TECH NOTE :: Structural Analysis using Strain Gauges and QuantumX

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Intro

This TECH NOTE explains some basics around structural analysis and testing and puts its focus on the overall measurement chain. It also represents a tutorial using a **double bending beam demo** where two weights with springs can be used to stimulate harmonic load and thus strain in the overall steal construction. This demo unit from HBM has been designed for training purposes in the field of strain related measurement and analysis. It shall demonstrate the **HBM measurement chain** in a simple way - starting with strain gauges used in a Wheatstone bridge, the instrument or amplifier converting analog to digital data and the software for physical data visualization, online calculation, data storage, post-process analysis and finally report generation.

Keywords: Fatigue, durability testing, life-time, experimental stress analysis (ESA), structural testing, static load test, strain gauge, data acquisition, noise reduction, alarm, long-term stability, QuantumX, catman, FEM, CAE, nCode DesignLife, GlyphWorks.

Main Focus of this TUTORIAL

This demo is focussing on the following topics:

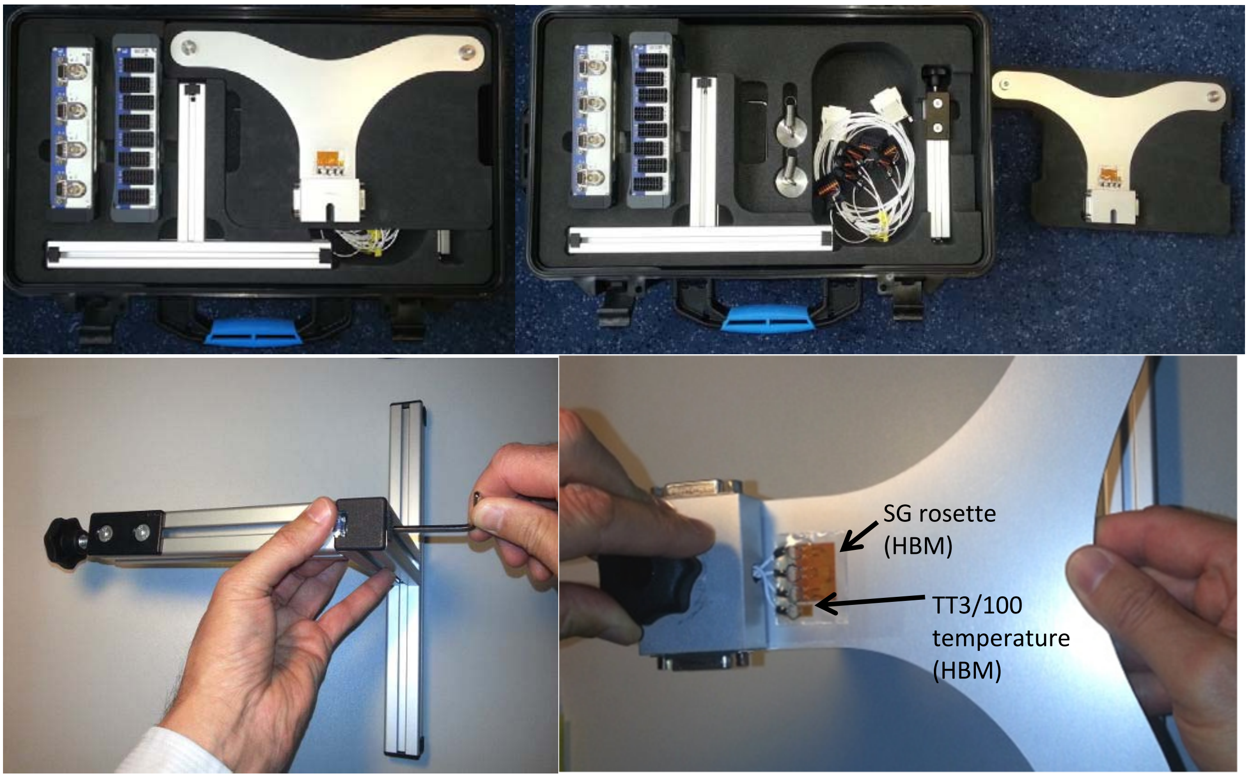
- Description of the engineering and testing disciplines
- Sensors for mainly strain and temperature measurement
- Instrument / data acquisition: Wheatstone Bridge
- Setting up the measurement chain and operating some tests
  - Parameterizing inputs
  - Online calculation (temperature compensation, strain gauge rosettes, counters, algebra, others)
  - Starting, stopping and storing data – the DAQ job
  - Visualization and analysis
  - Report generation
- Service Tasks
  - Shunt calibration

Parts of the Demo

The bending beam demo consists of the following parts:

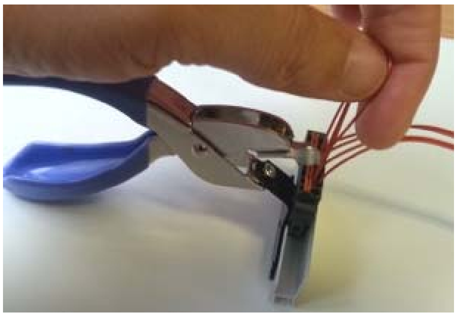
- Demo case
  - bending beam and space for up to two QuantumX modules including cable and adapters (modules are not part of the demo)
- Bending Beam Demo
  - Two weights (load) hanging on springs on a steel based bending beam in boomerang shape
  - 2 strain gauge rosettes applied closed to the most interesting analysis spots
  - 2 strain gauge based temperature transducers applied
  - Sub D 15 pin female socket
- QuantumX MX1615B strain gauge bridge module
  - 16 channels strain gauge full, half or quarter bridge, PT100 or voltage

The Demo



Pictures: Setting up the demo

Hint: Sensor wires just need to be pushed in to the connectors of MX1615B. Just leave the plug in the socket of the device for a quick and easy installation. Another approach for in-field use is a self-made tool pushing down every pin.



Classification of Tests

For this tutorial we use a “double bending beam” as demo. It allows us to hands-on explaining the complete measurement chain from sensor, over instrument to software and data analysis typically used in the field of structural analysis and testing. In this chapter testing fields are shown and classified.

Virtual PC based Structural Test using Finite Element (FE) based Fatigue Analysis
This test is a virtual test based on the FE model executed completely in the virtual environment of a PC. For this we recommend to use nCode DesignLife.

Material / Coupon / Fatigue Test
Target of this discipline is finding out detailed material properties according to pre-defined load tests. Material properties are highly dependent on type and composition as well as ageing and test environment. Life-time prediction focusses on strain or stress-life fatigue calculation based on time series data or rainflow matrix generating damage histograms. Typical driver in this field is the design and development of new materials like light metal, plastics or fibre reinforced structures.
For this purpose mechanical load is applied by screw-jacks, hydraulic pistons, servo-hydraulic pistons or electric machines applying uniaxial or biaxial tension in a static, quasi-static or dynamic (cyclic) way to the test specimen.

For highly dynamic tests special impact machines are used. Examples are the so called *split-Hopkinson bar*, *Charpy impact test* or *Drop Weight* test. Only a small amount of sensors are used in this field.

In this domain HBM offers the complete measurement chain and tool fully integrated or beside material testing machine suppliers.

Road Load Data Acquisition (RLDA)
The discipline Road Load Data Acquisition (RLDA) is an important step in mechanical engineering of a vehicle. RLDA belongs to the large durability testing domain. The “true” mechanical load is measured by different types of transducers and sensors applied to the vehicles chassis, body and other main mechanical parts. This test takes place in special proving grounds, on- or off-road or on railway tracks for whatever purpose vehicles are designed for. Data acquisition can go up to many hundred channels with mainly strain gauges. The acquired *load* is the source for post-process mathematical analysis consisting of *statistical analysis*, *data reduction methods* (rainflow, time-at-level, range-pair, level-crossing in time domain), *frequency analysis*, *comparison* with existing data and the final *damage calculation* (relative Miner rule, Wöhler curve). The extracted “golden file” is used for *lab based durability testing* of components, parts or full-scale vehicles, but also for further *FE based virtual fatigue calculation* or simulation.

In this domain HBM offers the complete measurement chain and tool set:

- High accurate strain gauge bridge inputs, next to universal inputs
- Powerful software offering offline parameterization (process integration / asset management)
- GPS for a later position based data analysis
- Support of vehicle protocols like CAN, CCP, XCP-on-CAN
- Support of Kistler wheel force transducers (WFT) over Ethernet measuring load in x-y and z direction
- Integration of meta data describing test cases, driver and weather condition
- Support of video cameras (web cam, GigE, FireWire)
- Remote access to Data Recorder(s) via mobile telecom network from anywhere via internet
- Powerful math

In a wider scope **structural health monitoring (SHM)** of bridges, oil rigs, towers for wind energy plants, tunnels or railway tracks can be seen as load monitoring over a longer period of time and with a large set of different sensors and other aspects like remote access, event or condition notifications or alarms, automatic data transfer and analysis and so forth. For many different large scale constructions monitoring helps understanding load conditions and thus calculating and estimating life.

In this domain HBM offers the complete turnkey solution or products and services covering monitoring jobs.

Lab based Structural Durability Testing

Durability testing is a common engineering method, where single system parts or full-scale products are evaluated for reliability and life-time in their end usage. For a ground vehicle this means all system parts like axles, spring-damper, doors, latches, steering, the overall white body or the complete vehicle. In aerospace industry we find parts or the complete aircraft. In Structural Durability Testing the job is done by stressing the part by a certain load condition s(t)imulated by actuators in a typical lab environment – typically static, quasi-static or also complex load models with often random sequence in order to assess and verify the safe life of the system part or the complete vehicle or product.

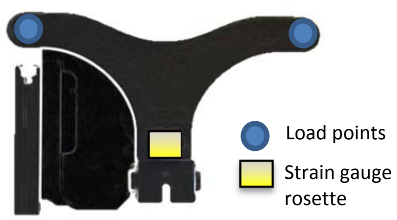
In a wider view this domain can also be seen as Experimental Stress Analysis (ESA).

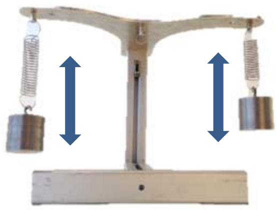
In this domain HBM offers the complete measurement chain evaluating the system under test:

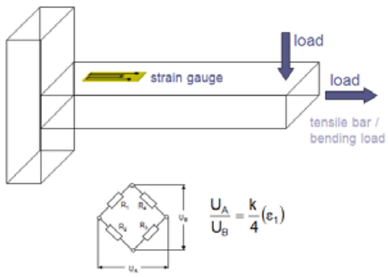
- Software reducing raw data and extracting the relevant parts (rainflow, histogram, fatigue damage spectrum, cumulative damage incurred from the S-N curve, Miner's)
- Load cells, strain gauges, displacement transducers
- Instruments and DAQ solutions 4 to 20.000 channels (centralized or distributed) covering all relevant transducers, sensors and other inputs and outputs
- Full digital integration into the load s(t)imulator based on EtherCAT (MTS, MOOG, Instron, …)
- Real-time calculated output of compensated output using multi component load cells with 2/3 or 6 DOF.

The Double Bending Beam

In this TECH NOTE we use a "double bending beam" as demo. It allows applying *static* or *quasi-dynamic* load to a structure in boomerang style.







The bending beam uses **steal AISI 1045**. The material characteristics are:

Mechanical Property	Short	Metric	English
Young's Module	E	200.000 N/mm²	29000 ksi
Poisons' ratio	σ	0,29	0,29
Ultimate tensile strength	UTS	585 MPa	84800 psi

Source: the matweb

Electrical Strain Gauges

A electrical strain gauge (SG) is a transducer used for determining the amount of strain. The most common type of strain gauge is the fully insulated foil gauge type forming a resistor. The SG is applied directly by an adhesive to the part under test or investigation. Every deformation deforms the SG as well and thus the length of the foil pattern and its resistance (Ohm).

The most heavily loaded areas in test objects, frequently small, are most interesting. So every effort is made to measure strain as accurately as possible. If measurements are made with a standard SG having a measuring grid length of 3 mm, a strain of 1 µm/m in this case would correspond to a change in length of just 0.003 µm. The SG method can be used to measure even smaller changes in length reliably. The relative change in resistance of the SGs with metallic measuring grids corresponds quite accurately to twice the strain of the measurement object ($\Delta R/R0 = 2 \times \Delta L/L0$), which means it is also a miniscule measurands. With a standard 120 Ω SG, a strain of 1µm/m generates a change in resistance of just 0.00024 Ω. To be able to measure such small changes in resistance in a stable manner, SGs are configured to form full bridges – the so called **Wheatstone bridge**.

Strain gauges are used in many applications in research and engineering: pure material, system or structural testing and life-time prediction, installed in load cells, pressure transducers or torque sensors, just to name the most common areas.

