TECH NOTE #002 :: Extra confidence in strain measurement with quarter bridges by internal shunting

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Abstract

This TECH NOTE gives you an overview of how internal shunt calibration in the HBM DAQ family MGCplus works. Besides explaining the circuitry for strain gauges connected in 3-wire and 4-wire configuration, it shows the calculation of amplitudes caused by the internal shunt resistor and points out the traceability situation and principle of this feature.
Internal shunt calibration within the HBM DAQ product range works very similar.
Terms like “channel calibration” and “channel health check” are often mentioned specifically in high-channel count applications. This TECH NOTE shows how internal shunt resistors in a DAQ system can be used to make testing more efficient and bring confidence in the quality of data.

Application description

To determine strength and durability, materials, components, and full-scale structures undergo static load or quasi-static durability (or fatigue) tests. The aim is to validate designs and FEM models and to exclude failure during operation by all means. In many industries, positive results of these tests are also mandatory to obtain certifications by authorities needed to take the step from development to official release and subsequently to series production.
The most common sensor in static and quasi-static testing is by far the strain gauge (in quarter bridge configuration). Therefore, it is of utmost importance to have an easy and traceable method ensuring that every strain gauge is correctly wired and all amplifier channels work precisely.

System overview

The system described in this TECH NOTE is HBM’s number one DAQ solution for high-channel count static and durability testing for example in the Aerospace industry: MGCplus with its 8-channel connection board and amplifier combinations (ML801B + AP814Bi and AP815i).
The combinations of ML801B and AP814Bi or AP815i are specifically designed for high-density strain measurements featuring up to 0.1 accuracy class with a noteworthy flexibility. Both connection boards AP814Bi and AP815i feature four levels of excitation voltage (0.5, 1, 2.5 and 5 V) and three internal completion resistors (120, 350 and 700 Ohm; 1,000 Ohm as option). The excitation voltages are symmetrical over the complete Wheatstone bridge, thus the measurement signals will be close to 0 V and influences of common-mode voltages are avoided. All measurement channels have own A/D converters and allow sampling rates of up to 2.4 kS/s per channel.
AP814Bi is suited for strain gauges in 3-wire configuration while AP815i supports strain gauges in 4-wire configuration, half and full bridges.
The screenshots describing the process are derived from HBM’s DAQ software catman AP (a TECH NOTE version for HBM’s high channel count software catman Enterprise is available upon request).

Strain gauge wiring configurations

Connecting strain gauges in 3-wire configuration is the most simple, common and cost-effective solution. HBM amplifiers feature a patented regulated 3-wire configuration shown in Figure 1 that constantly adjusts the supply voltage V_{in} according to the wire resistance (HBM patents DE 19957088 and DE 10131375 B4).

