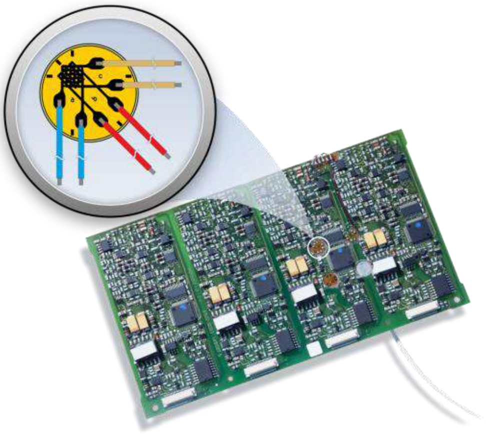
TECH NOTE: Strain and Strain Rate Measurement on Printed Circuit Boards (PCBs)

Version: 2019-02-19
Status: public



Intro

In the course of our daily lives, we have to place trust on electronic components integrated in cars, smartphones, airplanes, and countless other devices, according to their reliability. In many of these products printed circuit boards (PCBs) are integrated. The reliability of complex electronics and overall electrical systems is a result of experienced development and intensive testing.

The aim of this Tech Note is to give you an overview about mechanical PCB testing. The document describes how strain gauges are installed on PCBs and how to analyse test data in order to evaluate whether the PCB is reliably working within the specified mechanical constraints or whether it might get damaged during manufacturing process, transport or operation.

Keywords: strain gauge, printed circuit board, PCB testing, data acquisition, QuantumX, catman

Main Focus of this TUTORIAL

This Tech Note is focussing on the following topics:

- Theoretical background of PCB testing
- Strain gauge application on printed circuit boards
- Strain and strain rate measurement on PCBs in the context of durability testing
- Set up of the measurement chain as well as operating some tests
    - Parameterizing inputs
    - Starting, stopping and storing data – the DAQ job
    - Visualization and analysis

Theoretical Background

PCBs are exposed to mechanical and thermal impacts not only during their manufacturing process, but also during their transport and in action (for example: deformation, misuse, vibration, shock, thermal exposure).

During the manufacturing process of PCBs, the following failures and stresses may occur:

- Bending strain during the installation of connectors, power rails, cooling plates, contact pins, solder terminations, or battery holders
- Breakage during mounting of surface-mounted device (SMD), surface-mounted technology (SMT), and through-hole device (THD), through the hole (THT) and pin in hole (PIH) fitting
- Stress cracks and dislodging of solder points with ball grid arrays (BGA)
- Transient strain peaks during separation (determination of critical strains/shear strains during separation)
- Elevated mechanical stress (strain) that occurs due to press fitting, screw tightening, or encapsulation processes in housings
- Broken SMD capacitors due to high bending stress in other steps of the process
- Hard touchdown of the test probes during the ICT test

During transport and operation, the following impacts could lead to failure:

- Mechanical load (static)
- Vibration and shock (dynamic)
- Thermal effects resulting in cracks caused by thermal expansion (differing α values of housing, heat sink, printed circuit board, and electronic components)

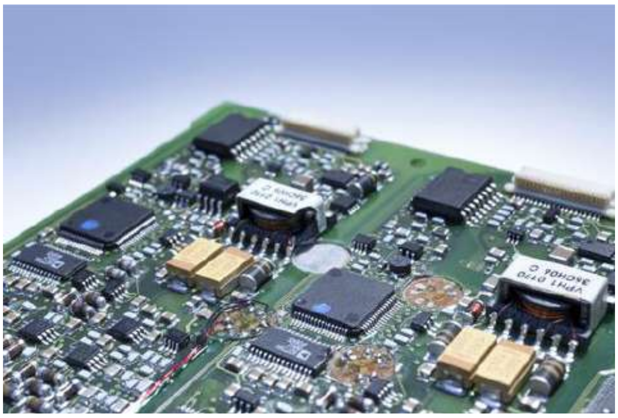


Figure 1: Strain gauge rosettes installed on PCB

All these effects can lead to a complete failure of components. If a systematic failure of a PCB is detected too late, the fulminating costs would be massive. The costs would continue to increase, as long as the detection of the malfunction is delayed. The rule of 10 shows that the later a systematic failure of a new product is detected, the costs per defect unit multiply by a factor of 10.

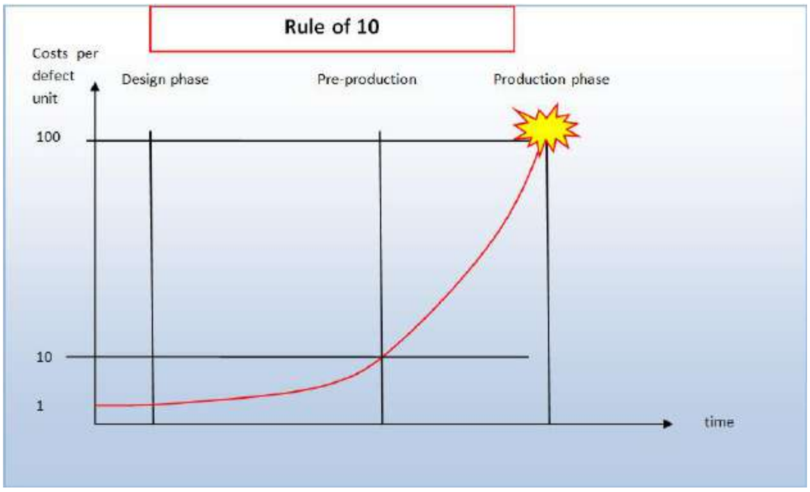


Figure 2: Rule of 10

Extended Requirement and international standards for PCB testing

Based on the fact that detecting systematic failures at an early stage of development is absolutely essential, OEM manufacturers have increasingly begun to request their suppliers to check the mechanical quality of PCBs.

The utilization of PCBs has increased in recent years due to the following reasons:

- Use of lead-free solder (RoHS conformity, EU guideline) that is more sensitive in relation to mechanical load and tends to crack earlier (flexure-induced damage)
- More compact construction elements such as ball grid arrays (BGA) instead of surface-mounted devices (SMD)
- Stiffer contacts that lead to higher mechanical tension

International associations such as **IPC (Association Connecting Electronics Industries) and JEDEC (Joint Electron Device Engineering Council) – 9704** have been established, and these provide guidelines describing where and how and wherewith strain measurements on PCBs have to be performed.

Many companies have created their own test procedures to ensure that all manual handling steps are executed correctly during the assembly as well as developed test scenarios for PCB testing to cover all relevant cases.