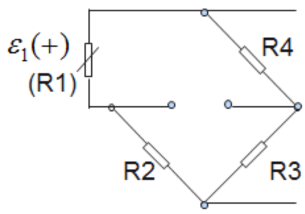
There are also optical strain gauges available, most of them based on Fibre Bragg technology (FBG), mainly used because of high levels of strain, high numbers of load cycles, high electromagnetic stress or installations in explosive environments. More info on hbm.com.

As seen below strain gauges can be applied to almost any material - metal, concrete, plastic, composite (carbon fibre), concrete or even human bones. Still using SG is a very cost effective way analysing structures and components. The SG catalogue from HBM helps you to select the right SG and instrument.

The Whetstone Bridge

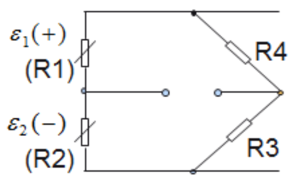
In general measurement bridges balance two halves of a resistive, inductive or capacitive circuit where one half of the circuit is changing its value due to physical influence. The bridge is either implemented in the transducer itself (full bridge) or is added to the transducer in the amplifier (half or quarter bridge). The result is then a ratio of bridge output voltage to excitation voltage (e. g. in mV/V).

The Whetstone Bridge is resistive. A single metallic strain gauge typically with 120 or 350Ω applied to a system under test is integrated in a so called quarter bridge configuration. Resistor R2 is a high precision resistor with 120 or 350 Ohm and is used as completion resistor inside the instrument. The bridge is supplied by a certain excitation voltage and the returned signal voltage is measured back in ratio metric normalized way (mV/V).

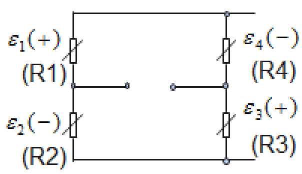


In order to calculate the strain from the gauge factor must be known. This number is provided together with the strain gauge from HBM.

BUT, environmental conditions are not ideal – variance in temperature around the strain gauge or test piece will influence results. This effect can be normalized in many ways. Per default HBM strain gauges are made of constantan reducing temperature effects. So in case temperature does not vary much it might be OK. The software can also compensate temperature influence if temperature is measured and the compensation curve is known (part of HBM strain gauge package). Last but not least using the Wheatstone bridge for temperature compensation is also possible in half bridge or full bridge configuration. Please find all different ways of strain gauge configurations in the Hofmann book from HBM available as free download.



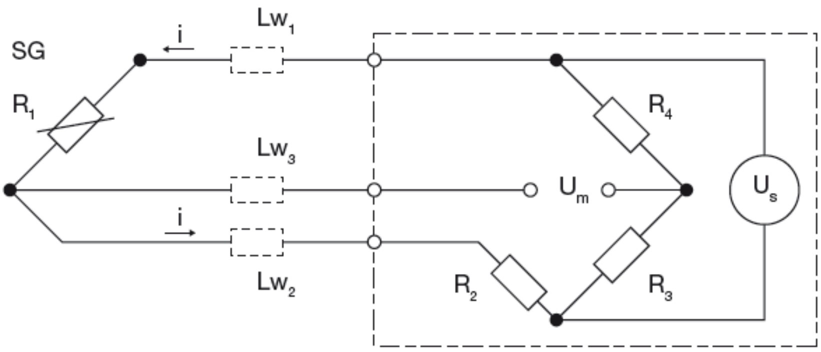
Transducers and instrument are often located up to several hundred meters apart. The cable therefore becomes an integral part of the measuring chain which must not be underestimated. This includes considerations of the total cost of a measuring



point. Good shielding of the cable is always important. It must surround the inner cores from the transducer up to the electronics like a Faraday cage. The shield must be laid out flat in the connectors. If connector casings have screw connections, they are part of the shield design. Current must never flow through the shield, as this would induce interference in the measurement signal.

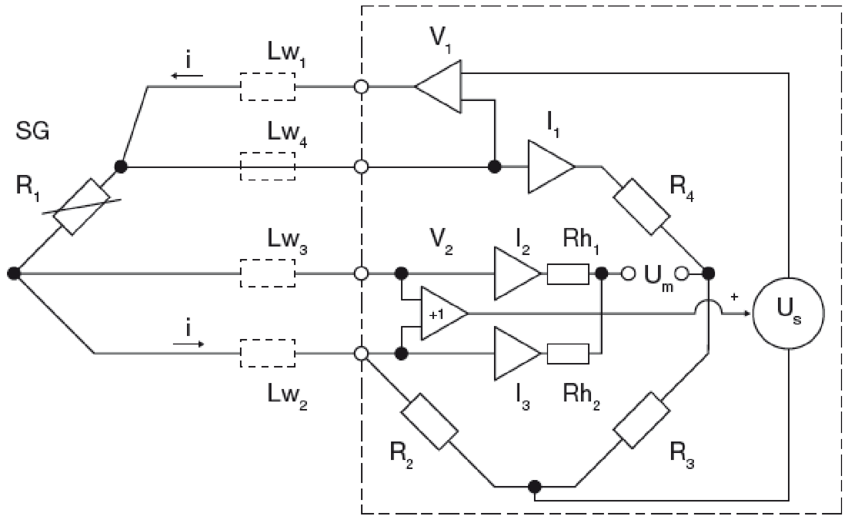
In the case of errors in the measuring chain caused by line resistance, two things are often neglected: the temperature response of the copper cable (4% in change per 10 K) and the asymmetry of a pair of conductors. In practical applications, differences of up to 5% are found even in twisted pairs.

This means that an error effect from cable resistance could be equal to many times more than the measurands. Special connecting methods, most of them also combined with carrier frequency amplifiers, are used to achieve accurate results despite this problem. The oldest and simplest connecting method is the three-wire circuit for quarter bridge applications. In this method the measuring potential on the SG (R1) is tapped with a third conductor. This ensures the line resistors of the bridge circuit are symmetrically assigned and avoids extremely large zero offsets. The circuit requires the line resistors to be equal in magnitude. Since practically no current is flowing through line Lw3 its resistance does not cause an error.



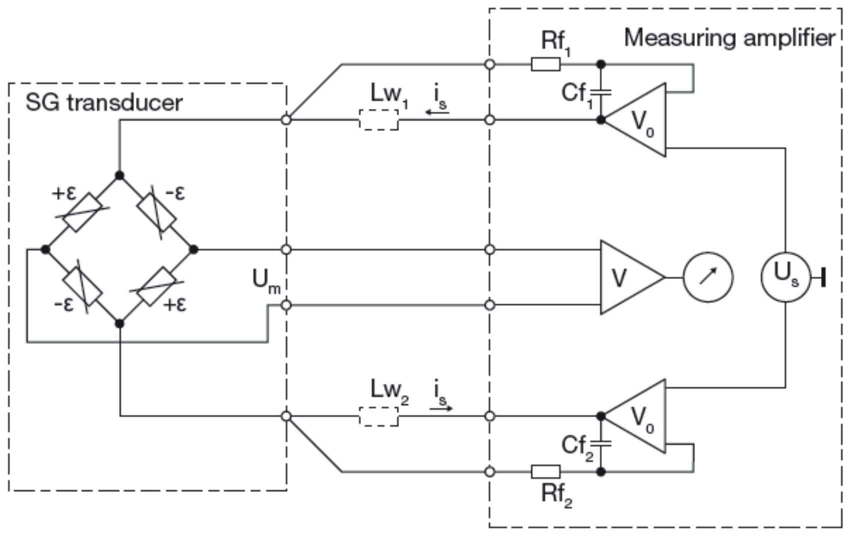
However, the voltage drops on Lw1 and Lw2 do lead to decreased sensitivity which the three-wire circuit is unable to compensate for.

The **four-wire method** is able to compensate for these defects with the appropriate electronic control circuits. The amplifier V1 regulates the voltage drop on Lw1. V2 measures the voltage drop on Lw2 and increases the bridge excitation voltage by the same amount. The impedance converter I1 is used to prevent current loading on line Lw3 due to the bridge resistance R4. Impedance converters I2 and I3 with auxiliary resistors Rh1 and Rh2 assign the voltage drop over Lw2 in equal parts to the SG (R1) and completion resistor R2. If there are still other contact and switch resistors in the measuring circuit, their voltage drops are also eliminated. The circuit arrangement is suitable for both constant excitation voltage (DC) and alternating voltage or also called carrier frequency (CF), and allows for cable lengths up to 200 meters and more. It should be noted in this regard that a constant current supply with large strains changes the measuring sensitivity of SGs and significant non-linearities occur. In bridge circuits, by contrast, both with large SG resistance tolerances and also with large strains, the measurement sensitivity remains nearly constant and the deviations in linearity are negligibly small. This property of bridges also ensures that a shunt signal (activating an instrument internal shunt resistance with some kOhm in parallel to the completion resistor R2) remains constant almost completely independently of the tolerances of the SG resistance R1 and can therefore be used for channel health check purposes.



In **half bridge configuration** using five wires is the best approach.

A **full bridge configuration** is used in applications where the highest degree of accuracy is required and in best case six wires are used compensating cable length influences. Measuring amplifiers supply the connected transducers with the bridge excitation voltage U_S, resulting in the excitation current i_S. This current causes voltage drops on line resistances (Lw1, Lw2) of the measurement cable with ensuing measurement errors.

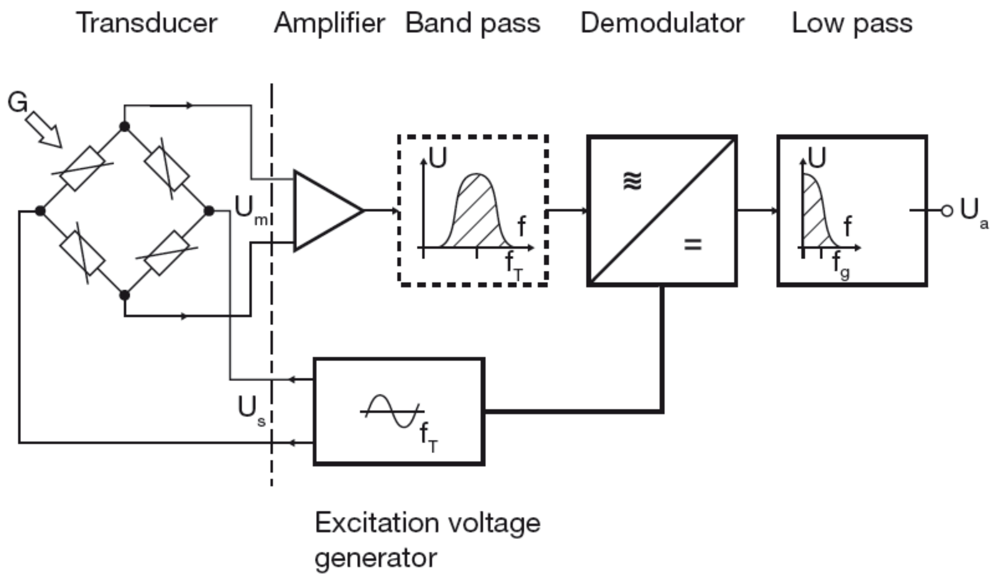


These errors can be avoided with a six-wire circuit, which taps the incoming bridge excitation voltage on the transducer and directs it back to the amplifier by means of two additional lines. The amplifier compares the bridge excitation voltage that is returned with the reference voltage and increases its output voltage by the amount of the voltage drops. Components Rf1, Cf1 and Rf2, Cf2 are used to stabilize the control circuit.

The nominal output signals of SG transducers are several millivolts, and must frequently be measured with high resolution. By contrast, input interference signals may be many volts in magnitude. Good suppression of interference voltage by the amplifier is therefore essential, as is a good connecting method. Measurement voltage U_m, bridge excitation voltage U_s and return voltage U_r are conducted in separately shielded, twisted line pairs to reduce the effect of electrical and magnetic fields. In carrier frequency amplifiers, this also has the effect of preventing crosstalk from the bridge excitation voltage to the measuring leads, i.e. a link between the supply lines and the measuring voltage lines. Since charge/discharge currents flow into the cable capacitance in carrier frequency amplifiers, the amplitude of Um is reduced and rotated in the phase due to internal bridge resistance. The two resistances RB/2 ensure that the returned voltage U_r undergoes the same change in amplitude and phase as U_m. Since the measuring amplifier always forms the measured value from the ratio U_m/U_r which completely corrects both voltage drops caused by the supply current and errors resulting from the charging/discharging of cable capacitances.