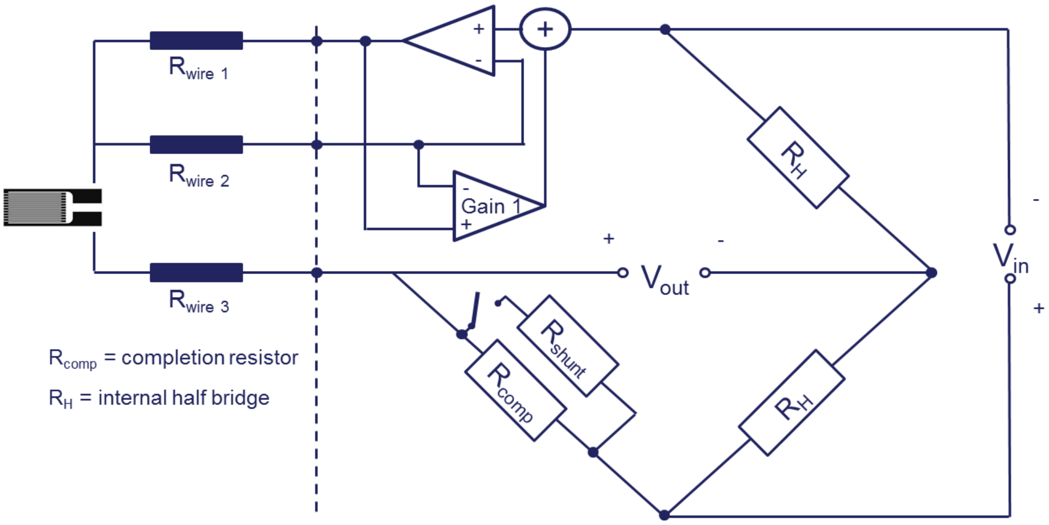


Figure 1 – HBM-patented 3-wire configuration (simplified)

The wire resistance Rwire 1 is constantly monitored. By assuming symmetrical wire resistances Rwire 1 and Rwire 3 Vin is adjusted accordingly. In a symmetric cable, therefore, there is no change in sensitivity even in case of a temperature drift affecting cable resistance. Given the formula of the Wheatstone bridge for quarter bridge configuration which is

$$\frac{V_{out}}{V_{in}} = \frac{\Delta R}{2(2R_0 + \Delta R)} \qquad \frac{V_{out}}{V_{in}} = \frac{\Delta R}{4R_0}$$

Equation 1 – Wheatstone bridge formula (quarter bridge, exact and linearized)

a change in R_0 (which is $R_{wire\ 1} + R_{wire\ 3}$ + RSG) leads to a correspondent change in V_{in}. Therefore V_{out} is not affected by a temperature change.
The aforementioned assumptions and calculations are valid assuming the cable resistance and contact resistance of the connector being symmetrical. In case of non-symmetrical resistances, the only configuration capable of effective compensation of changing temperatures is the four-wire quarter bridge configuration shown in Figure 2.

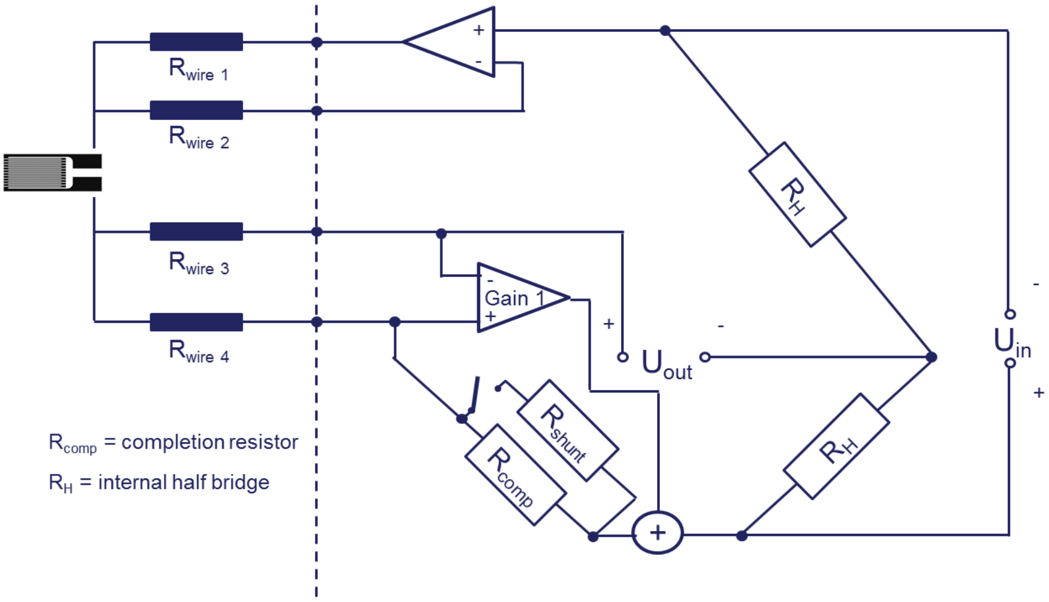


Figure 2 – HBM 4-wire configuration (simplified)