How to measure strain on PCBs

Numerical simulation methods such as FEA are limited in their scope since they are based on mathematical model approaches. Therefore, physical tests on real PCBs are at least additionally required to test the real strain behavior of the board.

Other test methods such as CTs and X-rays are not sufficiently adequate to check the influence of the mechanical impact and are, on top of that, expensive methods to employ. Strain values are the only reliable calculations for measuring the mechanical deformation of PCBs.

Therefore, strain gauges are designated to measure the deformation of the PCBs to an extremely accurate degree. PCBs are usually small in dimension, and the challenge is to install strain gauges in the limited space available.

HBM offers over 2000 different strain gauges for special applications, alongside some specialized strain gauges for PCB strain measurement.

The RF91 three-grid miniature rosette, for example, is an excellent product to measure strain on miniature components. It is available in different variants. Three-grid rosettes are used for PCB strain measurement applications since the direction of principal strain is unknown.

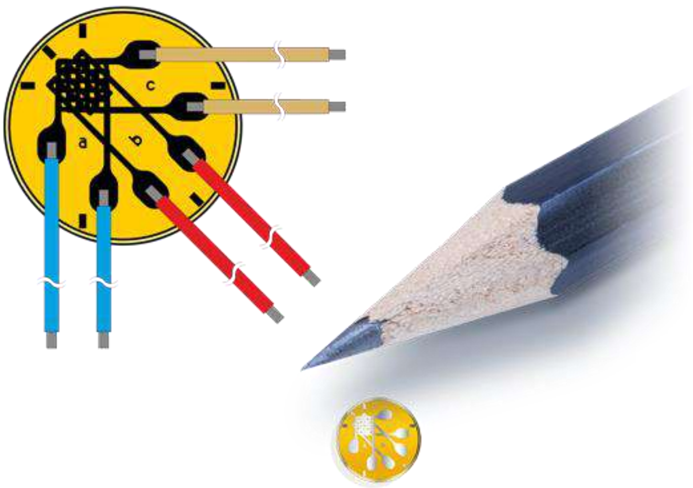
RF91 is available in two different versions:

- Prewired
- With integrated solder pads

It is only 5mm in diameter and can, therefore, be mounted easily on PCBs. Other strain gauges, such as the RY31-3/120 (6.9mm diameter), can also be used for PCB testing. More information about this product is available on the website. It can also be ordered via the HBM web shop.

Key facts about the HBM RF91 miniature rosette

- Only 5mm diameter for miniature applications
- 120 Ω resistance
- Deliverable ex stock
- Measurement of two-axis tension state when the principal stress direction is unknown
- Three-stacked measurement grids
- Temperature compensation for austenitic and ferritic steel as well as aluminum
- Prewired (0.5m) or with solder pads
- No soldering on strain gauge
- For two-, three-, and patented HBM four-wire configuration usable
- Different colors of paint-insulated cooper wire



Where to measure strain on PCBs

The tension status on PCBs is mostly unknown and quite mechanically complex. Strain situations result in the deformation of a plate. Plate deformation does not follow the classic models of beam deformation or torsion of a shaft, which are quite accurately described by linear electrostatics.

Furthermore, it needs to be considered that an assembled PCB contains a lot single components that are soldered or connected in different ways to the PCB. This means that a PCB is quite heterogeneous in its material properties.

It is neither useful nor possible with respect to cost and time to check every single section of a PCB according to the strain properties and behaviour.

Therefore, measurements on PCBs are set at areas where the risk of failure is estimated to be especially high, such as:

- Corners: Corners can be mechanically critical if they are fixed.
- Stiff regions of the board (e.g. the ones close to capacitors): Big elements lead to increased stiffness of PCB.
- Regions close to interconnect (solder-joint failures): Solder points are weak points in terms of yield strength.

How to install RF91 miniature rosette on PCBs (quick-step guide)

- In the first step, the PCB needs to be prepared for the installation of a foil strain gauge. Therefore, an even surface is required. Depending upon the location at which the foil strain gauge needs to be positioned, a disassembly of the PCB is required. By desoldering electronical elements and using a milling cutter, the surface can be prepared. The milling of the surface is required to remove the paint layer on the PCB. (Attention: Removing of components influences the stiffness of the PCB.)
- In the next step, the PCB surface needs to be cleaned. Cleaning before bonding strain gauges is an unavoidable requirement!
- Do not use aggressive solvents. Such solvents can cause tension in the PCB material.
- Use one drop of HBMs Z70 cold curing bond to wet the designated area for the strain gauge.
- Attach the RF91 rosette at the designated area.
- Use a Teflon paper to ensure that only strain gauge and PCB are bonded.
- Apply slight and homogeneous pressure on the rosette to bond it to the PCB for around one minute.
- Remove the Teflon paper afterwards as shown.

