TECH NOTE #TN121: Complete measuring chain comprising an MCS10 multi-component sensor (force, torque), QuantumX®, and catman® software from HBK

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Introduction

Although multi-component sensors were uncommon years ago, the use of such sensors has become increasingly important. Multi-component sensors are used in many applications. Here are just a few examples:

- Functional testing of components and systems (for example, automotive: trailer, aerospace: fuselage tests)
- Monitoring of production and assembly processes (for example, aircraft assembly)
- Robotics (for example, manufacturing, positioning, grinding, polishing, etc.)
- Fatigue strength testing (for example, seats, hinges, etc.)
- Tyre testing in development and production
- Structural testing of structural components and additions to buildings (for example, solar systems, roof superstructures, etc.)
- Experimental multi-axial load determination as input for FEM analysis of virtual models

HBK has built up extensive knowledge regarding the construction, development, production and use of highly accurate multi-component sensors due to numerous projects implemented over the past few years. The MCS10 has been in series production for several years now and is available in many variants.

Requirements going beyond the existing product series can be designed and manufactured to meet customer requirements.

This document focuses primarily on the integration of the MCS10 into HBK hardware and/or software.

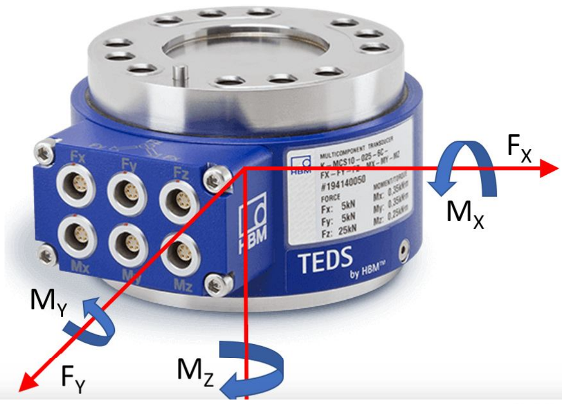
The MCS10 multi-component sensor from HBK

Up to six forces and torques on three axes (x, y, z) can be measured in combination with the MCS10 multi-axis sensor. This means that the MCS10 is ideally suited for use in mechanical engineering, test benches, and in research and development. It returns a three-dimensional image of the measurement setup with maximum precision, up to accuracy class 0.1. Thanks to its innovative construction with flange, the MCS10 achieves optimal measurement properties.

When common, multi-component transducers are used, the individual signal channels often affect each other. This type of interference, referred to as crosstalk, is reduced to a minimum by the MCS10 to ensure a problem-free signal. HBK also offers an individual compensation matrix for the MCS10, which can be used to further improve precision in combination with an HBK measuring amplifier.

- Accuracy class: Up to 0.1
- Degree of protection (according to EN 60529): Up to IP67
- Measuring range: Axial from 5 to 200 kN, transverse from 0.05 to 3.5 kNm

Crosstalk



If a single load is applied, for example, the axial force F_z, the other measuring bridges will output a very small signal due to their operating principle. This unwanted signal is called ‘crosstalk’.

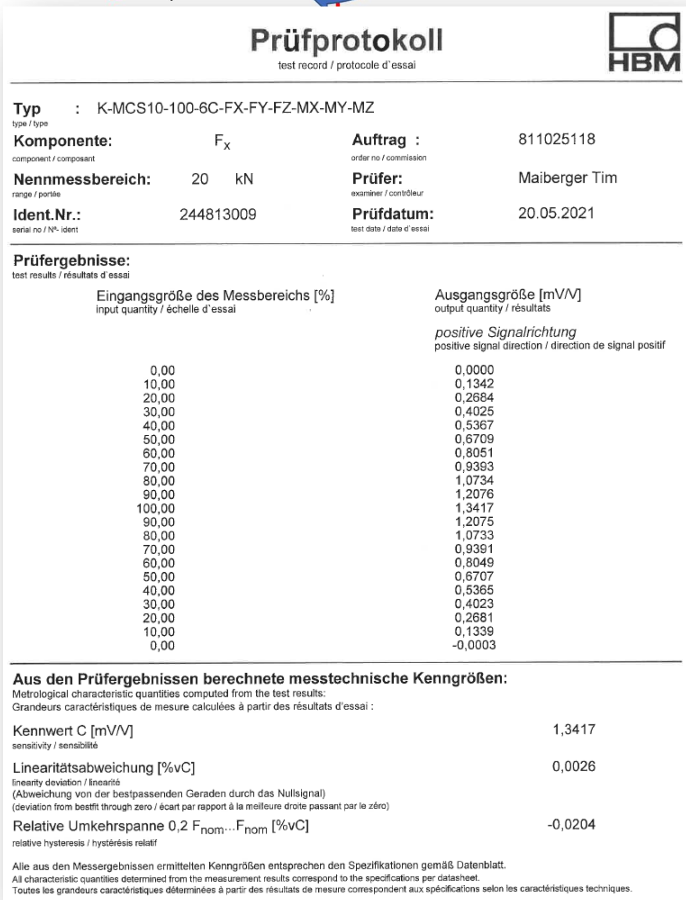
The individual crosstalk of each of these sensors is determined as a result of several calibrations. These calibrations provide a crosstalk matrix.