Both wire resistances $R_{wire\ 1}$ and $R_{wire\ 4}$ are constantly monitored and Vin is adjusted accordingly. Even in an asymmetrical cable, therefore, there is no change in sensitivity even in case of a temperature drift affecting the lead wire resistances differently. Using the formula of the Wheatstone bridge for quarter bridge configuration (Equation 1) a change in R_0 (which is $R_{wire\ 1}$ + $R_{wire\ 4}$ + RSG) leads to a correspondent change in V_{in}, and V_{out} is not affected by a temperature change.

HBM internal shunt resistors

Both configurations compensate for the wire resistances between DAQ and strain gauge. However, even if shunting is not necessary to determine the wire resistances, HBM strain gauge amplifiers still feature an internal shunt for channel check and calibration purposes.

In MGCplus amplifiers an 86.6 kΩ shunt resistor R_{Shunt} (+30 Ω from the field effect switch) is located in parallel to the completion resistor R_{comp}. (see Figure 1 and Figure 2) The shunt switch allows parallelizing R_{comp} and R_{Shunt} in a very short and well-defined way, excluding cable resistance. Whether the shunt is active or not, the active strain gauge is always part of the circuit and therefore the correct wiring of it is also checked in a simple way.

Assuming R_{comp} = 350.0 Ω, when the shunt switch is closed, the equivalent resistance is:

$$R_{Equiv} = \frac{R_{Shunt} * R_{Comp}}{(R_{Shunt} + R_{Comp})}$$

Equation 2 – equivalent resistance

This results in R_{Equiv} = 348.592 Ω.

The resulting nominal unbalance is:

$$\frac{V_{out}}{V_{in}} = \frac{R_{SG} + \Delta R_{SG}}{R_{SG} + \Delta R_{SG} + R_{Equiv}} - \frac{1}{2}$$

Equation 3 – nominal unbalance

Assuming the active strain gauge RSG at 350.0 Ω and no pre-strain, i.e. ∆RSG at 0 Ω, this results in V_{out}/V_{in} = 1.008 mV/V. Why this ideal (an untypical) case in which the strain gauge has a resistance of exactly 350.0 Ω is not necessary will be explained further down.

As the parallel between R_{comp} and R_{shunt} is not influenced by any other external resistance (cable or internal amplifier resistors) the result can be considered an absolute reference when performing a channel check or shunt calibration in catman AP or Enterprise. Cable length has no influence on the unbalance induced by the shunt resistor.

Traceability situation and realistic exemplary calculation

Due to the well-defined unbalance internal shunt calibration is a valuable way to carry out an independent check of gain stability across the whole measuring chain. This gives high certainty that everything works correctly and with the expected precision.

Actually, the shunt resistor is a traced calibration method. The resistor manufacturer traces the impedance value back to a National Institute of Standard (e.g. NIST, PTB). By comparing the theoretically calculated amplitudes and the generated amplitudes, also the amplifier itself is traced back to this national standard – completely independent from the first calibration method used during amplifier manufacturing, which can also be traced back to national standards.

At this point it is also important to explain how the amplitude is measured. The measured imbalance is the difference between the state in which the shunt is not active and active. Figure 3 below helps to understand why this is important.

	without shunt	with shunt	Δ
Vout/Vin with RSG = 350 Ω	0,000 mV/V	1,008 mV/V	1,008 mV/V
Vout/Vin with RSG = 352 Ω	1,425 mV/V	2,432 mV/V	1,008 mV/V

Figure 3 – Exemplary calculation based on Equation 3 of shunt resistor effect

Even if a strain gauge with high pre-strain, e.g. 3,000 µm/m is connected, the imbalance (Δ) caused by activating the shunt resistor is still the same. This is crucial as strain gauges typically never have a resistance value of 350.0 Ohm, but a slightly different value.