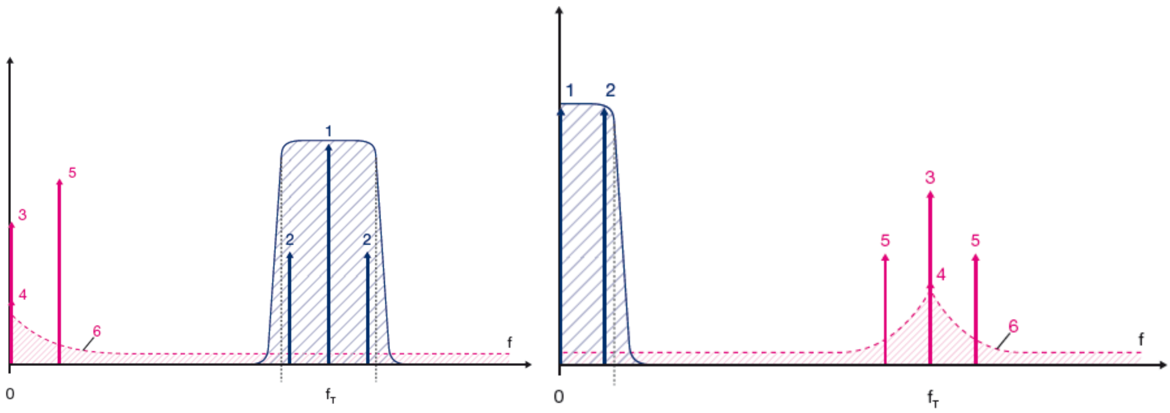
Carrier Frequency based Excitation Voltage in a Wheatstone Bridge

If very small measurement signals need to be measured in an environment of high electro-magnetic interference, carrier frequency based amplifiers is a good choice. They modulate the measurement signals and transform them into a frequency range that lies outside the typical noise and interference influences. Carrier frequency amplifiers supply transducers with an AC voltage that usually exhibits a sinusoidal or rectangular waveform. Only passive transducers such as resistance thermometers, SGs and inductive transducers can be measured in that way.



The shown full bridge transducer is supplied by an alternating voltage working as bridge excitation voltage U_S from the measurement amplifier. The measured signal U_m controlled by the physical measurands G is modulated proportionally to the excitation amplitude and carrier frequency. U_m is represented by the amplitude at the given carrier frequency f_T. The signal is amplified, runs through a band-pass filter that suppresses all signals outside the transfer range, and is then rectified with the correct phase in the demodulator. After this step the signal is smoothed by a digital low-pass filter on the output side. A dynamic load in a frequency range of $0 \ldots f_g$ appears on the amplifier input as an amplitude-modulated signal ($f_T \pm (0 \ldots fg)$). After amplification it is transformed back to the range $0 \ldots f_g$ by the demodulator. The carrier frequency amplifier principle requires more extensive circuitry compared to DC amplifiers, but is capable of separating measurement and interference signals suppressing them to the maximum. This makes it possible to eliminate the working point drift of amplifier input stages, thermo voltages and 50 or 60 Hz mains power interference signals, and to record the smallest measurement signals with high resolution and stability.

The measurement uncertainty for DC amplifiers is in the microvolt range, whereas carrier frequency amplifiers are able to resolve measurement signals reliably down to sub µV. For example, it is possible with carrier frequency amplifiers to measure the signal of a weak mechanical 50-Hz vibration reliably even if the measurement signal is overlaid by a much greater 50-Hz mains interference voltage.



Figures: left working with carrier frequency, right working with DC excitation.

The figures illustrate the working principle of carrier frequency amplifiers. The measurement signals “Static signal” (1) and “Dynamic signal” (2) are present on the amplifier input as amplitude-modulated carrier frequency voltages, while the interference signals “Input amplifier drift” (3), “Thermo voltages” (4), “50-Hz mains interference voltage” (5) and “Low-frequency flicker distortion” (6) are close to 0 Hz. Demodulation of the signals causes a frequency transformation and the signals change places. The static measurement signal is transformed to 0 Hz and the input amplifier drift as well as the thermo voltages and mains interference voltages are transformed to the range of the carrier frequency. Interference voltages can now be easily suppressed by using a low-pass filter on the output side. However, interference signals cannot be suppressed if they lie in the transmission band of the carrier frequency amplifier. Since the white noise extends evenly over all frequencies, the part of the noise voltage that lies in the transmission band of the carrier frequency amplifier is also transformed into the signal range. Thus carrier frequency amplifiers are able to eliminate practically all interference and error signals with the exception of white noise. The highest resolution of a carrier frequency amplifier physically possible is accordingly the ratio of the measurement signal to the noise voltage in the carrier frequency transmission band. The noise of a very good input amplifier is less than the noise of the transducer resistances. The absolute physical resolution limit of a good carrier frequency amplifier is therefore determined essentially by the noise of the transducer resistance. For example, the noise voltage of a 350 Ω SG transducer with a bandwidth of 1 Hz is just 0.0024 µV. Small 10-mV measurement signals can therefore still be measured with a resolution of 106 parts. Carrier frequency amplifiers have different carrier frequencies. The carrier frequency periodically charges and discharges the capacitances of the measurement cable, which can cause measurement errors. Since the error effect of the cable capacitances increases proportionately to the square of the carrier frequency, selecting the carrier frequency requires a compromise between the parameters for measurement accuracy, signal bandwidth and cable length. Amplifiers like the MX840B offer carrier frequency with 4.8 kHz and a resulting signal bandwidth < 1.5 kHz providing a wide range of bandwidth with all the advantageous of the carrier frequency method and are able to measure inductive full or half bridge sensors. However, they also exhibit the greatest effect of the cable. Cable lengths over 50 m should therefore be avoided. Measuring amplifiers with a low carrier frequency like 600 or 225 Hz meet higher requirements for accuracy even with cable lengths of a few hundred meters, but signal bandwidths is limited.

QuantumX Measurement Amplifier MX1615B

Quantum^{X} is a modular, freely scalable and distributable data acquisition system from HBM for measurement and testing purposes allowing quicker innovation. All modules offer Ethernet and FireWire interface and can be freely combined with each other. All channels work fully time synchronized - module to module with < 1 µs.

Picture: MX1615B – 16 channels strain gauge bridge amplifier

The MX1615B strain gauge bridge amplifier offers 16 channels. Every channel can be individually parameterized via software, supporting:

- **Strain gauges in the following configuration**
  - full bridge in 6 wire technology
  - ½ bridge in 5 wire technology
  - ¼ bridge in 3 or 4 wire technology (4 wire with DC and AC excitation)
  - Selectable excitation voltage: 0,5 / 1 / 2.5 / 5 V **constant** or **carrier frequency (CF)** based with maximum noise oppression
  - Internal 100 kOhm shunt resistor for channel health check or quick calibration
- **PT100** for temperature measurement
- **+/- 10 V** standardized voltage
- **Poti** for displacement measurement

Benefits working with QuantumX in general:

- Plug and measure using TEDS technology (IEEE 1451.4) – the electronic datasheet integrated in sensor or plug
- Freely scalable channel count (max data throughput of catman is 12 MS/s)
- Flexible sample rates: from 0.01 to 200 kS/s per channel
- Selectable digital low pass filter: Bessel / Butterworth from 0.1 … 2 kHz, filter off = max. bandwidth of 3 kHz
- Fully time synchronous parallel measurement
- Small size and light weight for mobile or portable use

Benefits working with QuantumX in strain gauge applications:

- No zero point shift
- No effect due to temperature variation around the connection cables
- No effect due to contact resistance (plug)
- Gauge factor does not vary with cable length (up to 200 m cable length possible)
- cable length automatically compensated
- compensating influence of ambient temperature of the module (AutoCal routines)

Our aim is to deliver measurement results with confidence. Maximum oppression of electro-mechanical noise sources coming from electrical power lines, machines or generators are achieved by:

- Carrier Frequency based excitation voltage measures strain with accurate amplitude but oppresses noise with lower frequency (but there is a price to pay for this outstanding technology: limited bandwidth – please calculate with 1/3 of CF. So here approximately 400 Hz)
- Galvanic isolation

For some applications it is needed to output the high quality strain gauge inputs in real-time over classic analog voltage output (MX878 / MX879) or over digital real-time bus protocol EtherCAT (CX27).
MX878 and MX879 offer also real-time math calculating a 6x6 matrix for cross talk compensation of applied strain gauges on a 6 DOF force transducer, also harmonic or arbitrary voltage output working as stimulation and finally limits switch or PID control.

catman®AP Software

catman®AP from HBM is a powerful software package for PC based data acquisition and data analysis with the following classified operation fields:

Live Data View and Storage

- visualize live data: physical quantities, digital bus signals, video, position (GPS), wheel force transducer, status in powerful objects over time, angle, other physical inputs or frequency of process and test data
  - y-t, x-y graph with history
  - online analysis frequency graph
  - numeric display
  - instrument
  - bar graph
  - interactive operation: switch, checkbox
- measurement and data acquisition jobs
  - high data throughput: 12 MS/s

  - start / stop condition: manual or automatic (trigger events), condition (zeroing)
  - data packaging: keep all data, peaks, cycle
  - storage format: binary, ASCII, Excel, MDF 3/4, Diadem, nSoft, Matlab, UFF, RPC III
  - meta information: tester, condition, part description

Live Data Analysis

- general online scientific math
  - basic algebra
  - statistics: class counting, min / max, mean, RMS
  - integral, differential
  - filter box / phase correction
  - trigonometric function, logic, ,
- structural durability testing math
  - rosette calculation: resulting strain, angle
  - cycle counter
  - vibration analysis in frequency domain
- powertrain / drivetrain math
  - angle based statistics: min, max, peak-to-peak

Post process Data Analysis and handling

- post process data analysis
  - graphical data visualization in time, frequency domain, position
  - data cleansing and preparation: curve operation (cut, eliminate outliers), statistics
  - general online scientific math
  - export in different data format
  - video based data analysis
  - structural durability testing math
  - powertrain / drivetrain math
- export data and report test result
  - export to different storage format
  - export visualization objects to Microsoft Word report template
  - printer page

Automating recurrent activity

- auto sequencer
- scripting

Additional system functionality

- Device configuration: communication, scan, parameterization, source naming, synchronization
- IO parameterization
  - online / offline
  - inputs (analog, digital, video, bus signals, GPS, …), outputs
- Diagnostics

Thanks to an intuitive user interface only a few mouse clicks start your measurement job. Simply configure the amplifier using TEDS, the transducer electronic data sheet, or the extendible sensor database – and the test can start. Many options for graphical data analysis and versatile export options make catman®AP a reliable and indispensable tool for every measurement technician.

PRACTICAL PART

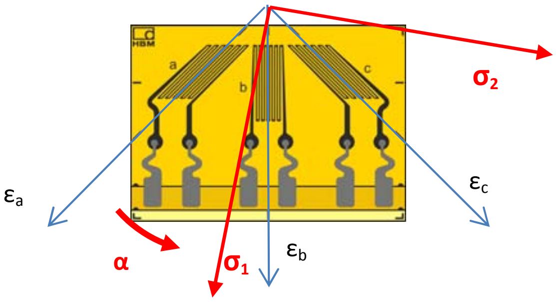
The transducers of the double bending beam are applied to the spots where we estimate the highest strain.

Strain Gauge Rosettes

A strain gauge rosette comes with a fix geometric pattern of three strain gauges that allows the software to calculation the overall strain and direction. Many variants with different positions and angles are available, where all three strain gauges are on top of each other or especially designed for residual stress analysis. The software catman®AP can calculate the principal direction of strain and angle in an easy way.

More information about all different types of strain gages can be found on our web page www.hbm.com.

On our bending beam demo two HBM strain gauge rosettes type **RY101-6/120** are applied with the following footprint:



Picture: strain gauge rosette package leaflet

From the measured strains and the known material properties (modulus of elasticity and Poissons' ratio), the absolute value and the direction of these mechanical stresses are determined. These calculations are based on Hooke's Law which applies to the elastic deformation range of linear-elastic materials.

In durability testing or in general experimental stress analysis 3-grid rosettes are used for strain measurement. These rosettes are available in 0° / 45° / 90° and 0° / 60° / 120° versions. The three measuring grids of the rosettes are designated with the letters a, b and c measuring the three strains ε_a, ε_b and ε_c.

The principle / orthogonal nominal stresses σ_1 and σ_2 are calculated for the 0° / 45° / 90° rosette by:

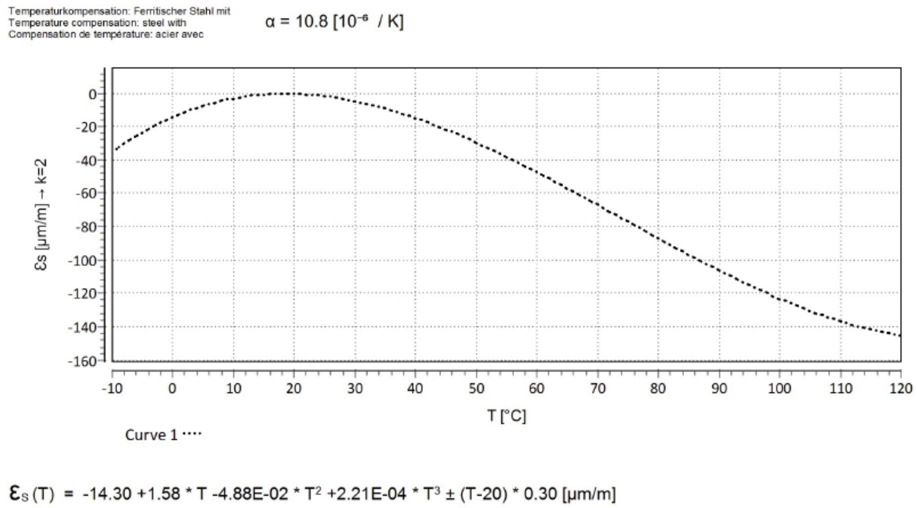
$$\sigma = \frac{E}{(1-\nu)} \times \frac{(\varepsilon a + \varepsilon c)}{2} \pm \frac{E}{\sqrt{2} \times (1+\nu)} \sqrt{(\varepsilon a - \varepsilon b)^2 + (\varepsilon c - \varepsilon b)^2}$$

The principal direction (angle) for 0° / 45° / 90° rosettes is calculated by:

$$\tan \alpha = \frac{2\varepsilon_b - \varepsilon_a - \varepsilon_c}{\varepsilon_a - \varepsilon_a}$$

Temperature effects

The resistance of the strain gauge does not only change in response to the given mechanical load but also to the changes in temperature of the test specimen and the overall environment. Temperature related effects can cause a significant error in strain measurements. This signal, called the apparent strain, is superimposed on the actual measure.