Based on this crosstalk matrix, HBK calculates a compensation matrix that enables the crosstalk to be corrected and thus reduced by a factor of 3 to 5.

The MCS10 test record

The test record of the MCS10 contains the test results of the individual forces and torques’ linearity test results as well as the compensation matrix and the crosstalk matrix.

All this is explained in more detail below together with an explanation of the use of the data from the test record.



Prüfprotokoll
test record / protocole d`essai

HBM

Typ : K-MCS10-100-6C-FX-FY-FZ-MX-MY-MZ
type / type

Komponente: F_X — **Auftrag** : 811025118
component / composant — order no / commission

Nennmessbereich: 20 kN — **Prüfer:** Maiberger Tim
range / portée — examiner / contrôleur

Ident.Nr.: 244813009 — **Prüfdatum:** 20.05.2021
serial no / Nº- ident — test date / date d`essai

Prüfergebnisse:
test results / résultats d`essai

Eingangsgröße des Messbereichs [%] input quantity / échelle d`essai	Ausgangsgröße [mV/V] output quantity / résultats *positive Signalrichtung* positive signal direction / direction de signal positif
0,00	0,0000
10,00	0,1342
20,00	0,2684
30,00	0,4025
40,00	0,5367
50,00	0,6709
60,00	0,8051
70,00	0,9393
80,00	1,0734
90,00	1,2076
100,00	1,3417
90,00	1,2075
80,00	1,0733
70,00	0,9391
60,00	0,8049
50,00	0,6707
40,00	0,5365
30,00	0,4023
20,00	0,2681
10,00	0,1339
0,00	-0,0003

Aus den Prüfergebnissen berechnete messtechnische Kenngrößen:
Metrological characteristic quantities computed from the test results:
Grandeurs caractéristiques de mesure calculées à partir des résultats d'essai :

Kennwert C [mV/V] — 1,3417
sensitivity / sensibilité

Linearitätsabweichung [%vC] — 0,0026
linearity deviation / linearité
(Abweichung von der bestpassenden Geraden durch das Nullsignal)
(deviation from bestfit through zero / écart par rapport à la meilleure droite passant par le zéro)

Relative Umkehrspanne 0,2 F_{nom}...F_{nom} [%vC] — -0,0204
relative hysteresis / hystérésis relatif

Alle aus den Messergebnissen ermittelten Kenngrößen entsprechen den Spezifikationen gemäß Datenblatt.
All characteristic quantities determined from the measurement results correspond to the specifications per datasheet.
Toutes les grandeurs caractéristiques déterminées à partir des résultats de mesure correspondent aux spécifications selon les caractéristiques techniques.

The linearity test results

The linearity test results are available as a simple table but are also increasingly written into the sensors’ TEDS chips by HBK.

So, in order to scale the amplifiers, you just need to connect the sensor cables to the amplifiers.

A little tip:
Please look at the linearity deviation specified in your sensor’s test records.

You will be delighted!

The MCS10’s compensation matrix

There are two matrices for calculating the compensated signals.

This matrix contains the compensation of mV/V to the physical unit:

		F_x	F_y	F_z	M_x	M_y	M_z
		[mV/V]	[mV/V]	[mV/V]	[mV/V]	[mV/V]	[mV/V]
F'_x	[kN]	14,90612	-0,01944	-0,05738	0,09137	-0,00764	-0,04791
F'_y	[kN]	-0,01400	14,93623	0,03727	0,00547	0,06615	0,02297
F'_z	[kN]	0,10210	0,01501	80,38255	0,20828	-0,04581	0,32593
M'_x	[kN·m]	-0,00225	0,00229	-0,00212	1,12338	-0,00193	-0,00477
M'_y	[kN·m]	-0,00083	0,00064	-0,00330	-0,00227	1,12382	-0,00006
M'_z	[kN·m]	-0,00292	0,00069	0,01231	0,00219	0,00027	1,43683

The following matrix contains the normalized compensation entries from physical unit to physical unit:

		F_x	F_y	F_z	M_x	M_y	M_z
		[N]	[N]	[N]	[N·m]	[N·m]	[N·m]
F'_x	[N]	0,99999	-0,00130	-0,00071	0,08133	-0,00680	-0,03335
F'_y	[N]	-0,00094	1,00001	0,00046	0,00487	0,05886	0,01599
F'_z	[N]	0,00685	0,00100	1,00003	0,18540	-0,04076	0,22685
M'_x	[N·m]	-0,00015	0,00015	-0,00003	0,99998	-0,00171	-0,00332
M'_y	[N·m]	-0,00006	0,00004	-0,00004	-0,00202	1,00001	-0,00004
M'_z	[N·m]	-0,00020	0,00005	0,00015	0,00195	0,00024	1,00004

How to use the values from the test record

The data from the test record is very easy to use!