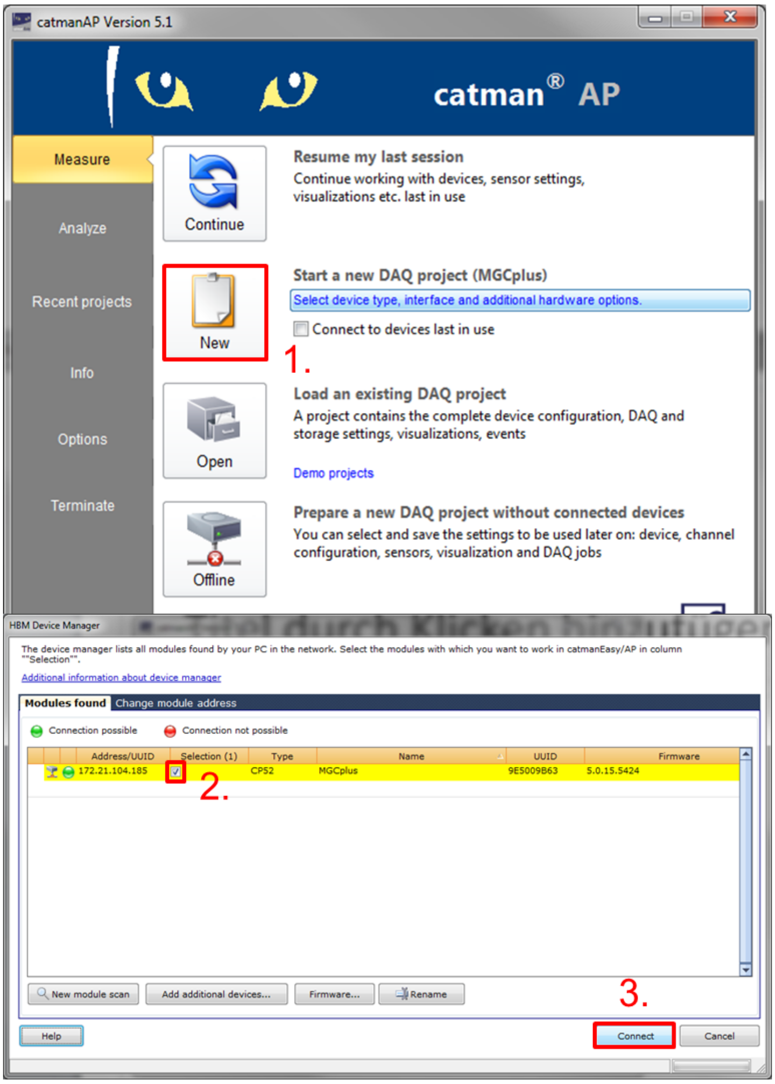
Summary

The described procedure works excellent for strain gauges in quarter bridge configuration as the internal completion resistor and the shunt resistor have a well-defined value. Soldering an external shunt resistor will bring contact resistances, cable resistances in series and other effects that will have an effect on the measured values and can therefore not be compared with the internal shunt calibration.
For full bridges the situation is different as the resistances of the bridge can differ significantly from the standard values of 120, 350, 700 and 1,000 Ohm and are not known a priori.

How to perform a shunt calibration in catman Easy/AP

First start the software and choose the hardware you want to work with (in this example MGCplus with CP52, ML801B and AP814Bi).