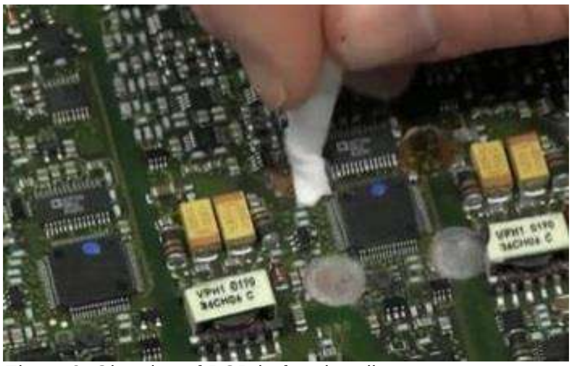


Figure 3: Cleaning of PCB before bonding

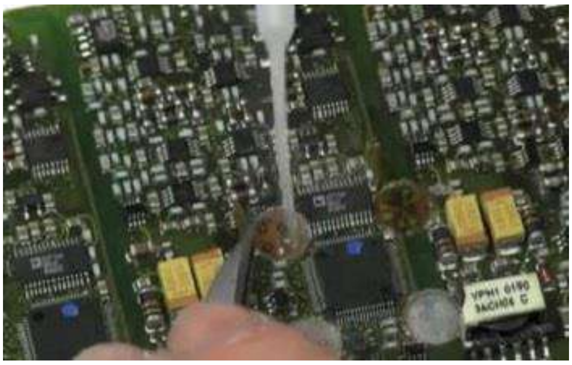


Figure 4: Application of bond on PCB surface

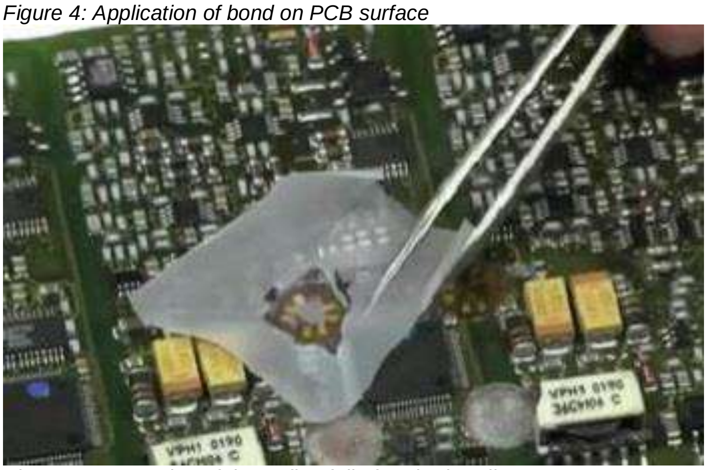


Figure 5: Separation of the Teflon foil after the bonding process

- Install strain relief on the measurement wire. It is absolutely essential to ensure that the strain gauge is uncoupled from the cable itself. Different options can be used to set a strain relief.
    1. Strain relief directly on the measurement cable
    2. Strain relief through solder pads

- Finally, check the quality of the strain gauge installation (resistance and isolation).

Figure 6: Strain relief directly on measurement cable

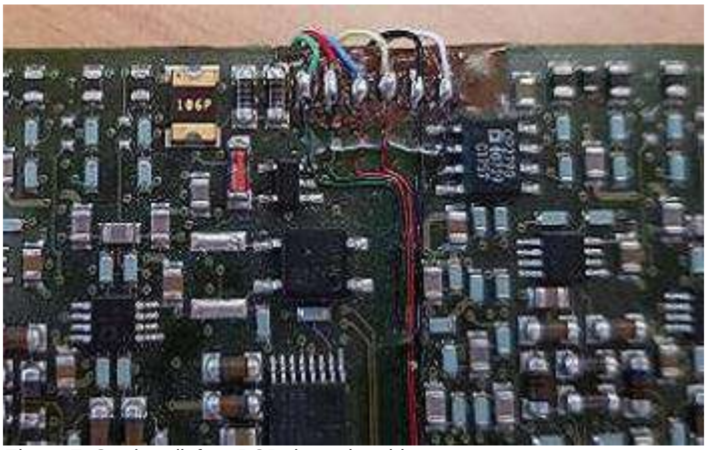


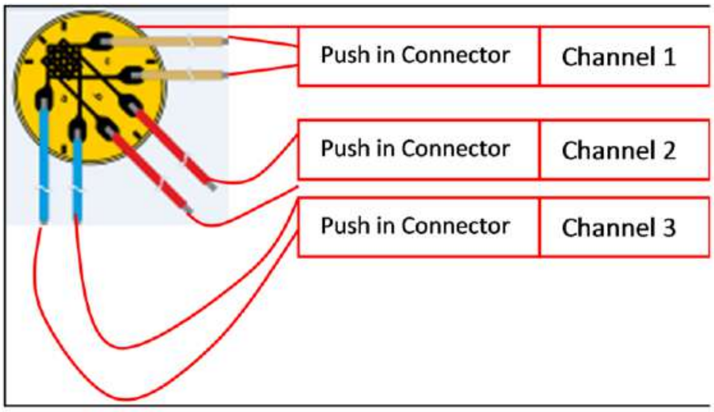
Figure 7: Strain relief on PCB through solder

How to connect RF91 miniature rosette to QuantumX MX1615B

- In this setup, a QuantumX MX1615B is an off-the shelf DAQ system of HBM, specialized for strain gauges applications
- The push-in connector can be easily used to quickly connect wires to the module.

Figure 8: Push-in connector

- The RF91 is a three-stacked grid rosette. For each grid, one quarter bridge channel is required. In total, three channels are required to perform the measurement calculations with RF91.



How to set up a strain (rate) measurement in catman®AP

As a reminder,

- *Strain* describes the relative change in shape or size of material due to externally-applied forces.

$$\varepsilon = \frac{\Delta l}{l}$$

- *Strain rate* describes the change in strain of a material with respect to time.

With the HBM DAQ software catman AP, it is easy to set up a PCB board strain measurement. A quick and easy visualization of data is one of the strengths of catman. Data recording can be performed differently using trigger or special time points. The latest versions of catman® support strain rate measurement (the strain is derived from the time). The following steps show how to set up a strain rate measurement in catman®:

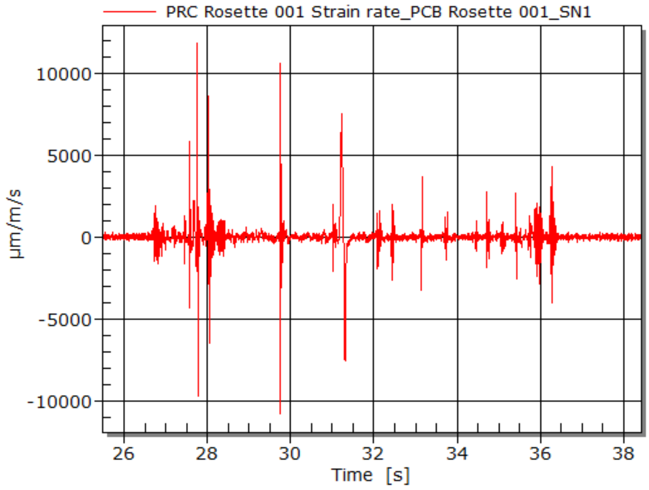


Figure 9: Strain rate measurement

The three measurement grids of the RF91 rosette allow the calculation of maximum and minimum principal strain (rates) as well as the corresponding angles.