Due to TEDS technology, the characteristic curves of the individual signals are automatically transferred from the respective TEDS chip to the amplifier as soon as the sensor cable is plugged into the respective QuantumX measurement amplifier.

Since you already have the values in the physical unit, you only need the values from the compensation matrix N; N·m → N; N·m.

Depending on where the compensation is carried out, the characteristic values of this matrix must be entered into the hardware or the software.

Compensation in the hardware in real time or in the PC software?

The compensation matrix can be run in real time in the hardware or in the PC software.

But what are the advantages and disadvantages of these two methods?

Compensation in the hardware (embedded/in real time) is used to transfer the compensated signals directly to a test bench, for example, via standardized voltage signals, EtherCAT™, PROFINET™, or CAN FD/CAN.

If you only need the compensated signals in the software, you can easily perform the compensation as a calculation in the catman software.

If you want to output the compensated values via the hardware, and also want to use them via the software, you must set up the compensation calculation in both the hardware and software.

Setup example

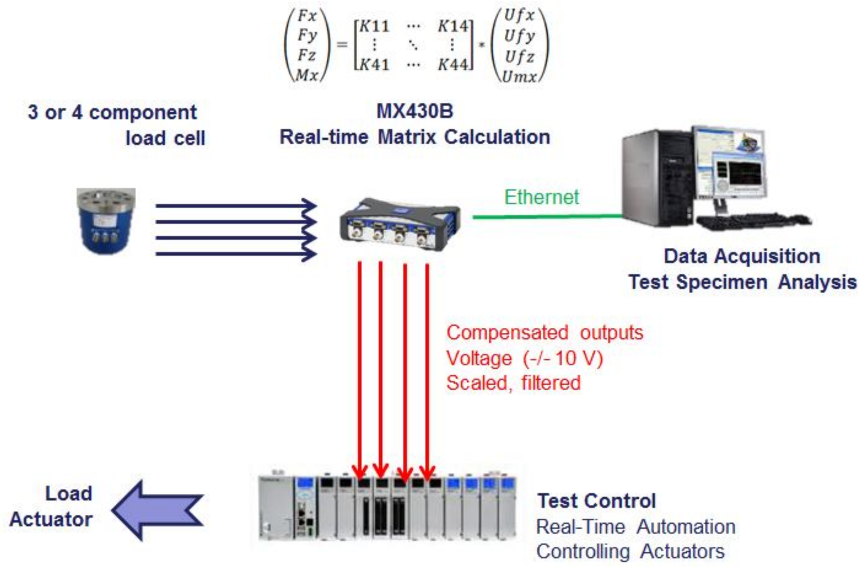


Figure 1: Wind tunnel balance

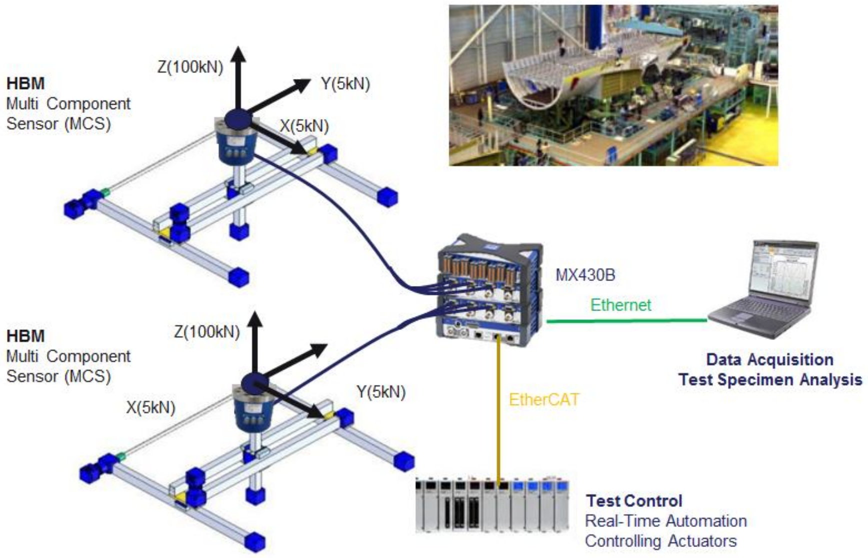


Figure 2: Aircraft fuselage testing

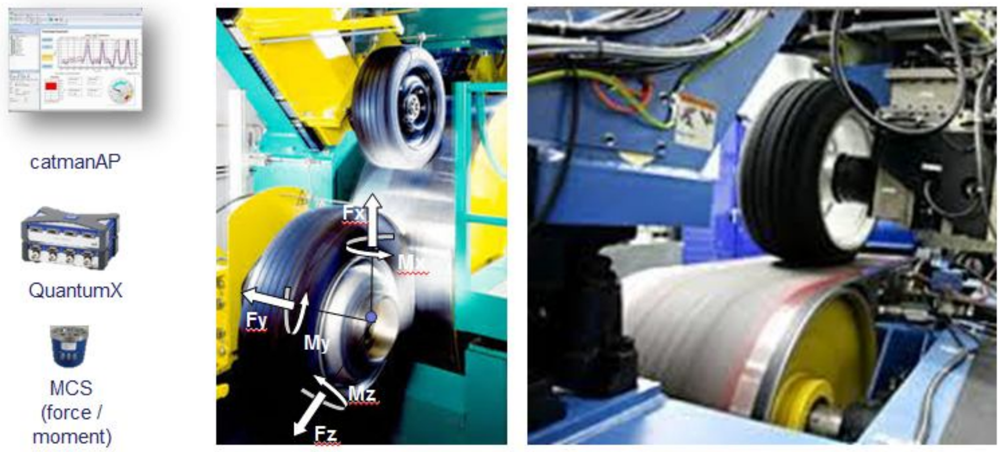


Figure 3: Tyre test bench

Compensation in the hardware

Compensation in the hardware means that the signals are compensated for in a QuantumX module such as MX430B, MX878B or MX879B and output in real time via a corresponding channel.