1. Start a new measurement project
2. Choose the hardware to connect to
3. Connect



Resume my last session
Continue working with devices, sensor settings, visualizations etc. last in use

Start a new DAQ project (MGCplus)
Select device type, interface and additional hardware options.
☐ Connect to devices last in use

Load an existing DAQ project
A project contains the complete device configuration, DAQ and storage settings, visualizations, events
Demo projects

Prepare a new DAQ project without connected devices
You can select and save the settings to be used later on: device, channel configuration, sensors, visualization and DAQ jobs

The device manager lists all modules found by your PC in the network. Select the modules with which you want to work in catmanEasy/AP in column ""Selection"".
Additional information about device manager

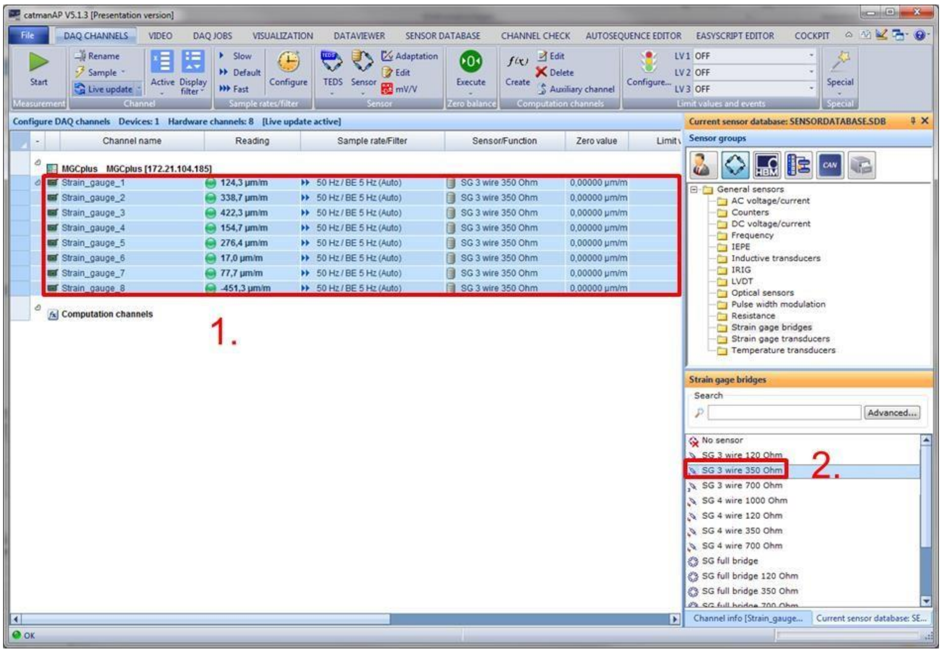
Modules found | Change module address

● Connection possible ● Connection not possible

Address/UUID	Selection (1)	Type	Name	UUID	Firmware
172.21.104.185	☑	CP52	MGCplus	9E5009B63	5.0.15.5424

The software catman AP allows you to assign a specific sensor datasheet or ready-to-use configuration out of a sensor database (SDB) to single or selected measurement channels (e.g. strain gauge (quarter bridge), 350 Ohms, 3-wire configuration).

1. Mark all channels you would like to configure.
2. Choose the sensor type and double-click on the desired one.



catmanAP V5.1.3 [Presentation version]

Configure DAQ channels Devices: 1 Hardware channels: 8 [Live update active]

MGCplus MGCplus [172.21.104.185]