Picture: strain gauge rosette package leaflet – temperature influence

So we need to find a solution how to compensate temperature and thus resistance changes of the measurement.

Various thermal effects contribute to the apparent strain:

- expansion of the test specimen
- change in the strain gauge resistance due to temperature
- contraction of the strain gauge measuring grid foil
- resistance of the connection wires

The apparent strain by temperature changes can be represented by the following formula:

$$\varepsilon_S(\mathrm{T}) = \left(\frac{\alpha_r}{k} + \alpha_b - \alpha_m\right) * \Delta\vartheta$$

With:

ε_s = apparent strain of the strain gauge
α_r = temperature coefficient of the electrical resistance of the measuring grid foil
α_b = thermal expansion coefficient of the measurement object
α_m = thermal expansion coefficient of the measuring grid material
k = gauge factor (sometimes called k factor) of the strain gauge
$\Delta\vartheta$ = temperature difference that triggers the apparent strain

Compensation

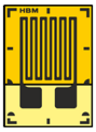
Temperature effects in strain gauge measurements can be compensated for example by setting up a half or full bridge. This approach makes uses the principle of a Wheatstone bridge reflecting the temperature influence of the measurement signal with opposite signs. If you know mechanical strain direction you can also apply a so called "compensation strain gauge" compensating temperature effects.

In our demo case using a quarter bridge strain gauge circuits we compensate the apparent strain by using a dedicted temperature sensor.

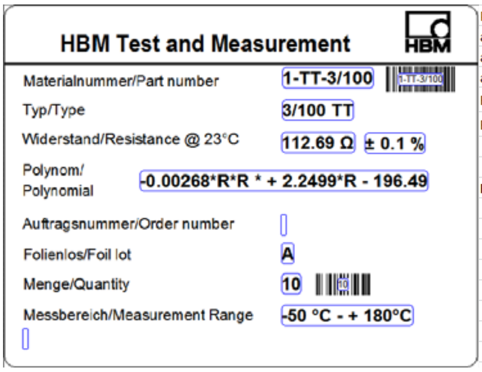
Temperature and resistance influence of lead wires, plugs, contacts and the amplifier heating itself is compensated by HBM strain gage bridge technology and QuantumX automatically. In our case by using a quarter bridge four-wire circuits.

Temperature Sensors

Temperature can be measured in many different ways. Most dominant transducer types are thermocouples and the resistive RTD types (PT100, PT1000, …), strain gauges, NTC, PTC or KTY. The "best choice" depends on temperature range, accuracy, size, dynamical behaviour, price, equipment I have and so forth.

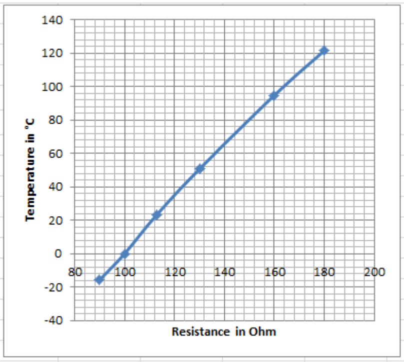


HBM offers a strain gauge and resistive based temperature sensor named **TT-3/100**
Similar to a Pt100 the resistance is 100 Ohm at 0 °C.
Linearization: polynomial per datasheet, table based with a quick comparison in EXCEL.
Connection technology: 4-wire (cable length compensation)



Polynomial lin.	a0 + a1*R + a2*R*R	
a0	-196,49	
a1	2,2499	
a2	-0,00268	
R_0	100	Ohm
R_{23}	112,69	Ohm

Resistance (Ohm)	Temperatur (°C)
90	-15,707
100	0
112,69	23
130	50,705
160	94,886
180	121,66



Picture: TT-3/100 temperature sensor from HBM

Working with the Software

Connect your QuantumX MX1615B via Ethernet to your PC or integrate into your Local Area Network.
Start catman and the demo project or create a new project and create everything from scratch. The following pages can be seen as tutorial with

Channel Parameterization
Channel parameterization in catman®AP can be done in different ways.

Live parameterization together with the instrument:
The most common workflow is by using the S**ensor Database** integrated in catman. This database can be seen as collection or description of many s**ensors represented by their digital datasheets** or just a **signal description** when it comes to pure voltage inputs**.** The sensor database can be stored on the same client catman is running or server based even with a local reference. Adding a new data sheet is easy as there are many templates available. This approach is highly reusable, channel configuration is quick and you can share sensors within a group. The sensor database also hosts CAN message descriptions or DBC files.

A **fully automatic** channel parameterization is possible through a **digital sensor datasheet** stored on a small chip based on **TEDS** technology located in the sensor or plug. TEDS stands for **T**ransducer **E**lectronic **D**ata **S**heet and describes in short words a standardized sensor datasheet based on different so called templates. TEDS is internationally standardized in IEEE1451 and allows true plug and measure getting quick results with many more advantageous. The above mentioned sensor datasheet can also be stored in a TEDS chip. Just drag and drop it to the channel with the sensor. All sensors with TEDS are clearly marked in the channel list.

Offline parameterization without the instrument:
There are two possible ways for an offline parameterization.
The **Wizard** is a step by step parameterization based on virtual instruments representing channels and their character.
The spreadsheet approach using an offline parameterization template you find in the catman route folder and based on **Microsoft Excel**. The spreadsheet shows all parameters. Larger companies, power users or users with many DAQ systems take this approach integrating their data acquisition jobs into their development and data flow processes which has aspects of an asset management.

In this experimental demo we mainly use quarter bridges and thus we will work with the **Sensor Database**.

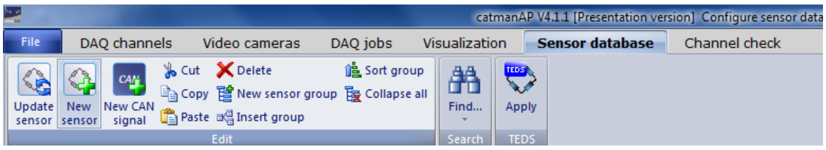
The typical sensor datasheet consists of

- Transducer name
- Calibration data / scaling type: physical -> electrical, scaling points
- Additional electrical information: supply voltage, bridge excitation type, resistance / impedance
- Meta information (identification, quality)
    - Manufacturer, type, model name, serial number
    - Calibration date and validity
    - User comments
    - real datasheet as PDF file

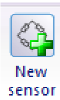
Just drag & drop the digital datasheet to the channel or highlight several channels and double click the sensor for parameterization.

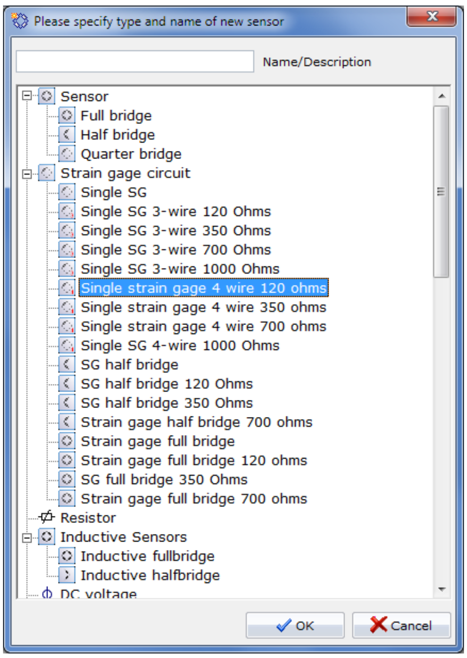
After parameterization you can also calibrate the measurement chain and then re-store the new scaling parameters in the sensor datasheet and the database. Please go to the “Sensor Database” tab and integrate all sensor or transducer types of this demo.

For this purpose you can also insert a new group into your sensor database under “my sensors”.



Now add a new sensor data sheets

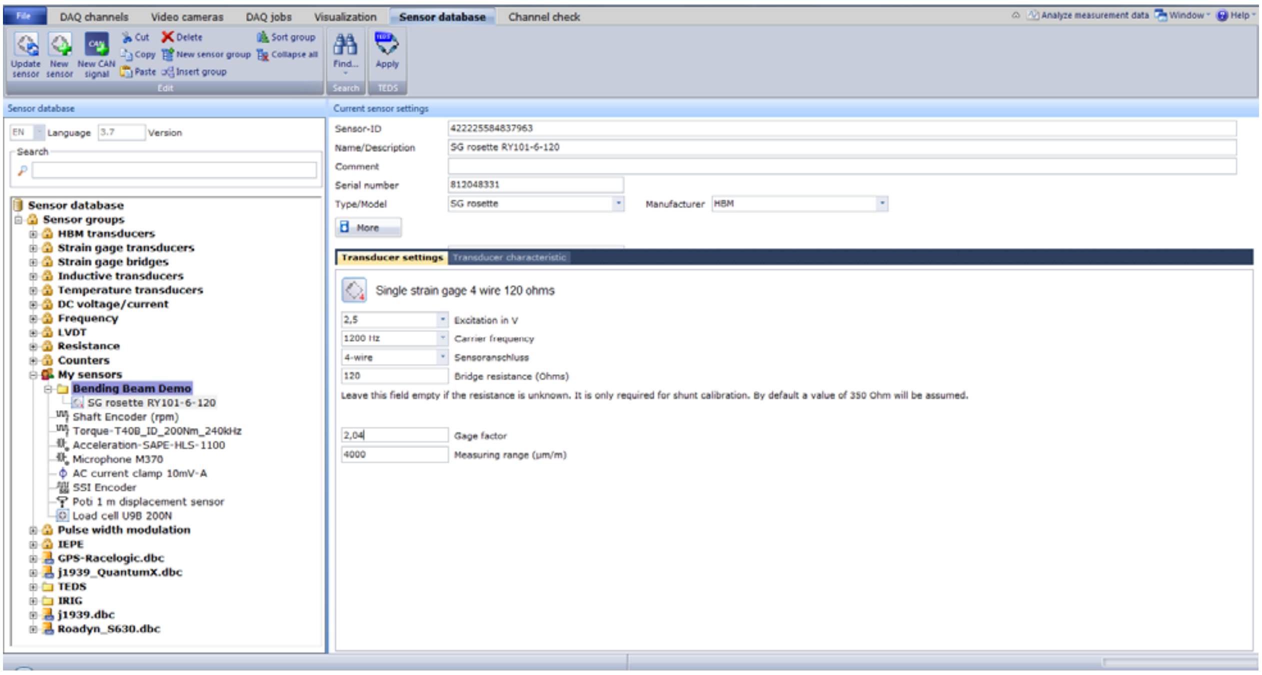




The strain gauge rosette

Take over all relevant information from the package leaflet.

