F_x of -13.7 N.

The force in the z direction is calculated accordingly by multiplying and summing the third row of the matrix a_{3j} with the vector of the indicated voltages u_j:

$$F_z = -321.0 \text{ N/(mV/V)} u_1 - 320.0 \text{ N/(mV/V)} u_2 - 317.3 \text{ N/(mV/V)} u_3 \\ - 321.1 \text{ N/(mV/V)} u_4 - 324.4 \text{ N/(mV/V)} u_5 - 323.9 \text{ N/(mV/V)} u_6$$

Matrix Plus for 6A / 6ADF sensors

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

Measured values: output signals $u_1, u_2, \dots u_6$ at channels 1 to 6	output signals $\underline{U}$
Measured values are output signals as mixed products: $u_1u_2, u_1u_3, u_1u_4, u_1u_5, u_1u_6, u_2u_3$ of channels 1 to 6	output signals $\underline{U}^*$
Calculated value: Forces F_x, F_y, F_z ; Moments M_x, M_y, M_z	Load vector $\underline{L}$.
Calculation rule: Cross product	$\underline{L} = \underline{A} \times \underline{U} + \underline{B} \times \underline{U}^*$

Example of a calibration matrix "B"

	$u_1 \cdot u_2$ in (mV/V) ²	$u_1 \cdot u_3$ in (mV/V) ²	$u_1 \cdot u_4$ in (mV/V) ²	$u_1 \cdot u_5$ in (mV/V) ²	$u_1 \cdot u_6$ in (mV/V) ²	$u_2 \cdot u_3$ in (mV/V) ²
F_x in N / (mV/V) ²	-0.204	-0.628	0.774	-0.337	-3.520	2.345
F_y in N / (mV/V) ²	-0.251	1.701	-0.107	-2.133	-1.408	1.298
F_z in N / (mV/V) ²	5.049	-0.990	1.453	3.924	19.55	-18.25
M_x in Nm / (mV/V) ²	-0.015	0.082	-0.055	-0.076	0.192	-0.054
M_y in Nm / (mV/V) ²	0.050	0.016	0.223	0.036	0.023	-0.239
M_z 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 a_{1j} with the rows j of the vector of the output signals u_j plus matrix elements B of the first row a_{1j} with the rows j of the vector of the mixed-quadratic output signals:

Example of F_x

$$F_x = -217.2 \text{ N/(mV/V)} u_1 + 108.9 \text{ N/(mV/V)} u_2 + 99.9 \text{ N/(mV/V)} u_3 \\ -217.8 \text{ N/(mV/V)} u_4 + 109.2 \text{ N/(mV/V)} u_5 + 103.3 \text{ N/(mV/V)} u_6 \\ -0.204 \text{ N/(mV/V)}^2 u_1u_2 - 0.628 \text{ N/(mV/V)}^2 u_1u_3 + 0.774 \text{ N/(mV/V)}^2 u_1u_4 \\ -0.337 \text{ N/(mV/V)}^2 u_1u_5 - 3.520 \text{ N/(mV/V)}^2 u_1u_6 + 2.345 \text{ N/(mV/V)}^2 u_2u_3$$

Example of F_z

$$F_z = -321.0 \text{ N/(mV/V)} u_1 - 320.0 \text{ N/(mV/V)} u_2 - 317.3 \text{ N/(mV/V)} u_3 \\ -321.1 \text{ N/(mV/V)} u_4 - 324.4 \text{ N/(mV/V)} u_5 - 323.9 \text{ N/(mV/V)} u_6 \\ + 5.049 \text{ N/(mV/V)}^2 u_1u_2 - 0.990 \text{ N/(mV/V)}^2 u_1u_3 + 1.453 \text{ N/(mV/V)}^2 u_1u_4 \\ + 3.924 \text{ N/(mV/V)}^2 u_1u_5 + 19.55 \text{ N/(mV/V)}^2 u_1u_6 - 18.25 \text{ N/(mV/V)}^2 u_2u_3$$

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

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 M_x , M_y and M_z 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 M_{x1} , M_{y1} , M_{z1} following a shift in force transmission (x , y , z) from the origin	$M_{x1} = M_x + y \cdot F_z - z \cdot F_y$ $M_{y1} = M_y + z \cdot F_x - x \cdot F_z$ $M_{z1} = M_z + x \cdot F_y - y \cdot F_x$
--	--

Note: The sensor is also exposed to the moments M_x , M_y and M_z , with moments M_{x1} , M_{y1} and M_{z1} displayed. The permissible moments M_x , M_y and M_z 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 BSC8 measuring amplifier with an input sensitivity of $2 mV/V$ and an output signal of $5V$ with a $2mV/V$ 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 $2 mV/V$ (BSC8).