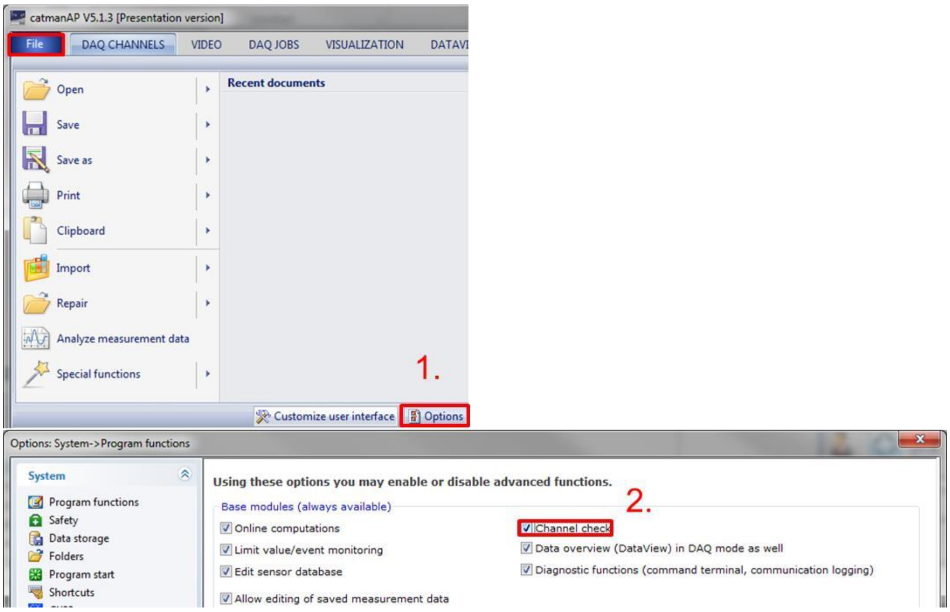
Channel name	Reading	Sample rate/Filter	Sensor/Function	Zero value
Strain_gauge_1	124,3 µm/m	50 Hz / BE 5 Hz (Auto)	SG 3 wire 350 Ohm	0,00000 µm/m
Strain_gauge_2	338,7 µm/m	50 Hz / BE 5 Hz (Auto)	SG 3 wire 350 Ohm	0,00000 µm/m
Strain_gauge_3	422,3 µm/m	50 Hz / BE 5 Hz (Auto)	SG 3 wire 350 Ohm	0,00000 µm/m
Strain_gauge_4	154,7 µm/m	50 Hz / BE 5 Hz (Auto)	SG 3 wire 350 Ohm	0,00000 µm/m
Strain_gauge_5	276,4 µm/m	50 Hz / BE 5 Hz (Auto)	SG 3 wire 350 Ohm	0,00000 µm/m
Strain_gauge_6	17,0 µm/m	50 Hz / BE 5 Hz (Auto)	SG 3 wire 350 Ohm	0,00000 µm/m
Strain_gauge_7	77,7 µm/m	50 Hz / BE 5 Hz (Auto)	SG 3 wire 350 Ohm	0,00000 µm/m
Strain_gauge_8	-451,3 µm/m	50 Hz / BE 5 Hz (Auto)	SG 3 wire 350 Ohm	0,00000 µm/m

Computation channels

Current sensor database: SENSORDATABASE.SDB

LV 1 OFF
LV 2 OFF
LV 3 OFF

The shunt calibration tab ("channel check") is not active by default. Therefore, it must be activated in the program options:



catmanAP V5.1.3 [Presentation version]

Options: System->Program functions

Using these options you may enable or disable advanced functions.

Base modules (always available)

☑ Online computations
☑ Limit value/event monitoring
☑ Edit sensor database
☑ Allow editing of saved measurement data
☑ Channel check
☑ Data overview (DataView) in DAQ mode as well
☑ Diagnostic functions (command terminal, communication logging)

Once you have activated the function in the options, you are ready to perform the shunt calibration.

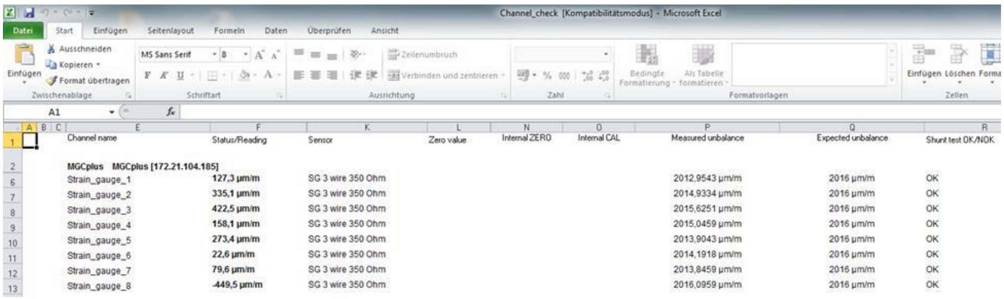
1. Go to the Channel Check tab.
2. Choose the allowed difference, typically 0.5%.
3. Mark the channels you would like to calibrate.
4. Perform the calibration.
5. If desired store the result in a spreadsheet.