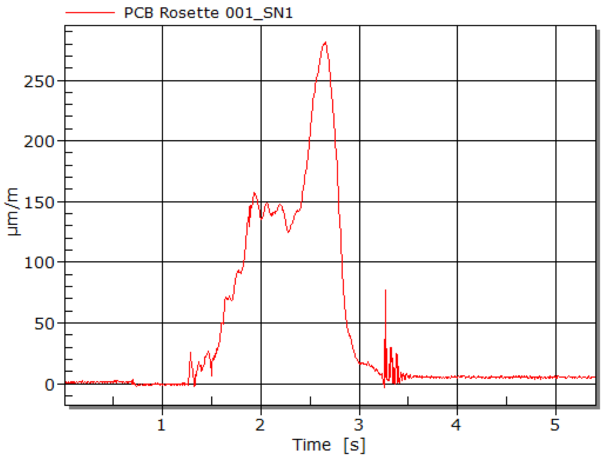
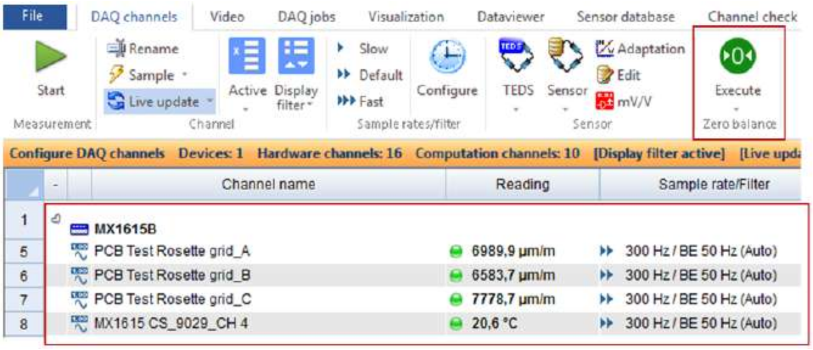
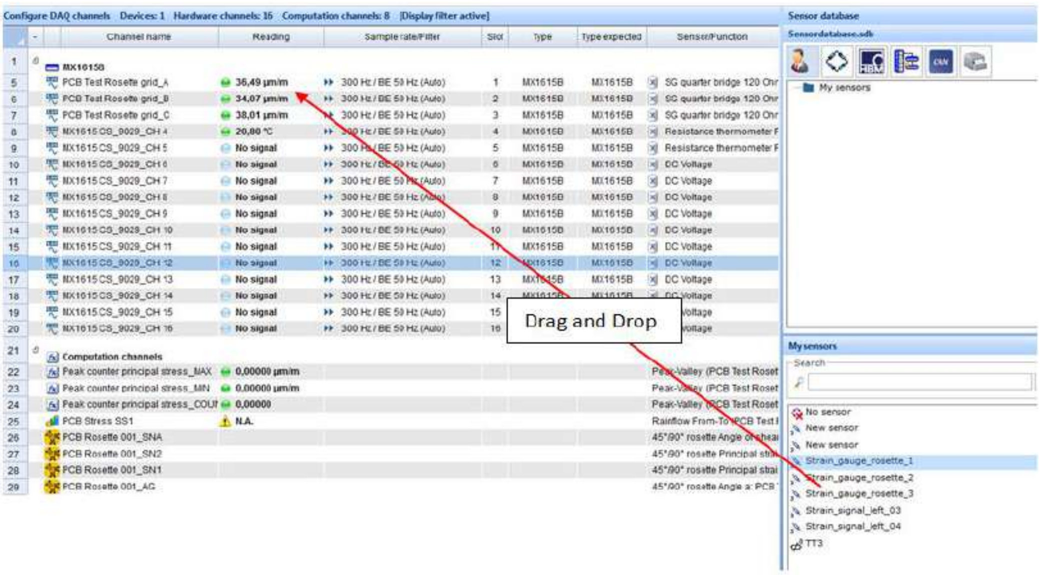


Figure 10: Maximum principal stress

- Open the catman® software and check the relevant channel of the strain gauge. Green lights indicate that the channel is detected and is ready for measurement. In this example, the three grids of the rosette are connected with channels 1, 2 and 3.

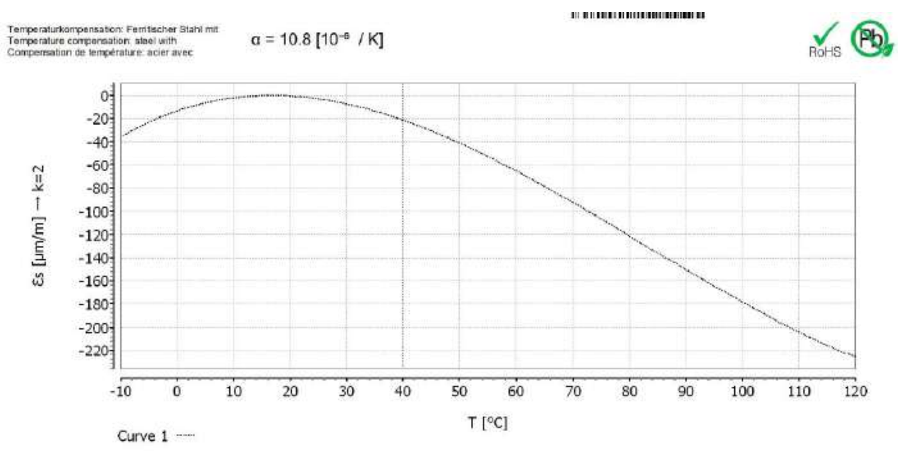
- Use the sensor database to assign the channels to the sensor application. In this case, drag and drop the 3-wire-120Ω strain gauge n to each of the three active strain channels.





Now, the sensor specifications need to be set. Set correct parameters by using the k-factor displayed on the datasheet of each HBM strain gauge package. Enter the excitation voltage, bridge factor and measurement range. Ensure that you look at the temperature compensation polynomial in order to correctly consider the temperature fluctuation properties of different materials.

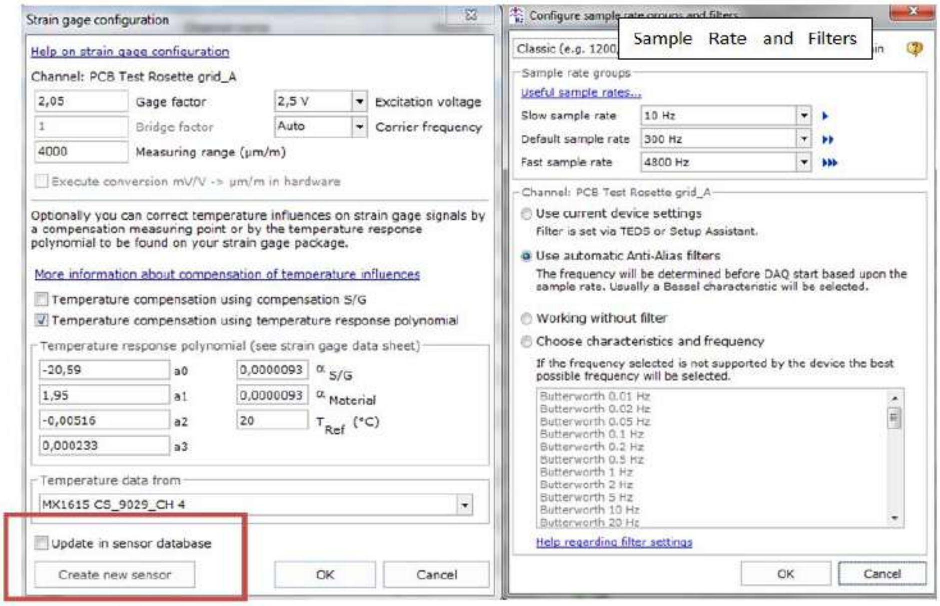
- Set the sample rate (classic or decimal) and filters correctly before beginning your measurement.