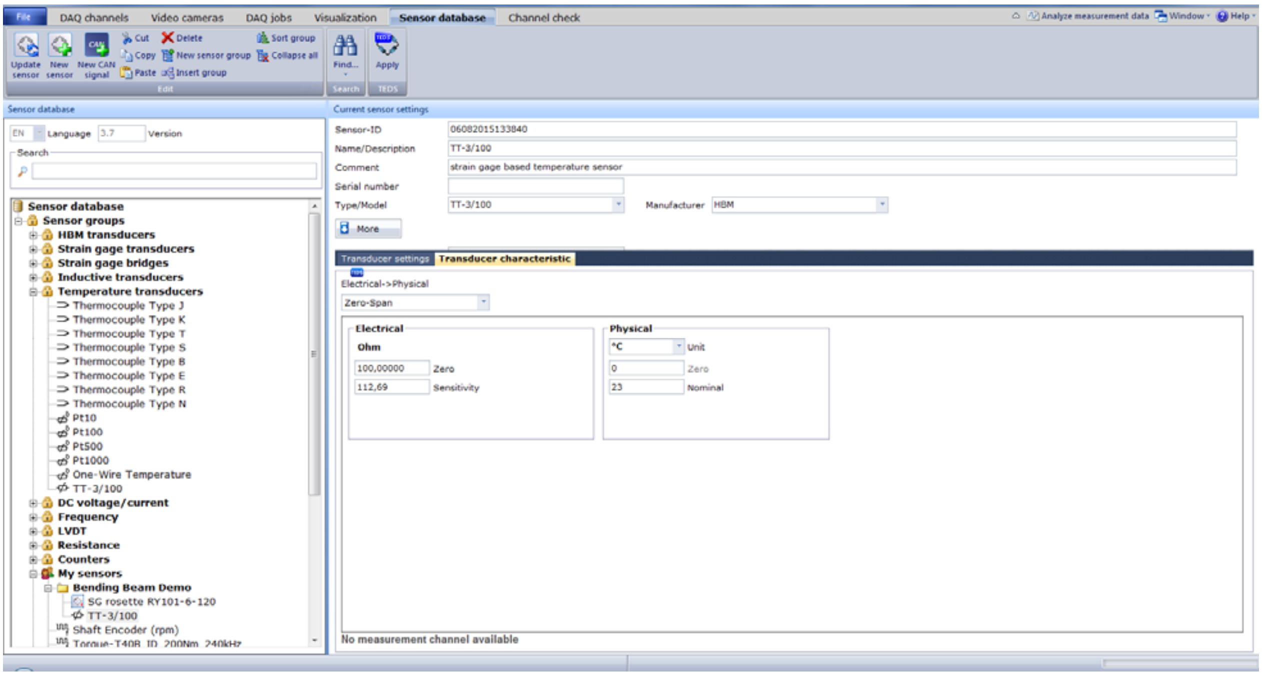
For the k factor just take one reference value. This value can be modified in the channel list as well.



The strain based temperature sensor

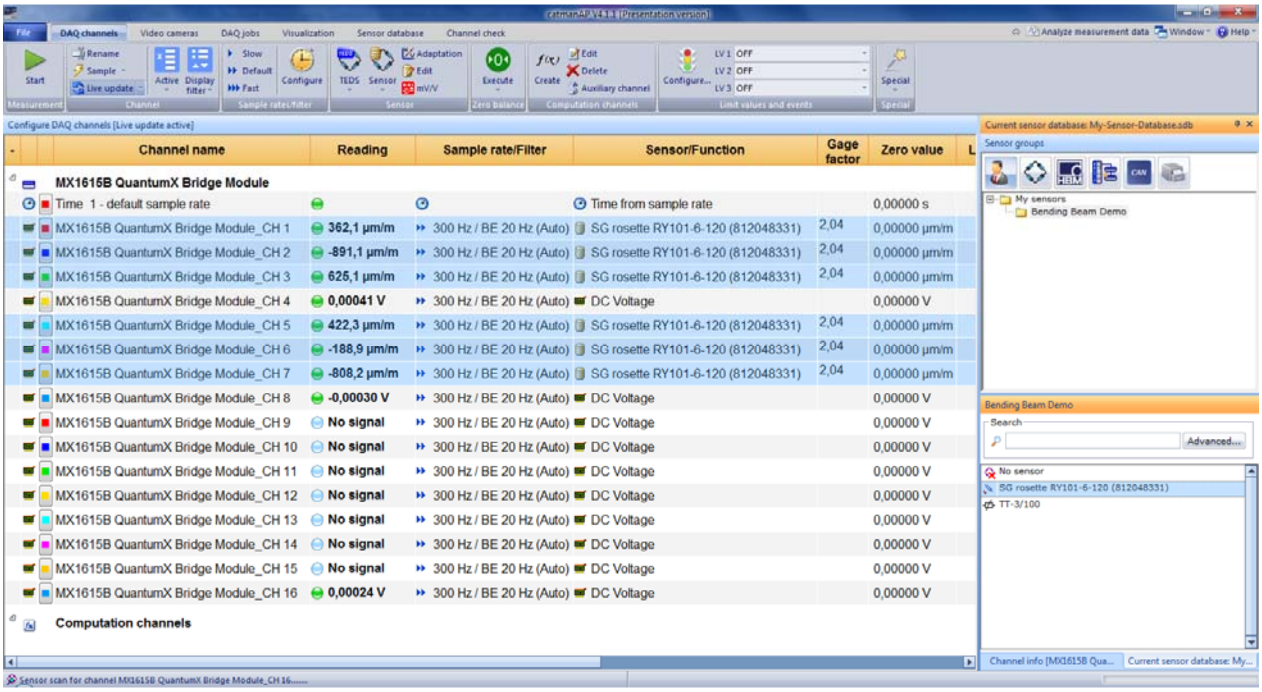
TT-3/100 is already part of the sensor database

So you can copy this type of sensor to the new group of sensors and modify it lightly.

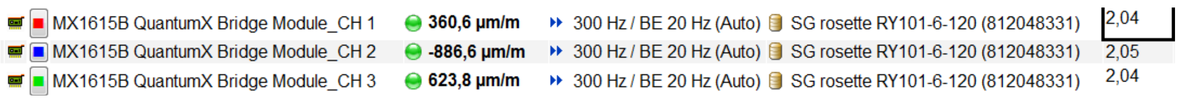


Channel parameterization

Now highlight all channels you want to parameterize with the same sensor type by holding down the Ctrl button of your keyboard, select the channels with your mouse and double click to the reference sensor of your sensor database.



Directly enter the correct k factors in the corresponding cell:



Parameterize the two channels with TT-3/100 temperature sensor in the same way.

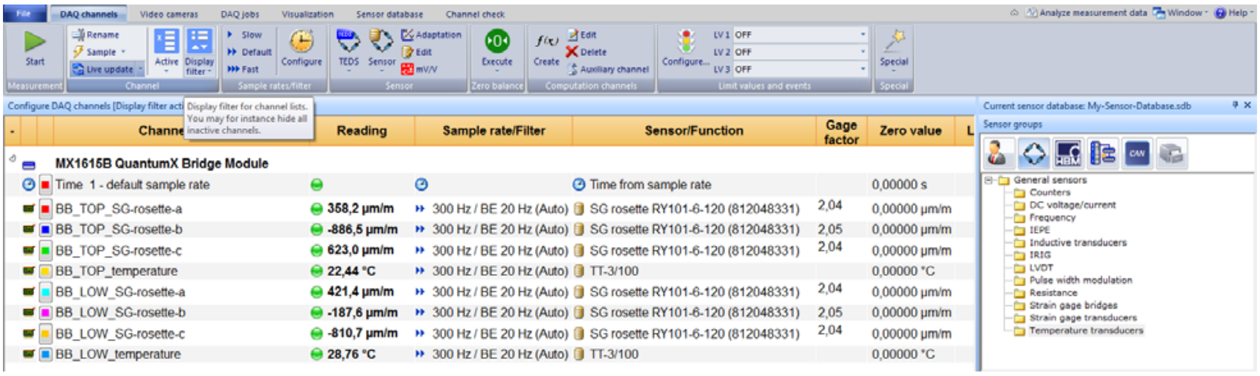
Signal Naming

Find appropriate names for all channels. This is important for **traceable data analysis**, **comparing** different test data or existing data and for a good test report.

Naming is somehow philosophy – some like to name the “measurement spot or location”, others name the “sensor or transducer” or like it more generic in taking over the “channel name of the device”.

Enter a name you can clearly identify the measurement spot in post-process data analysis several weeks later.
Here is a suggestion describing the measurement spot (bending beam top or lower section) and the sensor type (strain gauge rosette or temperature):

- BB_TOP_SG-rosette-a / BB_ TOP_SG-rosette-b / BB_ TOP_SG-rosette-c
- BB_TOP_temperature
- BB_LOW_ SG-rosette-a / BB_ LOW_ SG-rosette_b / BB_ LOW_ SG-rosette_c
- BB_LOW_temperature



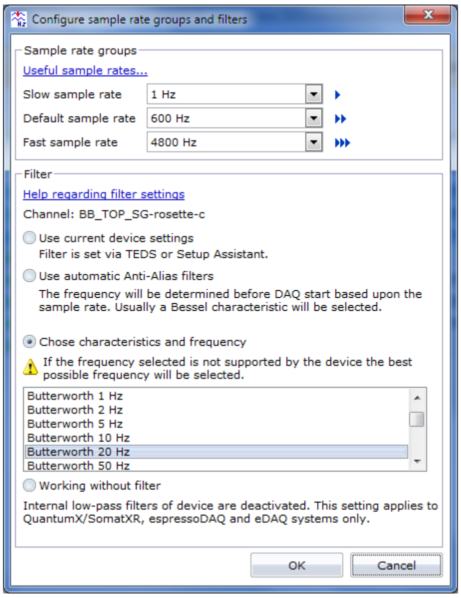
Sample rate and filter

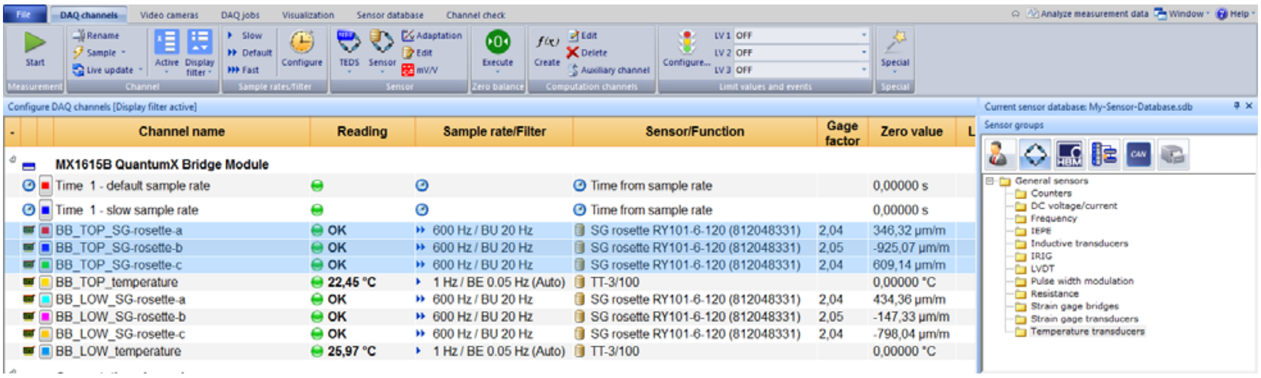
One generally good approach is working with a high sample rate and a filter offering max bandwidth per channel.

Then execute a test with active load and vibration, do a quick frequency analysis. Take the maximum frequency response and amplitude you need to consider in your analysis as "harming" and then take the adequate filter for the job. For slow mechanical systems we recommend using Bessel filter and a minimum of factor 10 for sample rate.

In our demo the frequency response with full dynamic load is **< 20 Hz** so we select:

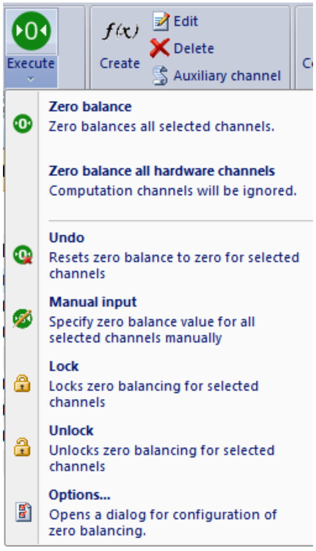
- Digital low pass filter: Bessel, 20 Hz corner frequency
- Sample rate: 600 Hz (here even factor 25)





Initializing channels

Before applying any load to the bending beam lock all temperature sensor inputs from zeroing.

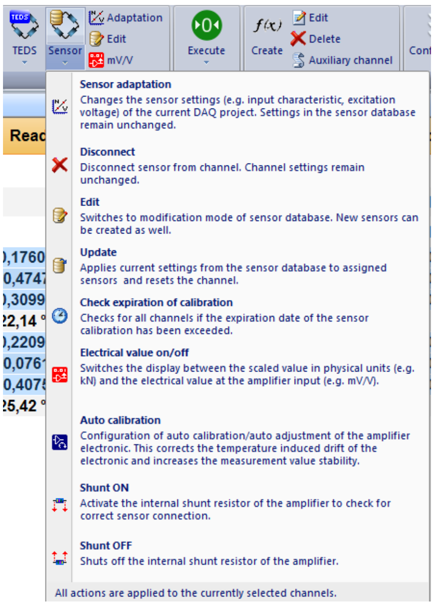


If you zero also the strain gauge inputs the channels will look like this. In this special case of a bending beam with alternating load we need to think about zeroing when calculating the angle. You will find out in a later step.