Which modules support matrix compensation?

MX430B

The MX430B can calculate its four input channels with each other in a matrix compensation.

This allows multi-component transducers to be processed with up to four forces or torques.

The output rate is limited to 5 kHz.

MX878B

The MX878B can carry out up to four matrix compensations with up to six signals. (Fx, Fy, Fz, Mx, My, Mz)

Any signal in the QuantumX system can be used in the calculations.

The output rate is limited to 5 kHz.

The signals can then be output via the analogue outputs of the MX878B, via EtherCAT or PROFINET™ with the CX27C or via CAN with the MX471C.

MX879B

The MX879B is also capable of carrying out up to four matrix compensations with up to six signals.

Any signal of any module in the QuantumX system can be used in the calculations.

The output rate is limited to 5 kHz.

The signals can then be output via the analogue outputs, via EtherCAT™ or PROFINET™ with the CX27C, or via CAN with the MX471C.

In addition, this module can activate digital outputs if limit values are exceeded or undershot.

Which interfaces can be used to output the signals?

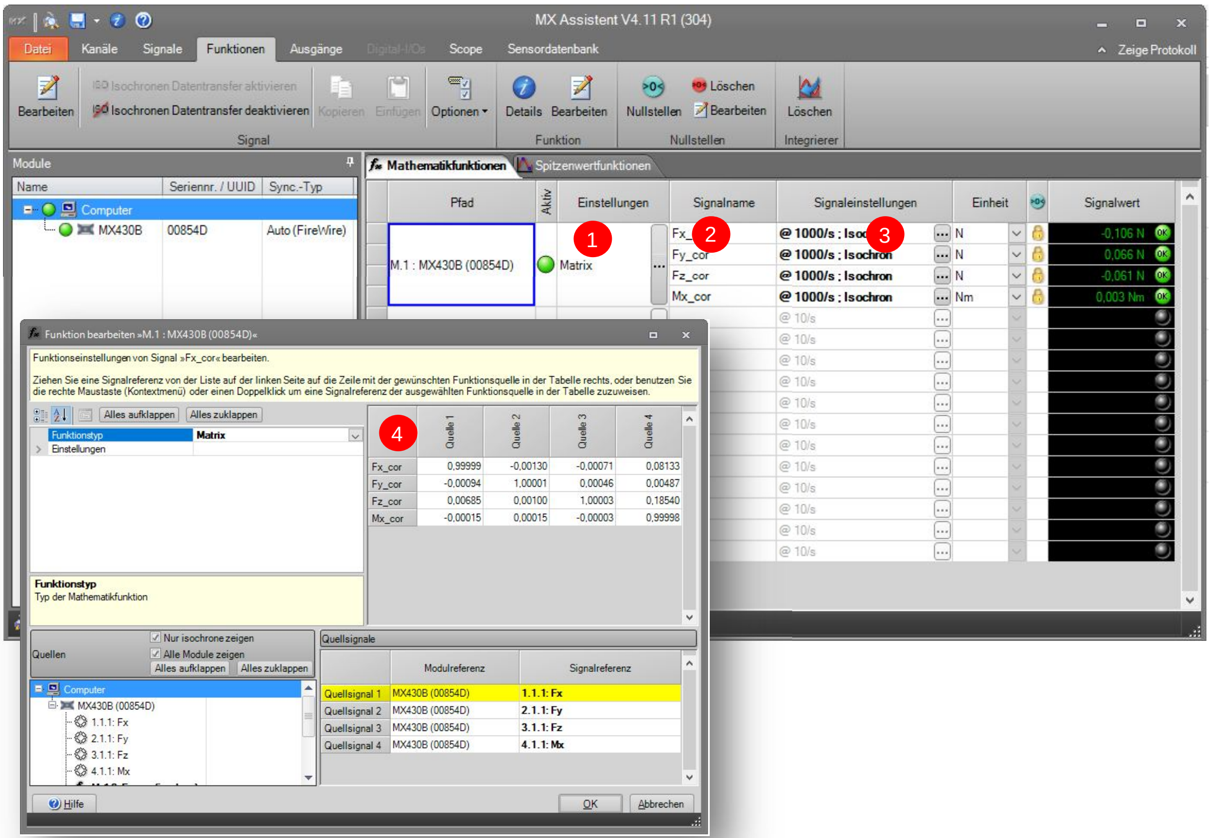
Analogue output ±10 V	MX878B (8 analogue outputs) or MX879B (8 analogue outputs + 32 digital inputs and outputs).
EtherCAT	MX878B or MX879B for the calculation and CX27C for the output on EtherCAT™.
PROFINET	MX878B or MX879B for the calculation and CX27C for the output on PROFINET™.
CAN	MX878B or MX879B for the calculation and via MX471C on one of the 4 CAN FD/CAN ports.