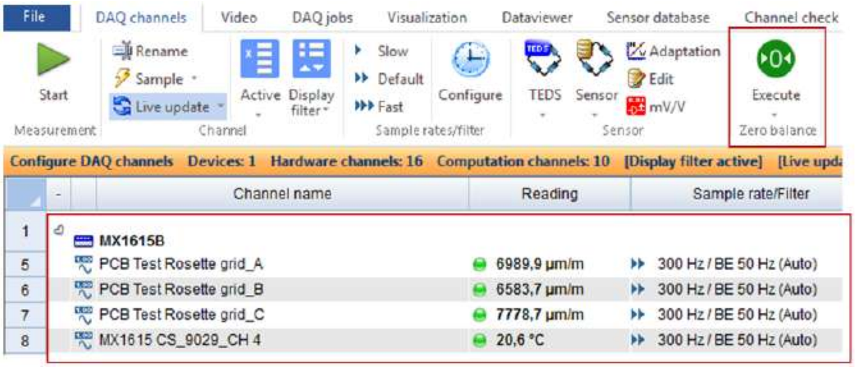
$\varepsilon_S(T)$ = -13.47 +1.67 * T -5.59E-02 * T² +2.27E-04 * T³ ± (T-20) * 0.30 [µm/m]

Figure 11: Extract from HBM data sheet

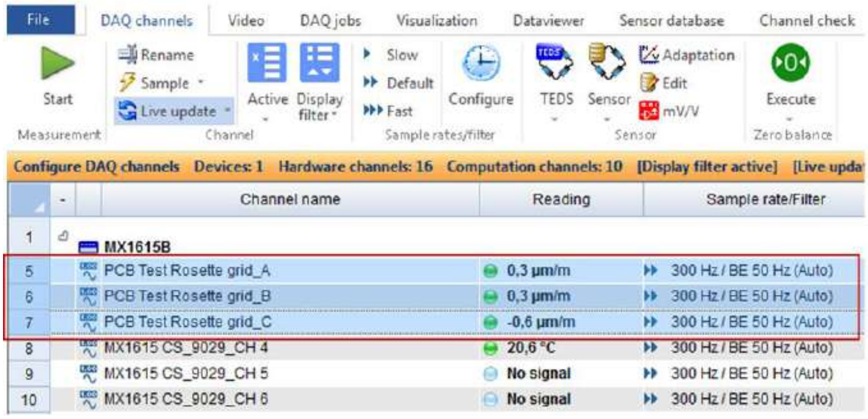
- Click on '*Create new sensor*' and activate '*Update in sensor data base*' to save your parameters in the database.



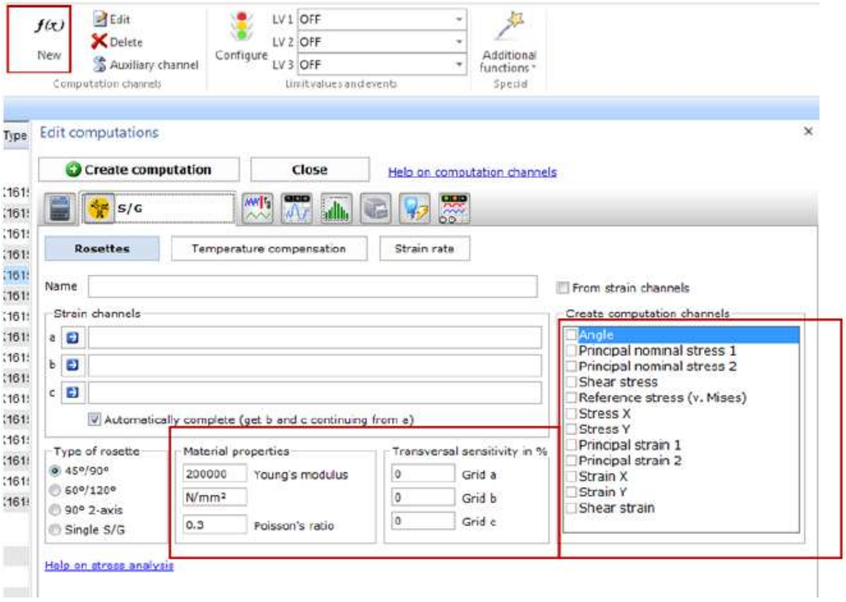
- Select all channels and zero the strain channels of the rosette.



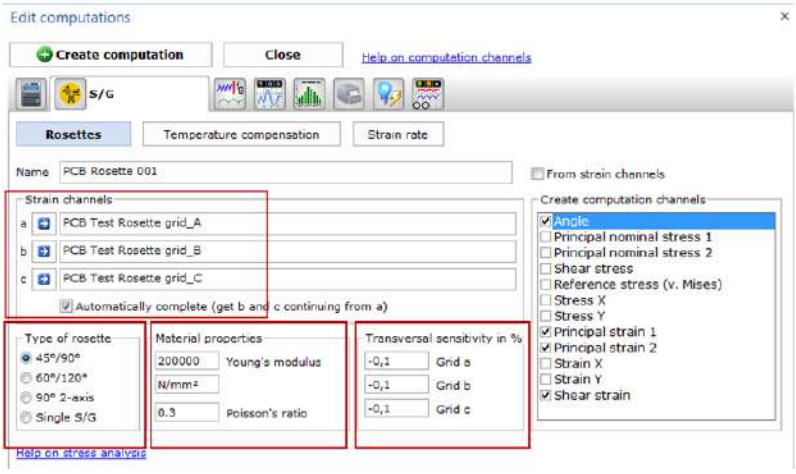
- Zeroed strain channels appear.



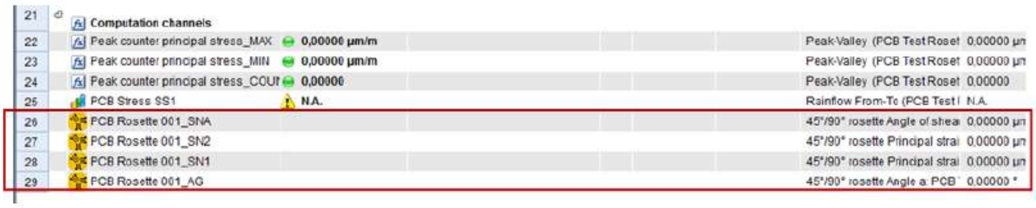
- Now we have to set up the rosette calculation channel. A new channel needs to be created, and catman® makes it easy for the user to create different setups for rosette calculations.