Channel name	Reading	Sample rate/Filter	Sensor/Function	Gage factor	Zero value
MX1615B QuantumX Bridge Module					
Time 1 - default sample rate			Time from sample rate		0,00000 s
Time 1 - slow sample rate			Time from sample rate		0,00000 s
BB_TOP_SG-rosette-a	-0,4 µm/m	600 Hz / BU 20 Hz	SG rosette RY101-6-120 (812048331)	2,04	345,01 µm/m
BB_TOP_SG-rosette-b	-0,3 µm/m	600 Hz / BU 20 Hz	SG rosette RY101-6-120 (812048331)	2,05	-925,87 µm/m
BB_TOP_SG-rosette-c	-0,6 µm/m	600 Hz / BU 20 Hz	SG rosette RY101-6-120 (812048331)	2,04	607,92 µm/m
BB_TOP_temperature	22,23 °C	1 Hz / BE 0.05 Hz (Auto)	TT-3/100		0,00000 °C
BB_LOW_SG-rosette-a	-0,3 µm/m	600 Hz / BU 20 Hz	SG rosette RY101-6-120 (812048331)	2,04	433,30 µm/m
BB_LOW_SG-rosette-b	-0,1 µm/m	600 Hz / BU 20 Hz	SG rosette RY101-6-120 (812048331)	2,05	-148,43 µm/m
BB_LOW_SG-rosette-c	0,1 µm/m	600 Hz / BU 20 Hz	SG rosette RY101-6-120 (812048331)	2,04	-798,89 µm/m
BB_LOW_temperature	25,51 °C	1 Hz / BE 0.05 Hz (Auto)	TT-3/100		0,00000 °C

Other channel parameters

There are a few other parameters available which shall be mentioned here:



Sensor adaption: changes sensor settings directly on the channel and afterwards it can be played back to the sensor database.

Check expiration of calibration: in case your company wide quality guideline says that all sensors need to be recalibrated every 12 months, this function allows you to check all used sensors if their calibration interval has been expired.

Electrical value: When working with ratio metric bridge type inputs you can select to show the readings also directly in mV/V.

Auto calibration: All QuantumX bridge inputs work with auto calibration routines per default. In this mode all inputs are cyclically switched to an internal reference source for some fragments of a second minimizing for example temperature influence.

Shunting: This functionality allows you to activate an internal or external shunt resistor to electrically stimulate unbalance the bridge.

Strain gauge temperature compensation

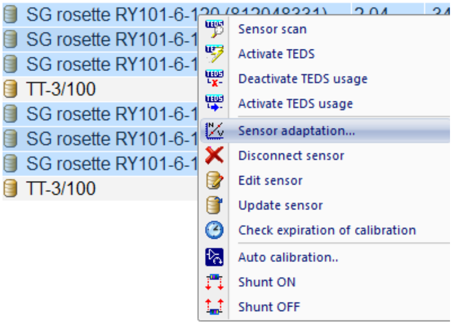
Compensating temperature effects of strain gauges with catman can be done by referencing the channel to:

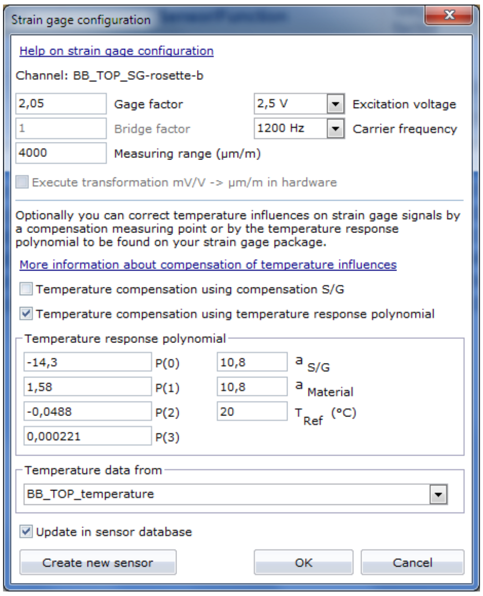
- a *compensation strain gauge*
- a *temperature response polynomials* for apparent strain as indicated on the strain gauge package (see above)

Channels with identical parameters for the corresponding temperature channel and polynomial can be handled together. Strain gauges from the same production batch always have identical polynomials.

When defining the temperature channels, note that the actual temperature of the material must be measured at the measuring point. Depending on the application, several temperature measurement points may be necessary.

In catman AP, the configuration dialog for a strain gauge can be accessed from the central "measurement channels" worksheet. To do this, highlight all strain gauge channels to be adapted with the mouse and right-click to open the "Sensor adaptation" dialog.

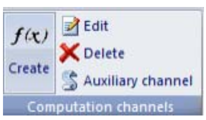




Highlight the second rosette and reference the relevant temperature channel.

Online processing – Rosette calculation

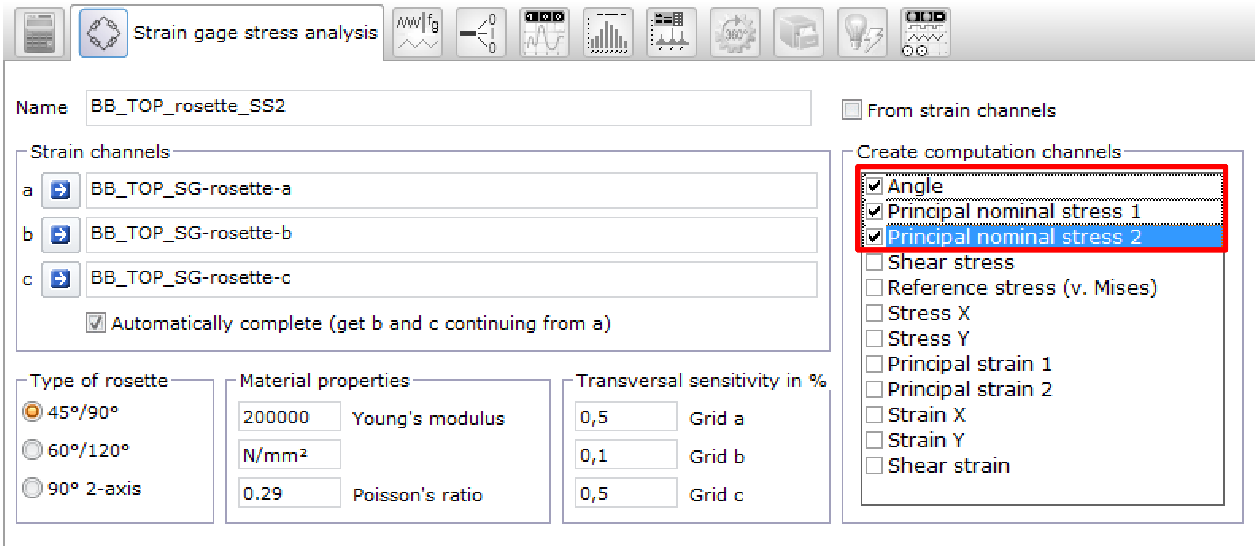
Online processing of measurement data is powerful. With this functionality you are able visualizing on the spot results and store all relevant data without a need for post processing. For this purpose catman offer a powerful and open **math calculator toolbox**.



Go to the channel overview and open the “Computation channels” and the “Strain gauge stress analysis” dialogue. Drag & drop the first channel of the rosette to the field “Strain channels” and parameterize accordingly for both rosettes.

Fill in all necessary parameters for the steel plate (see 1. chapter) and rosette geometry and transversal sensitivity.

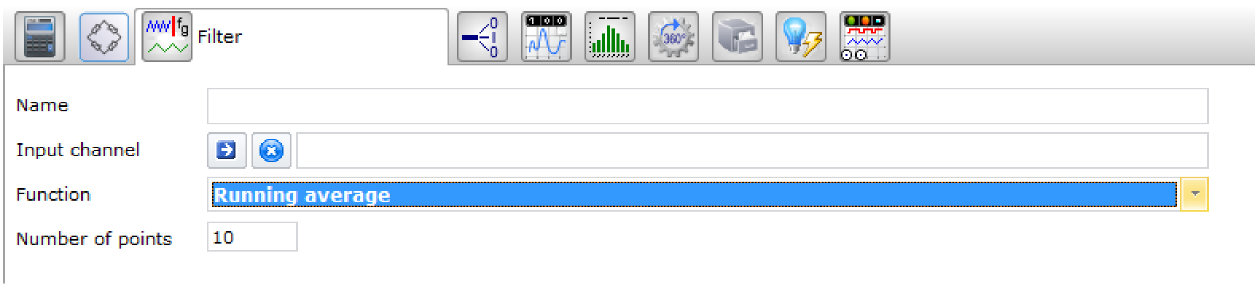
Create the computation channels for *Angle* and *Principle nominal stress 1 and 2*.



Online processing – Filter

All signals coming from QuantumX MX1615B are already digitally filtered as these signals can be used in real-time as well. Catman offers an additional **Filter toolbox** with the following filter types:

- Running average
- Running RMS
- Mean over a certain time window
- Low and high-pass Bessel or Butterworth
- Sound pressure filter (A-weighted in dB / dBA
- Phase correction (runtime delay)
- Human vibration filters with various weighting functions to EN ISO 8041 (for example W_d weighting for horizontal whole-body vibrations in the x or y direction. Refer also to ISO 2631)



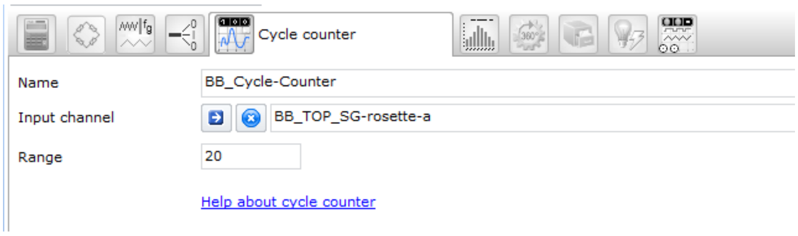
We don’t use extra filters in this demo.

Online processing – Cycle Counter

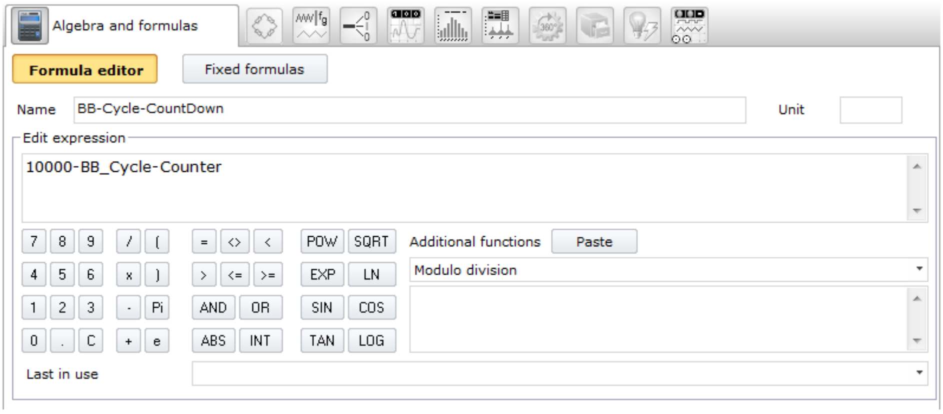
With periodic signals the **Cycle Counter** enables you to calculate the number of test or load cycles from one specific sensor.

Open the “Computation channels” and the “Cycle Counter” dialogue. Drag & drop the channel with the periodic signal into the field Channel to monitor. Specify the Span (hysteresis), i.e. the peak-to-peak amplitude which the signal must have as a minimum to be counted as an oscillation. Any form of signal can be taken and it does not need to be sinusoidal. Favourable values are, for example, 20% of a peak-to-peak amplitude. The value should be clearly above the signal noise level to prevent erroneous counting. Use a filter as required if you have a signal with short but high perturbation amplitudes.

Example: BB_TOP_SG-Rosette-a over 20 µm/m in relative range counts as 1 cycle.



With some basic algebra you can create a **Cycle Count Down** which can be used to stop the overall test, or for sending out an email or simple as overall indicator.