Practical implementation for output of the calculation with the MX430B

Since the characteristics of the sensor's individual forces and torques are already stored in the TEDS of these channels, the MX430B can immediately read the scaling of the channels, so you do not have to worry about it.

You can easily configure the matrix calculation using the MX Assistant.

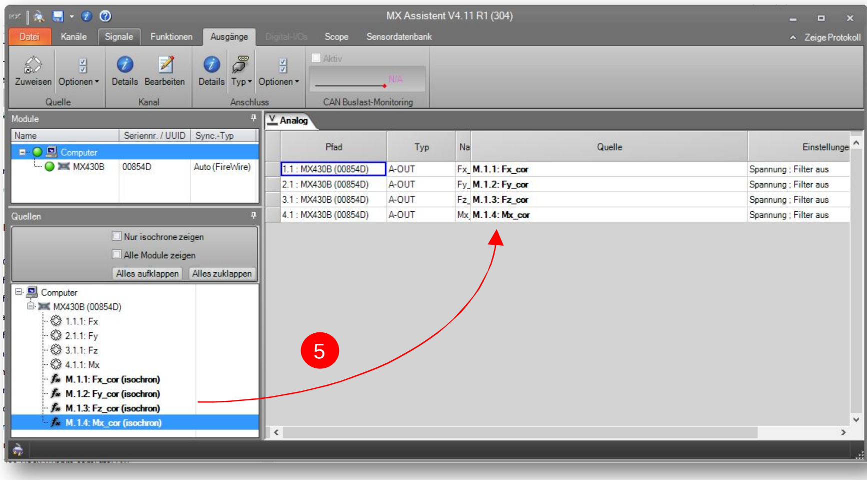
1. First, activate the Matrix function.
2. Assign appropriate names to the result channels.
3. Activate the isochronous mode for the result channels.
4. Finally, enter the coefficients from the test record into the corresponding fields.



5. Finally, select the interface for the output of the signals.

   This could be the analogue outputs of the MX430B.

   Here you can activate the analogue outputs and add the source channels by dragging and dropping.



Or you can use EtherCAT™ or PROFINET™ via the CX27C, or CAN bus via the MX471C.