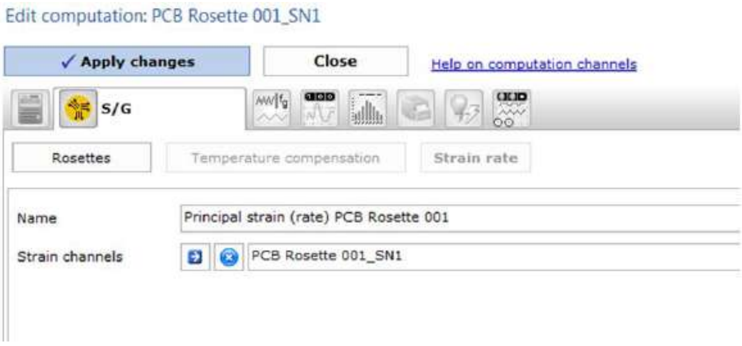
- Add all three channels in a, b, c and define the material properties and the transverse sensitivity of the gauges. Choose the right rosette type (0/45 or 60/120 for the three grid rosettes).
- Select the relevant strains (principal strain, shear strain).



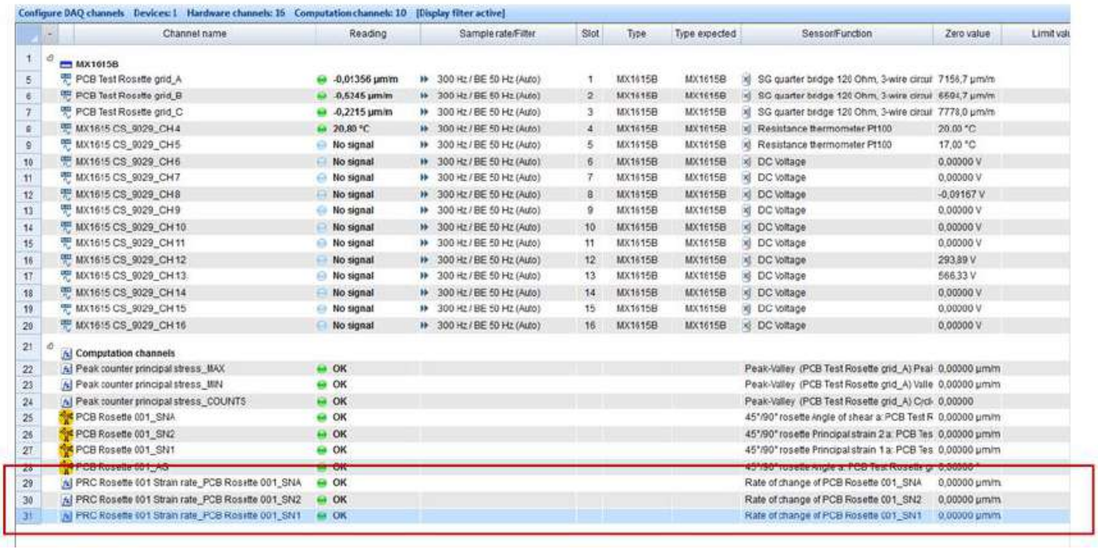
- Click on '*Create calculation*'. Now, the calculated channels appear in the channel list.



- Set a name and click on *'Apply changes'*



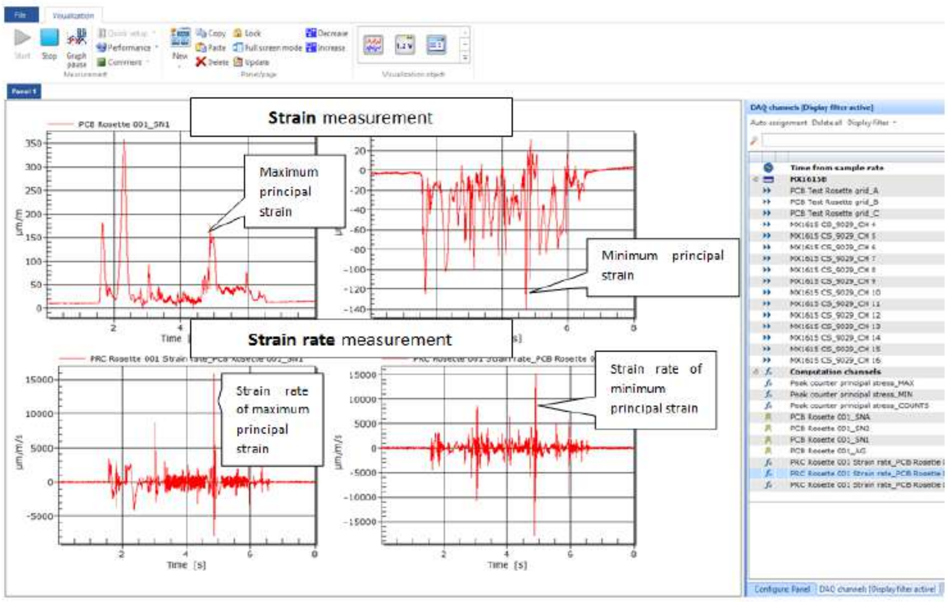
- The strain rate channels will appear in the *'computation channel'* list at the end.



Configure DAQ channels Devices: 1 Hardware channels: 16 Computation channels: 10 [Display filter active]