Online processing - Class Counting

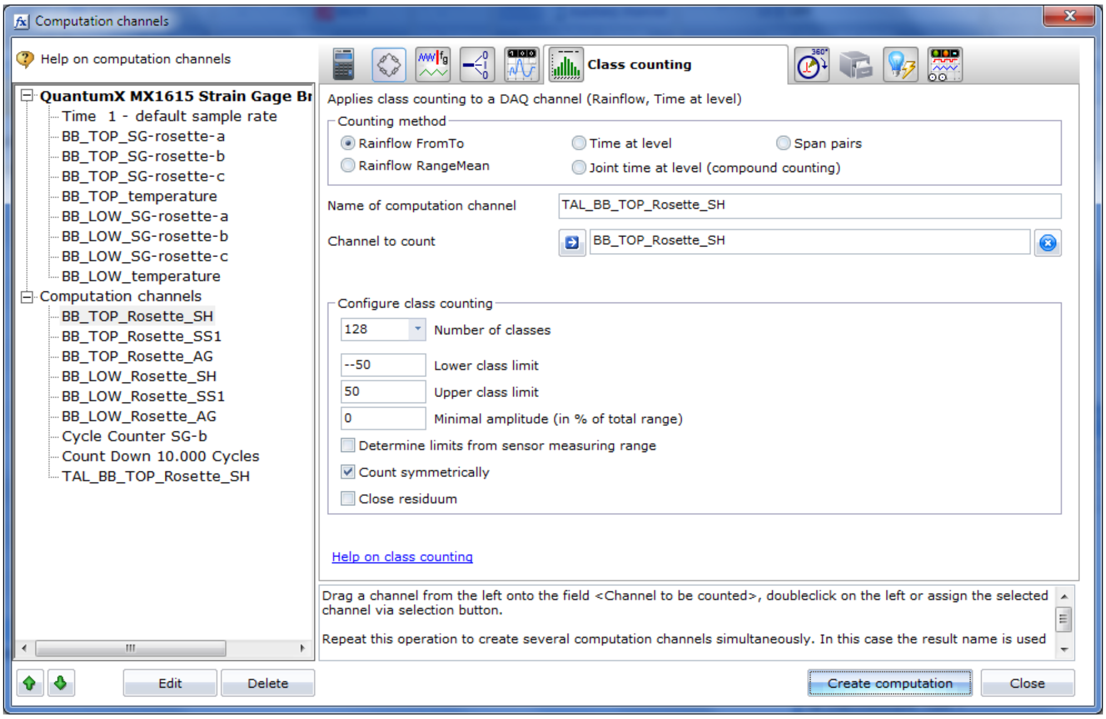
Especially in fatigue analysis but also in long term measurement jobs data classification and reduction to the relevant part is useful.

catman offers the following mathematical class counting methods:

- Time at level (TAL) determines how long a signal is located in a certain amplitude range subdivided into certain sections (or also called classes or bins), displayed in a 2D-histogram.
- Rainflow (FromTo or RangeMean) class counting is mainly used in material fatigue analysis. This method counts the frequency of occurrence of certain amplitude values of measured material stresses. To achieve this, the amplitude range of the output signal is subdivided into sections, the so-called classes or bins.
- Span pairs
- Joint time at level

Especially the rainflow-counting algorithm is the base for the so called Miner's rule in order to assess the fatigue life of a structure subject to complex and high-cycle fatigue loading tests. In high-cycle fatigue situations, materials performance is commonly characterized by an S-N curve, also known as a Wöhler curve. This is a graph of the magnitude of a cyclic stress (S) against the logarithmic scale of cycles to failure (N). S-N curves come from material or so called coupon tests where a regular sinusoidal stress is applied by a load machine counting the number of cycles to failure. Analysis of fatigue data requires techniques from statistics, especially survival analysis and linear regression.

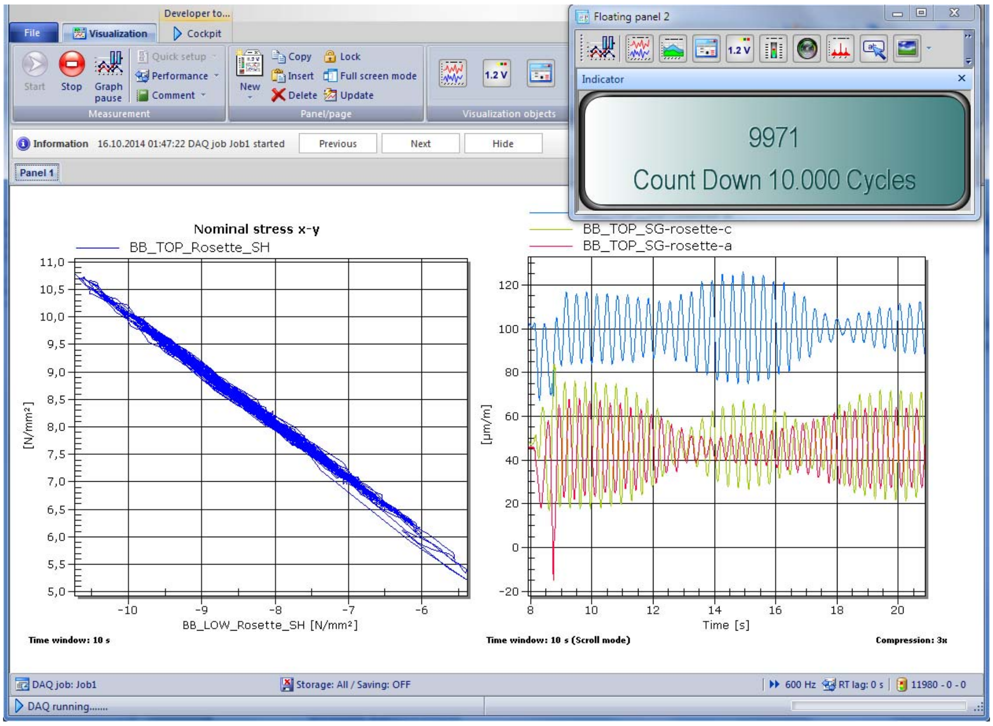
For simple periodic loadings like in the used demo model rainflow counting is not necessary. As an example we use the class counting method **Time at Level** on some inputs.



Visualization and Operation

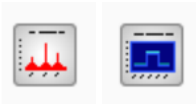
Catman offers many strong visualization objects.

You can use the Count Down as Floating Panel overlaying all panels or on a second screen together with other main signals you want to have in constant overview:



Frequency Analysis

In the menu you find three ways of FFT visualization objects:



Live FFT and Spectrogram

The Live FFT displays the frequency spectrum of one or more channels. Spectrograms show the spectra evolving over time while the FFT graph only shows the current frequency spectrum. Spectrograms can also be used in analysis mode - just drag a channel to the graph and the joint time frequency will be computed and displayed.

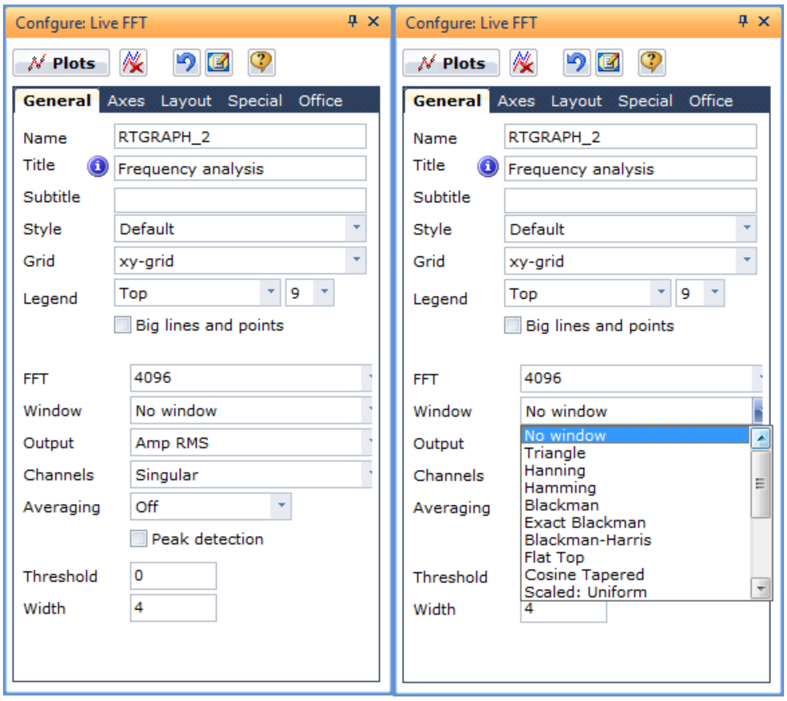
More precisely they display the so called Amplitude Spectrum in RMS (unit of time signal). A Live-FFT graph can display a single spectrum per channel or combine three channels to a single spectrum by performing a vector addition of the individual spectra. The latter scenario is for instance useful for tri-axial accelerometers. Use the "Channels" mode parameter to configure this property. With each incoming block of data a new FFT is computed. The spectrogram does not possess this feature. It can only show the spectrum of one channel at a time.

In addition to just display the spectra the graph keeps also track of the peaks detected in a spectrum. Up to 16 peaks can be detected. Peak detection is strongly determined by the "Threshold" and "Width" parameters - a peak must at least possess Width data points above Threshold to be considered as a valid peak.

If two or three channels are added to the graph, their spectra can be combined to a single summed spectrum, e.g.:
s = sqrt(s1*s1 + s2*s2 + s3*s3)

This mode is denoted as "vector sum" mode. It is useful for instance for 3-axial accelerometers. See the "Channels" mode parameter in the graph configuration dialog. The maximum number of channels which can be combined to a vector sum is three.

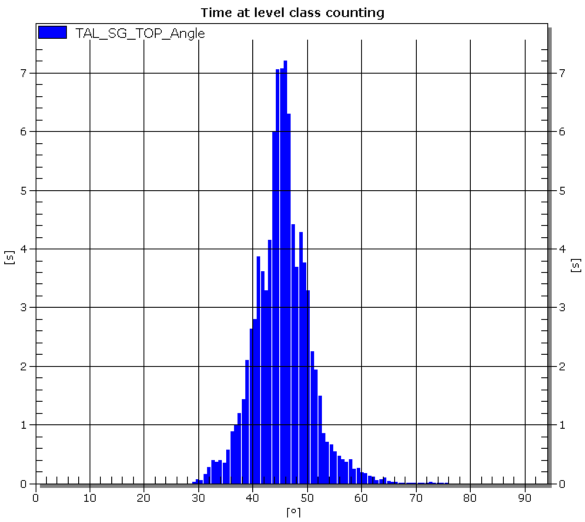
Live-FFT graphs have similar zoom and cursor support as standard graphs. The spectrogram has only a coarse frequency zoom (buttons in upper left corner of the graph).



The characteristics of the different FFT windows can be found in the www.

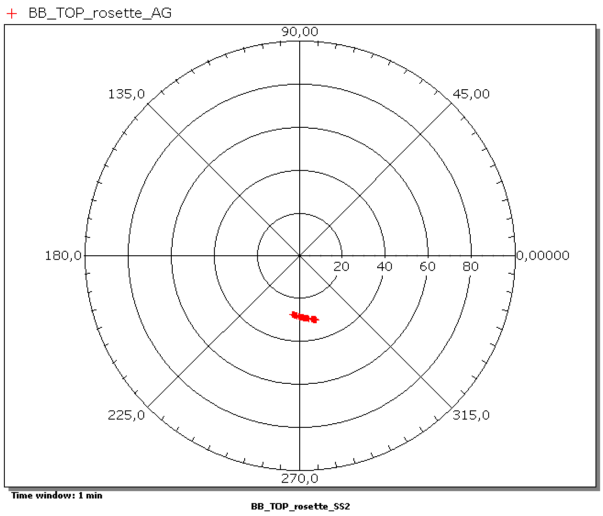
Class Counting

A Time-at-Level histogram of the angle might look like this:



Polar diagram

Principle nominal stress over angle might look like this:



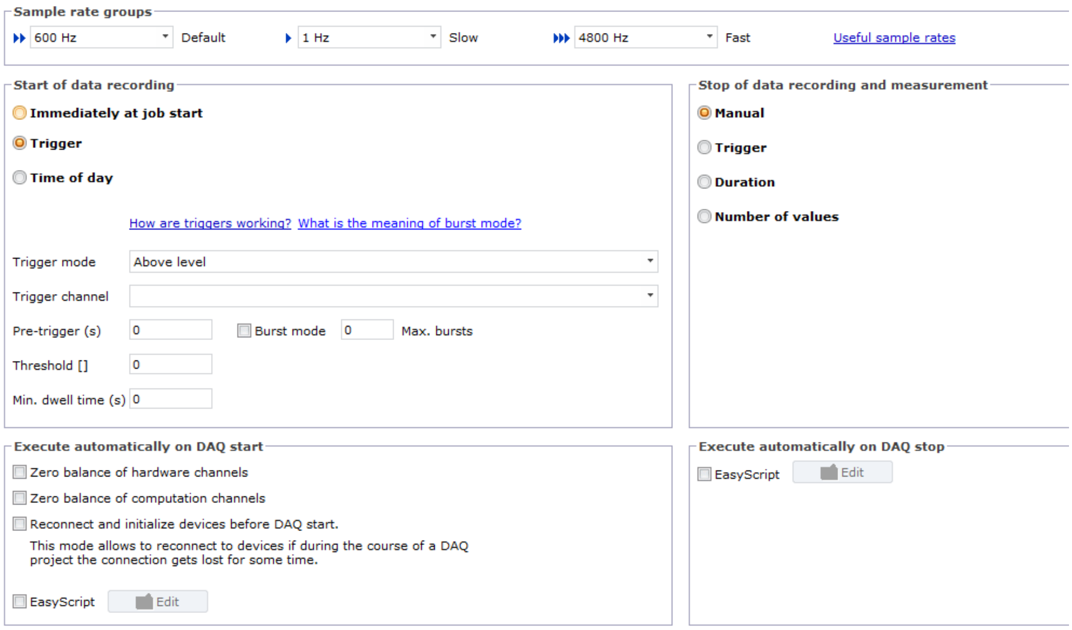
Data Acquisition Job and Storage

Storing data is the essential part in data acquisition. Listening to customer demands over many years catman®AP offers the most relevant options in starting and stopping data storage.

Please consider that beside the signal data also meta data is relevant and shall be stored in the data file.