0.5 % allowed difference

Switches internal shunt resistors of selected channels on and compares the resulting signal unbalance with the expected.

MGCplus MGCplus [172.21.104.185]

Channel name		Sensor/Function	Zero value	Internal ZERO	Internal CAL	Measured unbalance	Nominal unbalance	Shunt test OK/NOK
Strain_gauge_1	127,3 µm/m	SG 3 wire 350 Ohm	0,00000 µm/m			2012,9543 µm/m	2016 µm/m	● OK
Strain_gauge_2	335,1 µm/m	SG 3 wire 350 Ohm	0,00000 µm/m			2014,9334 µm/m	2016 µm/m	● OK
Strain_gauge_3	422,5 µm/m	SG 3 wire 350 Ohm	0,00000 µm/m			2015,6251 µm/m	2016 µm/m	● OK
Strain_gauge_4	158,1 µm/m	SG 3 wire 350 Ohm	0,00000 µm/m			2015,0459 µm/m	2016 µm/m	● OK
Strain_gauge_5	273,4 µm/m	SG 3 wire 350 Ohm	0,00000 µm/m			2013,9043 µm/m	2016 µm/m	● OK
Strain_gauge_6	22,6 µm/m	SG 3 wire 350 Ohm	0,00000 µm/m			2014,1918 µm/m	2016 µm/m	● OK
Strain_gauge_7	79,6 µm/m	SG 3 wire 350 Ohm	0,00000 µm/m			2013,8459 µm/m	2016 µm/m	● OK
Strain_gauge_8	-449,5 µm/m	SG 3 wire 350 Ohm	0,00000 µm/m			2016,0959 µm/m	2016 µm/m	● OK



	A B C E	F	K	L	N	O	P	Q	R
1	Channel name	Status/Reading	Sensor	Zero value	Internal ZERO	Internal CAL	Measured unbalance	Expected unbalance	Shunt test OK/NOK
2	**MGCplus MGCplus [172.21.104.185]**								
6	Strain_gauge_1	**127,3 µm/m**	SG 3 wire 350 Ohm				2012,9543 µm/m	2016 µm/m	OK
7	Strain_gauge_2	**335,1 µm/m**	SG 3 wire 350 Ohm				2014,9334 µm/m	2016 µm/m	OK
8	Strain_gauge_3	**422,5 µm/m**	SG 3 wire 350 Ohm				2015,6251 µm/m	2016 µm/m	OK
9	Strain_gauge_4	**158,1 µm/m**	SG 3 wire 350 Ohm				2015,0459 µm/m	2016 µm/m	OK
10	Strain_gauge_5	**273,4 µm/m**	SG 3 wire 350 Ohm				2013,9043 µm/m	2016 µm/m	OK
11	Strain_gauge_6	**22,6 µm/m**	SG 3 wire 350 Ohm				2014,1918 µm/m	2016 µm/m	OK
12	Strain_gauge_7	**79,6 µm/m**	SG 3 wire 350 Ohm				2013,8459 µm/m	2016 µm/m	OK
13	Strain_gauge_8	**-449,5 µm/m**	SG 3 wire 350 Ohm				2016,0959 µm/m	2016 µm/m	OK

References:

1. Manfred Kreuzer, “Strain Gage ¼ Bridge Calibration with Shunt Signals” www.hbm.com Applications -> Tips & Tricks -> Strain Measurement
2. Karl Hoffmann, “Applying the Wheatstone Bridge Circuit” www.hbm.com Applications ->Tips & Tricks -> Strain Measurement
3. Video on Non-linearities in Strain Measurement www.hbm.com Instruments -> MGCplus

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