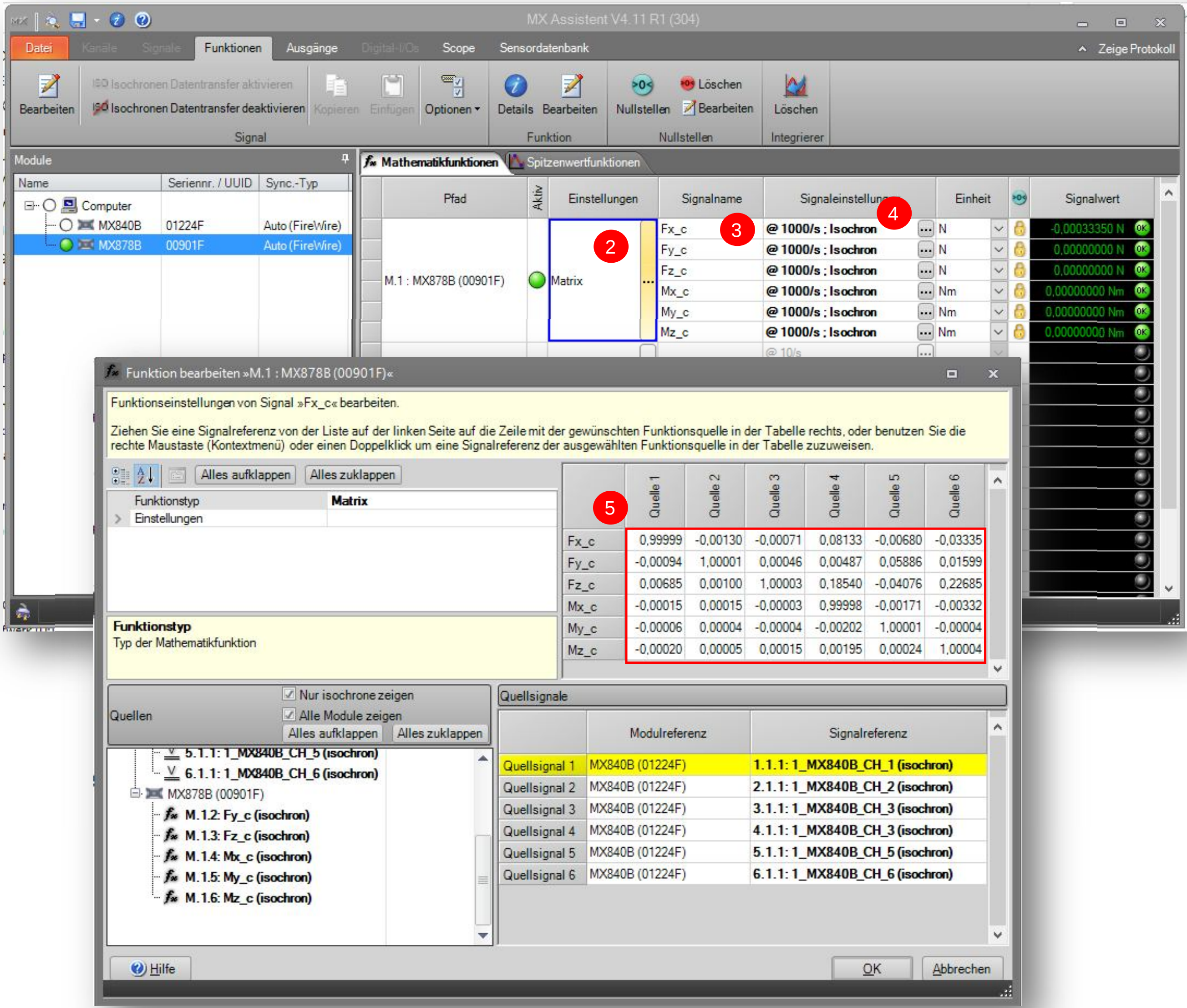
Practical implementation for matrix compensation with the MX878B or MX879B

To use the MX878B or MX879B for matrix calculation, you can connect the signals of the MCS10 to any module with the appropriate sensor technology.

Here too, the MCS10 delivers the complete characteristic curve of each channel to the respective amplifier channel via TEDS, so that the scaling of the sensor is done automatically.

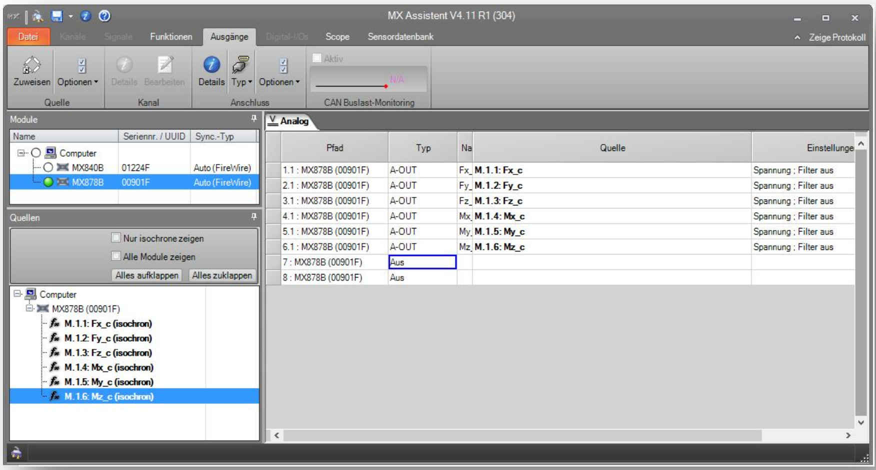
The following additional steps are required:

1. First, activate the isochronous data mode on the channels to which the sensor was connected. This allows the MX878B or MX879B to receive the signals.
2. In the MX878B or MX879B, activate the Matrix function.
3. Assign appropriate names to the result channels.
4. Activate the isochronous mode for the result channels.
5. Finally, enter the coefficients from the test record into the corresponding fields.



Practical implementation for output of the calculation via the ±10V analogue outputs

Both the MX878B and the MX879B can output the compensated values directly via analogue outputs. This operation is also self-explanatory.