Let's name the overall set of necessary information as **DAQ job**.

In most of the cases **triggers** start and stop DAQ jobs and activate data storage in a file.

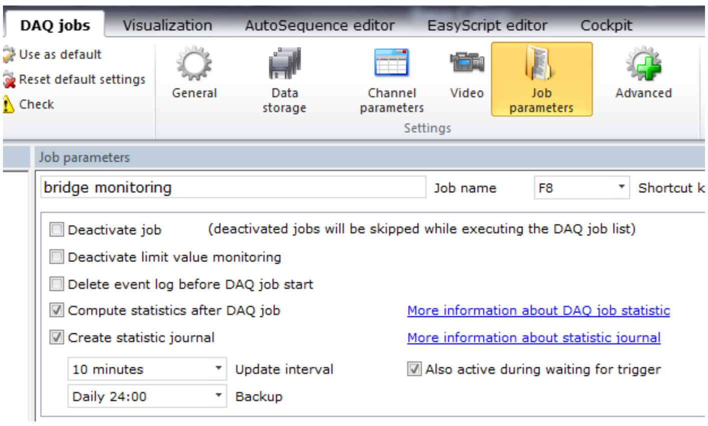


Create yourself the best start and stop condition – manual, triggered, time or sample based.

The Burst Mode can only be applied with DAQ jobs using a start trigger. If burst mode is active, the job will not terminate if the stop condition occurs. Instead the job starts waiting for the next start trigger event again. As a result, the final data file will contain many chunks of data, each representing a single trigger event (including pre-trigger)
The job will terminate if either the maximum number of bursts has been reached or if stopped manually (STOP button). All special storage modes like manual storage, peak storage, fast stream or cyclic interval storage are not applicable if bust mode is active. The DAQ job must use either Trigger or Duration as stop condition. In burst mode these conditions will determine the duration of the burst. If displaying channels from a file generated in burst mode, make sure to use a time channel for the x-axis of a graph! Just using the dt (from samplerate) would remove the time gaps between the individual trigger events. Any trigger event occurring before the stop condition (incl. post-trigger!) will not be considered.

The **Data storage** settings allow some helpful functionality. For **long term** structural testing data can be saved by special storage modes.

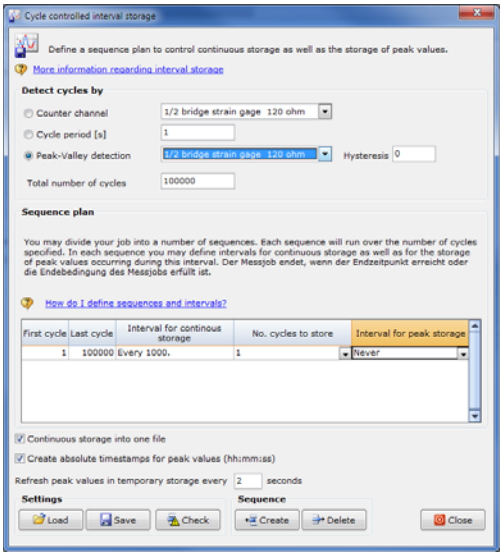
For **long term monitoring** application you can use the statistical journal parallel to the triggered DAQ job. For example in permanent bridge monitoring: crossing of a train is done as a triggered DAQ job, but all sensor data is also stored permanently in a an extra file, the statistical journal.



The **Cycle dependent interval** storage mode greatly reduces the amount of data stored during a long term measurement while retaining nearly all important information. It is usually applied in **fatigue or durability tests** where large numbers of load cycles are performed. During the test whole cycles may be stored at certain intervals as well as peak values. In the following example the peak values for every cycle will be stored and every 5th cycle a complete cycle will be stored. Instead of a load cycle you may alternatively use a time interval - in this case the term "cycle" is replaced by the term "time interval" using parameters like "every 10 minutes store all data for 30 s".

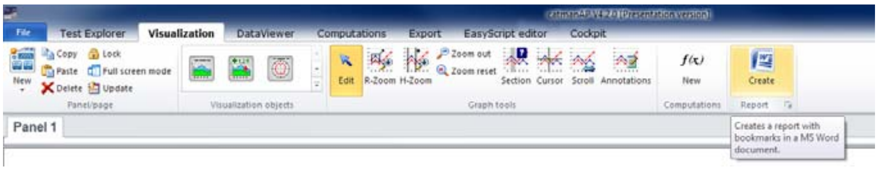
For every complete cycle stored a separate file will be created. Such a file may however contain more than one cycle if for example “with every 100th cycle two cycles shall be stored” or “for the first 10 cycles every cycle shall be stored”.

Peak values are saved to a single file after the test stops. In a simple way you can also parameterize periodically during measurement: Cycle dependant.



Report Generation

When working in analysis mode you can basically push all relevant data and results to a report template.



The combination of QuantumX and catmanEASY is a powerful solution for strain analysis and many more applications.

Appendix

Shunt Calibration or Channel Check

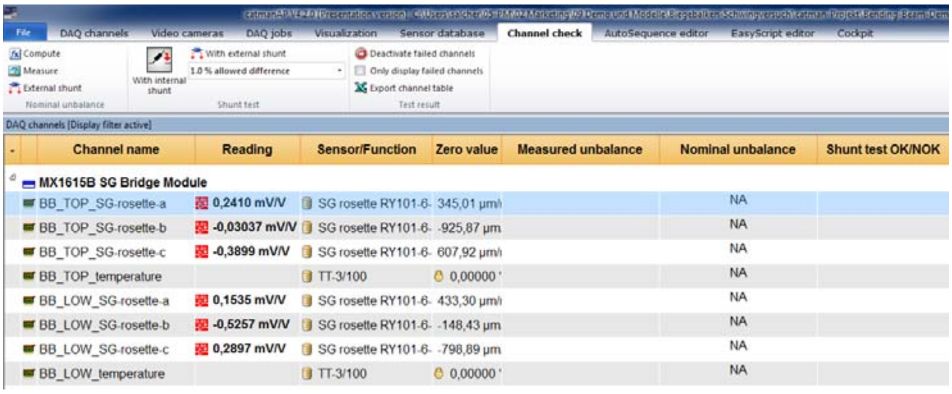
catman is able to perform a so called shunt calibration or in short a **shunt cal** of the channel and with a connected bridge configuration. For some users this is equal to "**channel health check**".

What is it for?

Channel Health Check

If the applied strain gauge and wiring in a bridge configuration is damaged for some reason this "channel health check" enables you to quickly check all channels in one automatic routine preventing you from measurement errors. Especially for larger channel counts this is a very efficient which helps reducing set up times before you actually start the DAQ job where visual inspections of the strain gauge applied and the wiring might be difficult and time consuming.

Go to the Channel check tab in catman and execute a channel health check:



Shunt Cal

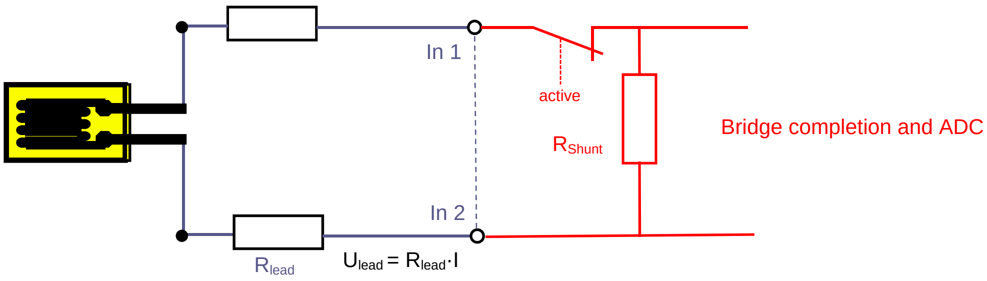
In some markets still full bridge transducers in 4-wire configuration are used so the resistance of the lead wires between the transducer and the DAQ device causes a drop of the supply voltage and thus it leads to a loss of sensitivity and accuracy. The cable length is not automatically compensated from the DAQ electronics. Even when the DAQ device supports 6-wire configuration but the 2 lead wires are just shorted in the connector of the device the overall idea of cable length compensation is not working.

This is the same when using single strain gauges in ¼ bridge configuration with only 2-wire. Most commonly seen for stress analysis is 3-wire especially in large channel count applications. Good to know that with single strain gauges in 4-wire configuration even temperature is compensated next to lead wire length.

The shunt calibration can be used to compensate the voltage losses in the leads to the strain gauge bridge. Parallel to the main strain gauge bridge arm a high-value resistor of typically 100 kΩ can be switched on which leads in return to a certain electrical input to the amplifier. The measured quantity can be used to calculate a 2-point calibration spot which can be stored on the channel and in the sensor database to linearize the channel.

The two point calibration for a strain gauge full bridge based on 350 Ω strain gauges:

1. bridge mechanically not under load and shunt resistor is OFF = 0 mV/V = 0 physical units
2. bridge mechanically not under load and shunt resistor is ON = 0,976 mV/V = 485 lbs (in case full range of the sensor is 1000 lbs = 2 mV/V



Graph: DAQ device internal shunt resistor switched in parallel

Example: 350 Ω strain gauge with 100 kΩ shunt resistor switched on.

Calculation:

$$\Delta R = \frac{R_{DMS} \cdot R_{Shunt}}{R_{DMS} + R_{Shunt}} - R_{DMS}$$

$$\frac{U_a}{U_e} = \frac{1}{4}\left(\frac{\Delta R}{R_{DMS}}\right)$$

$$\varepsilon = \frac{1}{k}\left(\frac{R_{Shunt}}{R_{DMS} + R_{Shunt}} - 1\right) \qquad \varepsilon = \frac{1}{2{,}03}\left(\frac{220000\Omega}{120\Omega + 220000\Omega} - 1\right) = \underline{\underline{-268{,}5}}$$

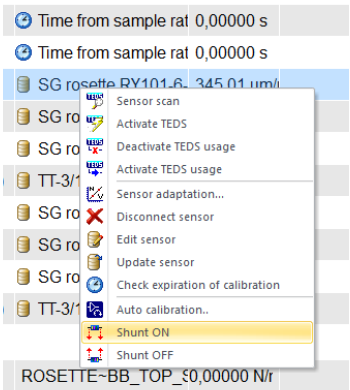
QuantumX MX1615B and shunt cal
QuantumX MX1615B offers on every channel a software controlled internal shunt resistor with 100 kΩ. First assign a sensor type to the channel. The channel has to be active and not in overload state.

The respective channels are automatically switched to electrical measurement in the channel check module since the data sheets are stating the shunt deviations in electrical values as well.

Please check the datasheet for the expected signal level when activating the shunt.

For MX1615B this shall be:
- Strain gauge quarter bridges: +1,0078 mV/V
- Half bridges: +1.0657 mV/V
- Full bridges: -1.0657 mV/V

To prepare the test two measurements will be performed on the DAQ channel one with and one without switching a defined resistance the so called shunt resistance. The resulting signal deviation the so called "expected deviation" is written into the table and stored in the catmanEASY DAQ project. This must happen before the actual series of measurements with correctly connected sensors.



To perform the shunt test this procedure is repeated and the measured deviation compared with the expected one stored in the DAQ project. If the difference is greater than a certain user defined percentage the check has failed. Depending on the outcome of the test the channel is marked in column "OK/NOK" either with a green point and OK or a red point and NOK.

Execution of measurements depends on the type of channel. For this reason hardware channels are classified into three different groups on module start:

Switching the shunt off is performed by the program itself. If sensors of type quarter bridge are assigned to QuantumX amplifiers the measuring of expected shunt is not necessary but can be calculated directly from sensor properties (Function "Automatic calculation").

Expected deviations can also be entered manually in the table if they are known to the user for example by a cal datasheet.

The different methods for determining the expected deviation can be found in the control "Shunt" in group "Prepare shunt test" of the catmanEasy/AP ribbon system, internal and shunt test in "Check" in group "Channel check". All functions can be used either on all channels in the table or only selected ones.

Additional functions encompass displaying of channels with built-in shunt functionality, with possibility of manual shunt or with failed shunt test only for better visibility and deactivating of channels with failed shunt-test in all DAQ jobs. Also the channel table can be exported to Excel.

The recording of a measurement series for shunt control is not a classical test. Three regular DAQ jobs will be performed over a user specified time frame. After the first job shunt will be switched on for channels supporting this functionality after the second job it will be switched off. For all other channels this must be done manually by the user. The measurement will be automatically exported. The user can also choose from which available DAQ job other basic job properties should be taken.

To execute the measurement series the program is switched into the measurement series mode from the channel check module. catmanEasy switches onto tab "Visualization" and displays a control group "Shunt control measurement series". It allows manual start of the three measurement series, termination of the measurement series mode and shows status info about the ongoing series. As long as this mode is not terminated normal DAQ job execution is not possible.

-- END

Literature

- Hoffmann, Karl Eine Einführung in die Technik des Messens mit Dehnungsmessstreifen
  Hottinger Baldwin Messtechnik GmbH 1987