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 $3.5 mV/V$ (BX8)

The unit of the factor is $(mV/V)/V$

The unit of the elements of the load vector ($u_1, u_2, u_3, u_4, u_5, u_6$) are voltages in V

Example of F_x

Analog output with BX8, input sensitivity $3.5 mV/V$, output signal $10V$:

$$\begin{aligned}
 F_x = & 3.5/10 \text{ (mV/V) / V} \\
 & (-217.2 \text{ N/(mV/V)} \cdot u_1 + 108.9 \text{ N/(mV/V)} \cdot u_2 + 99.9 \text{ N/(mV/V)} \cdot u_3 \\
 & -217.8 \text{ N/(mV/V)} \cdot u_4 + 109.2 \text{ N/(mV/V)} \cdot u_5 + 103.3 \text{ N/(mV/V)} \cdot u_6 \\
 &) + \\
 & (3.5/10)^2 \cdot (\text{(mV/V) / V})^2 \\
 & (-0.204 \text{ N/(mV/V)}^2 \cdot u_1 u_2 - 0.628 \text{ N/(mV/V)}^2 \cdot u_1 u_3 + 0.774 \text{ N/(mV/V)}^2 \cdot u_1 u_4 \\
 & -0.337 \text{ N/(mV/V)}^2 \cdot u_1 u_5 - 3.520 \text{ N/(mV/V)}^2 \cdot u_1 u_6 + 2.345 \text{ N/(mV/V)}^2 \cdot u_2 u_3 \\
 &)
 \end{aligned}$$

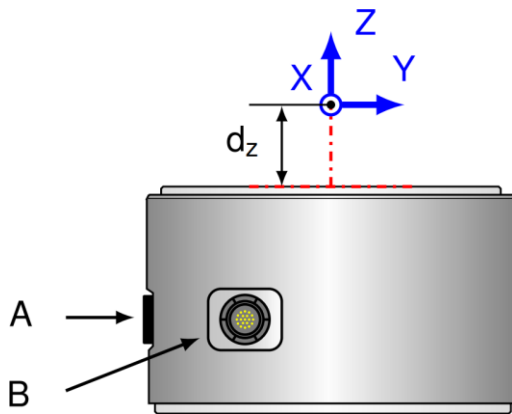
Matrix 6x12 for 6A sensors

With the sensors 6A150, 6A175, 6A225, 6A300 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 BX8.

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 F_x , F_y , F_z and moments M_x , M_y , M_z are calculated in the software BlueDAQ. There the 12 input channels $u_1 \dots u_{12}$ 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 BlueDAQ software.. The channels of connector "B" are assigned to channels 7...12 in the BlueDAQ software.

After loading and activating the matrix 6x12 in the BlueDAQ 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 BlueDAQ 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 $\underline{f} = \begin{bmatrix} F_x \\ F_y \\ F_z \\ M_x \\ M_y \\ M_z \end{bmatrix}$, the shifts vector $\underline{u} = \begin{bmatrix} u_x \\ u_y \\ u_z \\ \varphi_x \\ \varphi_y \\ \varphi_z \end{bmatrix}$

$$= \begin{bmatrix} c_{31} & c_{32} & c_{33} & c_{34} & c_{35} & c_{36} \\ c_{41} & c_{42} & c_{43} & c_{44} & c_{45} & c_{46} \\ c_{51} & c_{52} & c_{53} & c_{54} & c_{55} & c_{56} \\ c_{61} & c_{62} & c_{63} & c_{64} & c_{65} & c_{66} \end{bmatrix}$$

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

6A130 5kN/500Nm

Fx	Fy	Fz	Mx	My	Mz
0,0	0,0	0,0	0,0	0,0	343,4 kNm

When loaded with 5kN in x-direction, a shift of $5 / 93.8 \text{ mm} = 0.053 \text{ mm}$ in the x direction, and a twist of $5 \text{ kN} / 3750 \text{ kN} = 0.00133 \text{ rad}$ results about the y-axis.

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

With $M_x = 500 \text{ Nm}$ a twisting of $0,5 \text{ kNm} / 505,2 \text{ kNm} = 0.00099 \text{ rad}$ results about the x-axis, and a shift from $0,5 \text{ kNm} / -3750 \text{ kN} = -0,000133 \text{ m} = -0,133 \text{ mm}$ in the y-axis.

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

Calibration Matrix for 5AR Sensors

The sensors of the type 5AR allow the measurement of the force F_z and the moments M_x and M_y .

The sensors 5AR may be used for displaying 3 orthogonal forces F_x , F_y , and F_z , when the measured torques are divided by the lever arm z (distance of force application F_x , F_y of the origin of the coordinate system).

	ch1	ch2	ch3	ch4
F_z in N / mV/V	100,00	100,00	100,00	100,00
M_x in Nm / mV/V	0,00	-1,30	0,00	1,30
M_y 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 u_j

$$F_z = 100 \text{ N/mV/V } u_1 + 100 \text{ N/mV/V } u_2 + 100 \text{ N/mV/V } u_3 + 100 \text{ N/mV/V } u_4$$

Example: on all 6 measurement channels is $u_1 = u_2 = u_3 = u_4 = 1.00 \text{ mV/V}$ displayed. Then a force F_z results of 400 N.