	Channel name	Reading	Sample rate/Filter	Slot	Type	Type expected	Sensor/Function	Zero value	Limit valu
1	MX1615B								
5	PCB Test Rosette grid_A	-0,01356 µm/m	300 Hz / BE 50 Hz (Auto)	1	MX1615B	MX1615B	SG quarter bridge 120 Ohm, 3-wire circui	7156,7 µm/m	
6	PCB Test Rosette grid_B	-0,5245 µm/m	300 Hz / BE 50 Hz (Auto)	2	MX1615B	MX1615B	SG quarter bridge 120 Ohm, 3-wire circui	6594,7 µm/m	
7	PCB Test Rosette grid_C	-0,2215 µm/m	300 Hz / BE 50 Hz (Auto)	3	MX1615B	MX1615B	SG quarter bridge 120 Ohm, 3-wire circui	7778,0 µm/m	
8	MX1615 CS_9029_CH4	20,80 °C	300 Hz / BE 50 Hz (Auto)	4	MX1615B	MX1615B	Resistance thermometer Pt100	20,00 °C	
9	MX1615 CS_9029_CH5	No signal	300 Hz / BE 50 Hz (Auto)	5	MX1615B	MX1615B	Resistance thermometer Pt100	17,00 °C	
10	MX1615 CS_9029_CH6	No signal	300 Hz / BE 50 Hz (Auto)	6	MX1615B	MX1615B	DC Voltage	0,00000 V	
11	MX1615 CS_9029_CH7	No signal	300 Hz / BE 50 Hz (Auto)	7	MX1615B	MX1615B	DC Voltage	0,00000 V	
12	MX1615 CS_9029_CH8	No signal	300 Hz / BE 50 Hz (Auto)	8	MX1615B	MX1615B	DC Voltage	-0,09167 V	
13	MX1615 CS_9029_CH9	No signal	300 Hz / BE 50 Hz (Auto)	9	MX1615B	MX1615B	DC Voltage	0,00000 V	
14	MX1615 CS_9029_CH10	No signal	300 Hz / BE 50 Hz (Auto)	10	MX1615B	MX1615B	DC Voltage	0,00000 V	
15	MX1615 CS_9029_CH11	No signal	300 Hz / BE 50 Hz (Auto)	11	MX1615B	MX1615B	DC Voltage	0,00000 V	
16	MX1615 CS_9029_CH12	No signal	300 Hz / BE 50 Hz (Auto)	12	MX1615B	MX1615B	DC Voltage	293,89 V	
17	MX1615 CS_9029_CH13	No signal	300 Hz / BE 50 Hz (Auto)	13	MX1615B	MX1615B	DC Voltage	566,33 V	
18	MX1615 CS_9029_CH14	No signal	300 Hz / BE 50 Hz (Auto)	14	MX1615B	MX1615B	DC Voltage	0,00000 V	
19	MX1615 CS_9029_CH15	No signal	300 Hz / BE 50 Hz (Auto)	15	MX1615B	MX1615B	DC Voltage	0,00000 V	
20	MX1615 CS_9029_CH16	No signal	300 Hz / BE 50 Hz (Auto)	16	MX1615B	MX1615B	DC Voltage	0,00000 V	
21	Computation channels								
22	Peak counter principal stress_MAX	OK					Peak-Valley (PCB Test Rosette grid_A) Peal	0,00000 µm/m	
23	Peak counter principal stress_MIN	OK					Peak-Valley (PCB Test Rosette grid_A) Valle	0,00000 µm/m	
24	Peak counter principal stress_COUNTS	OK					Peak-Valley (PCB Test Rosette grid_A) Cycl	0,00000	
25	PCB Rosette 001_SNA	OK					45°/90° rosette Angle of shear a: PCB Test R	0,00000 µm/m	
26	PCB Rosette 001_SN2	OK					45°/90° rosette Principal strain 2 a: PCB Tes	0,00000 µm/m	
27	PCB Rosette 001_SN1	OK					45°/90° rosette Principal strain 1 a: PCB Tes	0,00000 µm/m	
28	PCB Rosette 001_AS	OK					45°/90° rosette Angle a: PCB Test Rosette gr	0,00000 °	
29	PRC Rosette 001 Strain rate_PCB Rosette 001_SNA	OK					Rate of change of PCB Rosette 001_SNA	0,00000 µm/m	
30	PRC Rosette 001 Strain rate_PCB Rosette 001_SN2	OK					Rate of change of PCB Rosette 001_SN2	0,00000 µm/m	
31	PRC Rosette 001 Strain rate_PCB Rosette 001_SN1	OK					Rate of change of PCB Rosette 001_SN1	0,00000 µm/m	

- Go to *'Visualization'* and configure your own GUI



Data analysis in catman®

The aim of the analysis is to check if the measured data meets the acceptable criteria for the PCB strain. The following diagram illustrates the boundary lines as a function of the strain rate and the board thickness according to IPC / JEDEC-9704A (2012).

The idea is that the maximum principal strain (Y-axis) should not exceed a certain value. With increased PCB thickness higher principal strains are acceptable. Additionally, another criterion needs to be considered – the strain rate. This means that the lifespan of a PCB is impacted not only by the pure value of the maximum principal strain but also by the speed of changing the strain (impulse). Fast changes in material usually result in earlier micro cracks and material damage.