The analogue outputs can be activated, and the source channels assigned intuitively as well.

Practical implementation for output of the calculation via EtherCAT™, PROFINET™ or CAN FD/CAN bus

The procedure for output via EtherCAT™, PROFINET™ or CAN is very similar for all three interfaces.

In the MX878B or MX879B, the signals must be set to isochronous data mode and connected to the CX27C or MX471C output module via FireWire.

In the output modules, the signals to be sent can be selected, or all signals set to isochronous data mode will be used for transmission.

For EtherCAT™ and PROFINET ™, the general configuration files (ESI/GSDML) can be loaded from the HBM homepage, or individual configuration files can be created by MX Assistant.

You can create the DBC file using MX Assistant for output via the CAN bus.

This enables integration into your hardware without any problems.

Compensation in the PC software

Compensation in the PC software means that the signals are read by the hardware before the compensated values are computed in the software. This can be done in catman, LabVIEW™, or any other software that can be used to access the QuantumX system.

Since the channels have already been configured automatically via TEDS and the signal name, scaling and unit are visible in the software seconds after the connection, only the input values have to be calculated according to the contents of the compensation matrix. Each sensor connector can then be plugged in individually – the calculation remains as it is since it is based on the signal names.

The calculation formulas

In this case, too, the compensation matrix N; N . m N; N . m is →used, as the measured values are already scaled in N and Nm.

Kompensierter Ausgang = compensated output = Kompensationsmatrix compensation matrix · Eingang · input

$$\begin{pmatrix} F'_x \\ F'_y \\ F'_z \\ M'_x \\ M'_y \\ M'_z \end{pmatrix} = \begin{bmatrix} K_{11} & K_{12} & K_{13} & K_{14} & K_{15} & K_{16} \\ K_{21} & K_{22} & K_{23} & K_{24} & K_{25} & K_{26} \\ K_{31} & K_{32} & K_{33} & K_{34} & K_{35} & K_{36} \\ K_{41} & K_{42} & K_{43} & K_{44} & K_{45} & K_{46} \\ K_{51} & K_{52} & K_{53} & K_{54} & K_{55} & K_{56} \\ K_{61} & K_{62} & K_{63} & K_{64} & K_{65} & K_{66} \end{bmatrix} \cdot \begin{pmatrix} F_x \\ F_y \\ F_z \\ M_x \\ M_y \\ M_z \end{pmatrix}$$

The necessary formulas can be created directly from the compensation matrix.

Here are all the formulas of the matrix:

$F'x = (K_{11} * Fx) + (K_{12} * Fy) + (K_{13} * Fz) + (K_{14} * Mx) + (K_{15} * My) + (K_{16} * Mz)$

$F'y = (K_{21} * Fx) + (K_{22} * Fy) + (K_{23} * Fz) + (K_{24} * Mx) + (K_{25} * My) + (K_{26} * Mz)$

$F'z = (K_{31} * Fx) + (K_{32} * Fy) + (K_{33} * Fz) + (K_{34} * Mx) + (K_{35} * My) + (K_{36} * Mz)$

$M'x = (K_{41} * Fx) + (K_{42} * Fy) + (K_{43} * Fz) + (K_{44} * Mx) + (K_{45} * My) + (K_{46} * Mz)$

$M'y = (K_{51} * Fx) + (K_{52} * Fy) + (K_{53} * Fz) + (K_{54} * Mx) + (K_{55} * My) + (K_{56} * Mz)$

$M'z = (K_{61} * Fx) + (K_{62} * Fy) + (K_{63} * Fz) + (K_{64} * Mx) + (K_{65} * My) + (K_{66} * Mz)$