The calibration matrix A of 5AR sensor has the dimensions 4×4

The vector u of the output signals of the measuring amplifier has the dimensions 4×1 . The result vector (F_z , M_x , M_y , H) has the dimension of 4×1 .

At the outputs of ch1, ch2 and ch3 after applying the calibration matrix, the force F_z and the moments M_x and M_y are displayed. On the Channel 4 output H is constantly displayed 0V by the fourth line.

Commissioning of the sensor

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

Step	Description
1	Installation of the BlueDAQ software
2	Connect the measuring amplifier BX8 via USB port; Connect the sensor 6A 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 BlueDAQ software
5	Main window: Button AddChannel;

Step	Description
	Select device type: BX8 Select interface: for example COM3 Select channel 1 to 6 to open Button Connect
6	main window: Button Special 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 Serialnumber.matrix. b) Button Select Sensor and select Serial 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

interface Multi-axis Sensor

Sensors

Add Sensor Number of Sensors 1 Number of sensors stored in device 1

Remove Model Name K6D225 50kN/10kNm Sensor displayed 1

Sensor Mode Storing location Z:\...\19302461.dat Enabled Calculated by decive Sensor Serial No 19302461

Six-axis, 6x12 Matrix

General Zero Signals Matrix

Channel assignment

☐ Compo. 7 to 12

ForceX

Component 1: 1: Com 3_1 assigned to 6ax 1

ForceY

Component 2: 2: Com 3_2 assigned to 6ax 1

ForceZ

Component 3: 3: Com 3_3 assigned to 6ax 1

TorqueX

Component 4: 4: Com 3_4 assigned to 6ax 1

TorqueY

Component 5: 5: Com 3_5 assigned to 6ax 1

TorqueZ

Component 6: 6: Com 3_6 assigned to 6ax 1

Rename Channels

Distance offsets

X-direction 0 m

Y-direction 0 m

Z-direction 0 m

Unit Meters

Maximum Values (read only)

Force X 50000 N Torque X 10000 Nm

Force Y 50000 N Torque Y 10000 Nm

Force Z 100000 N Torque Z 10000 Nm

OK Enable this sensor Disable this sensor Cancel

interface Multi-axis Sensor

Sensors

Add Sensor Number of Sensors 1 Number of sensors stored in device 1

Remove Model Name K6D225 50kN/10kNm Sensor displayed 1

Sensor Mode Storing location Z:\...\19302461.dat Enabled Calculated by decive Sensor Serial No 19302461

Six-axis, 6x12 Matrix

General Zero Signals Matrix

Channel assignment

☒ Compo. 7 to 12

Chan. 9_1

Component 7: 7: Com 9_1 assigned to 6ax 1

Chan. 9_2

Component 8: 8: Com 9_2 assigned to 6ax 1

Chan. 9_3

Component 9: 9: Com 9_3 assigned to 6ax 1

Chan. 9_4

Component 10: 10: Com 9_4 assigned to 6ax 1

Chan. 9_5

Component 11: 11: Com 9_5 assigned to 6ax 1

Chan. 9_6

Component 12: 12: Com 9_6 assigned to 6ax 1

Rename Channels

Distance offsets

X-direction 0 m

Y-direction 0 m

Z-direction 0 m

Unit Meters

Maximum Values (read only)

Force X 50000 N Torque X 10000 Nm

Force Y 50000 N Torque Y 10000 Nm

Force Z 100000 N Torque Z 10000 Nm

OK Enable this sensor Disable this sensor Cancel

Configuration as Master / Slave

Advanced Device Settings

Device: GSV-6 to BX8 COM No. 203 Ser No. 17255043 Firmware: 1.50 Build: 678 Hardware: 4.0

Filter Digital I/O Analog Out Value Mode Administration

I/O number: 16 Terminal name / Pin-No.: 4.4 Actual Level: Low (0V)

I/O type: Sync. Master

Triggered value sending Mode: Actual values

Threshold compared with: Actual value

Threshold switch Mode: Hysteresis switch (normal)

Line Inverted: Not inverted

Default output level: Low (0V)

Function: Digital I/O No. 16 is a master output for using synchronization with several devices.

ON-Threshold: 0 OFF-Threshold: 0

DIO levels: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

Store to device

OK

Advanced Device Settings

Device: GSV-6 to BX8 COM No. 203 Ser No. 17255043 Firmware: 1.50 Build: 678 Hardware: 4.0

Filter Digital I/O Analog Out Value Mode Administration

I/O number: 16 Terminal name / Pin-No.: 4.4 Actual Level: High (5V)

I/O type: Sync. Slave

Triggered value sending Mode: Actual values

Threshold compared with: Actual value

Threshold switch Mode: Hysteresis switch (normal)

Line Inverted: Not inverted

Default output level: High (5V)

Function: Digital I/O No. 16 is a slave input for using synchronization with several devices.

ON-Threshold: 0 OFF-Threshold: 0

DIO levels: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

Store to device

OK