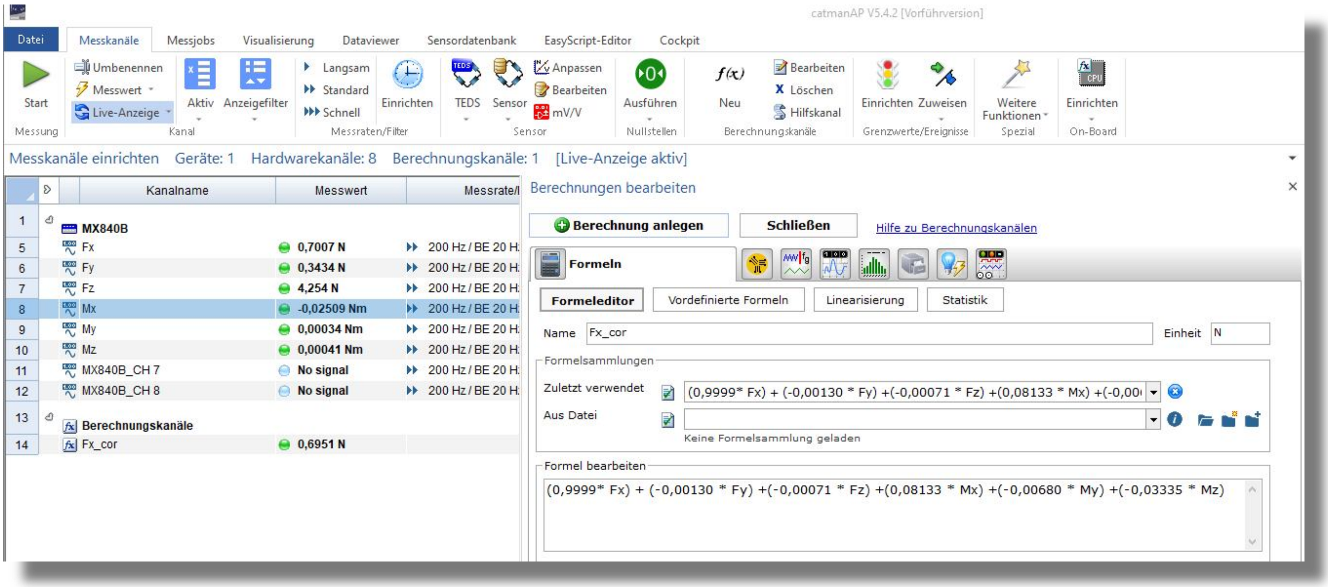
		F_x	F_y	F_z	M_x	M_y	M_z
		[N]	[N]	[N]	[N·m]	[N·m]	[N·m]
F'_x	[N]	0,99999	-0,00130	-0,00071	0,08133	-0,00680	-0,03335
F'_y	[N]	-0,00094	1,00001	0,00046	0,00487	0,05886	0,01599
F'_z	[N]	0,00685	0,00100	1,00003	0,18540	-0,04076	0,22685
M'_x	[N·m]	-0,00015	0,00015	-0,00003	0,99998	-0,00171	-0,00332
M'_y	[N·m]	-0,00006	0,00004	-0,00004	-0,00202	1,00001	-0,00004
M'_z	[N·m]	-0,00020	0,00005	0,00015	0,00195	0,00024	1,00004

For the compensation matrix listed above, the formula for calculating the corrected force F'x is now used as an example:

$F'x = (0.9999 * Fx) + (-0.00130 * FY) + (-0.00071 * Fz) + (0.08133 * MX) + (-0.00680 * My) + (-0.03335 * Mz)$

Practical implementation in catman

The formula created can be used 1:1 in catman.

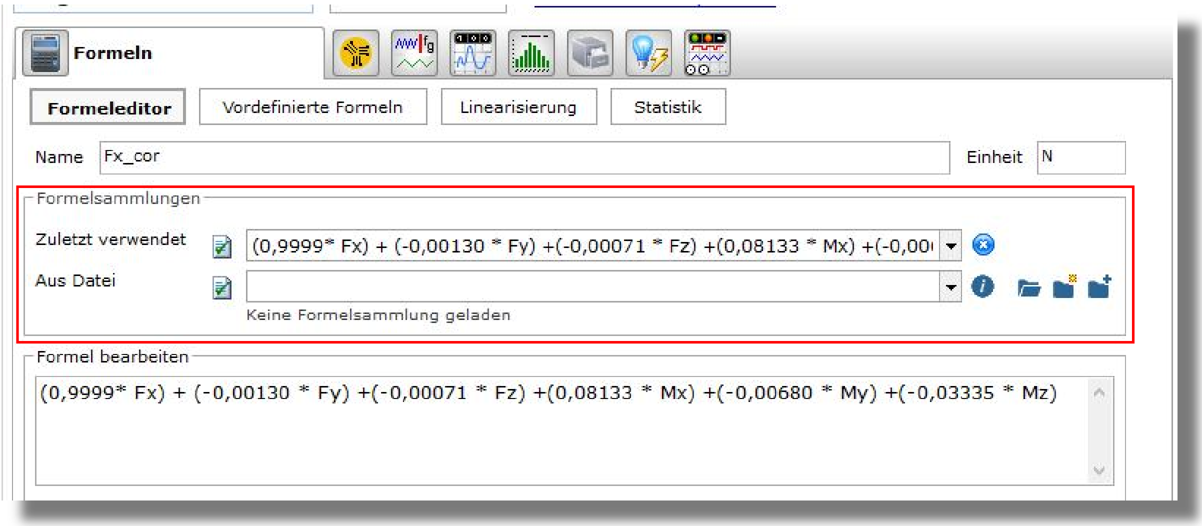


In this case, we have named the corrected force F_x_cor.

A little tip

If you use different multi-component sensors in different measuring tasks, the compensation calculations used need to be adapted.

The integrated formula library enables formulas to be saved in catman and inserted into your project at the touch of a button. Of course, you can also make your formula library available to colleagues.



We wish you success in your measurement or test projects using the integrated measurement chain from HBK.

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