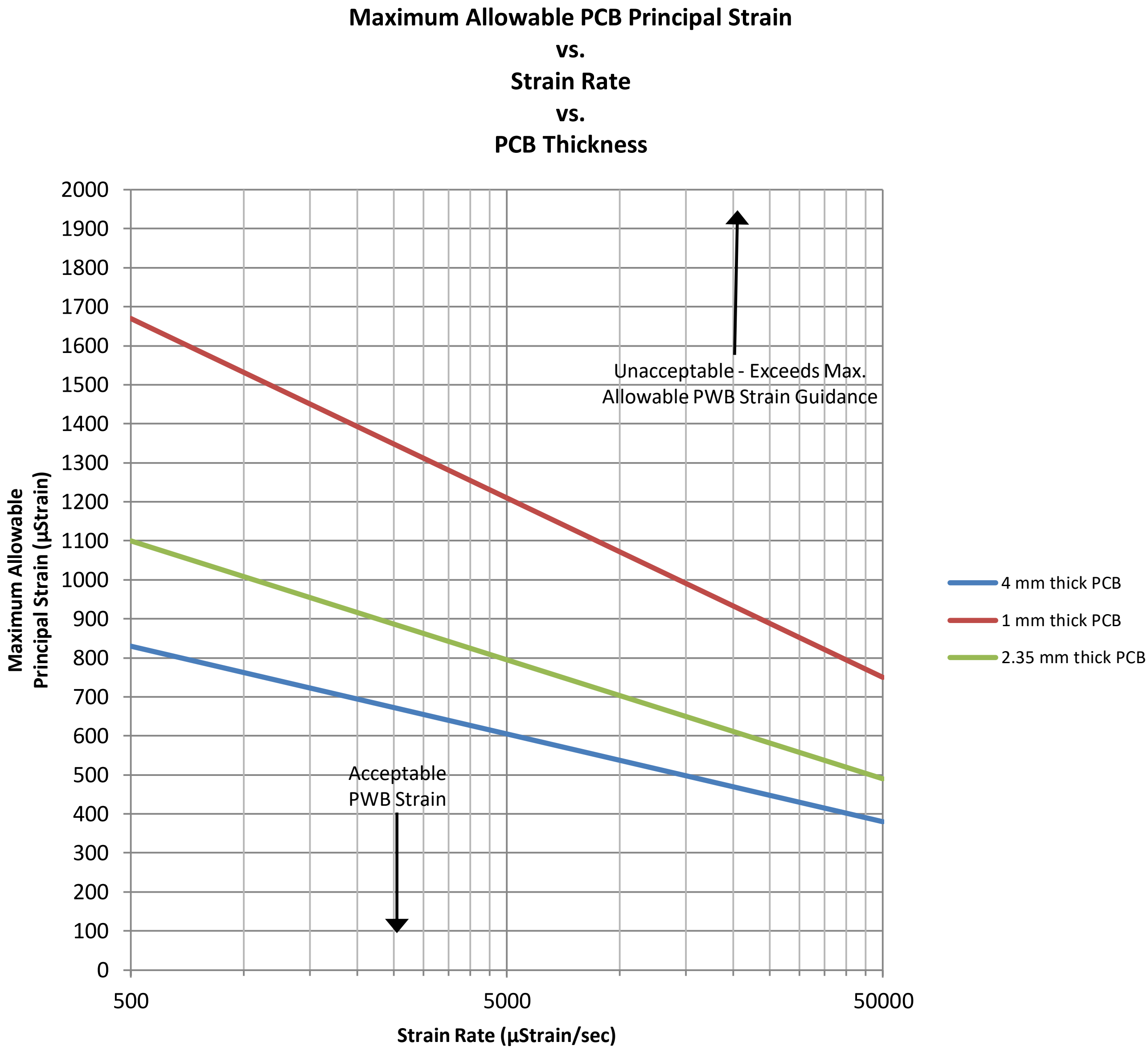
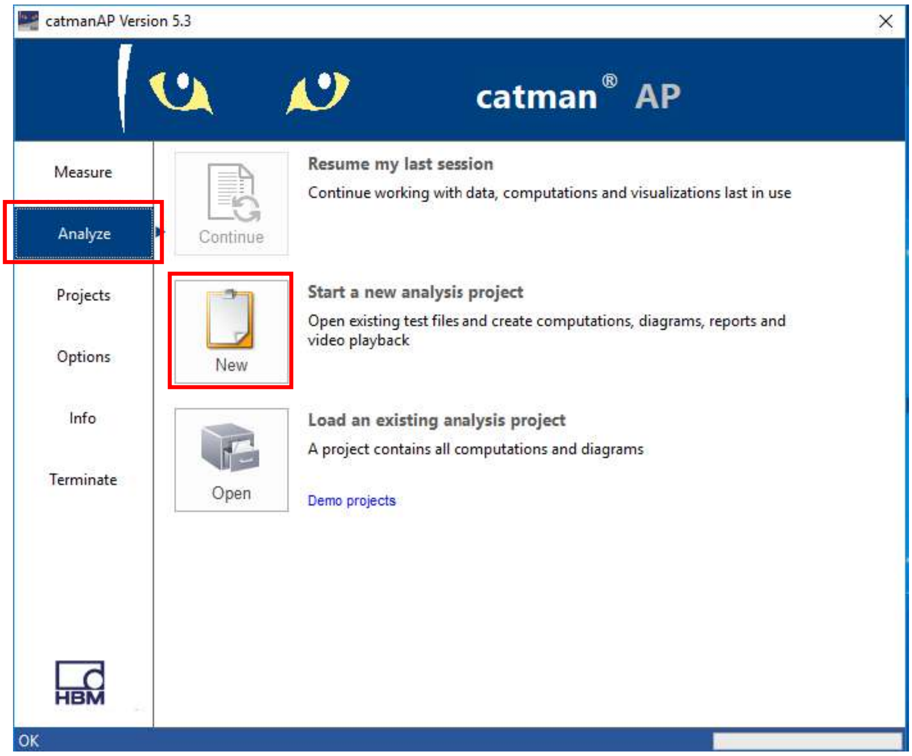
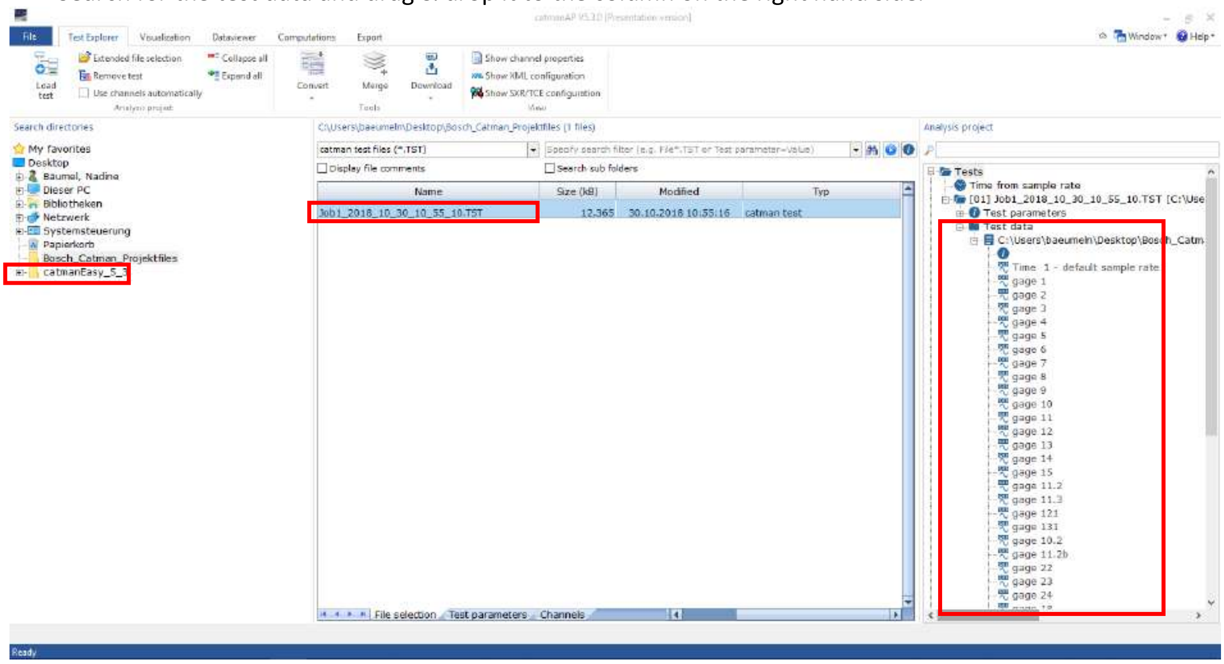


Figure 12: Maximum Allowable PCB Principal Strain based on IPC/JEDEC-9704

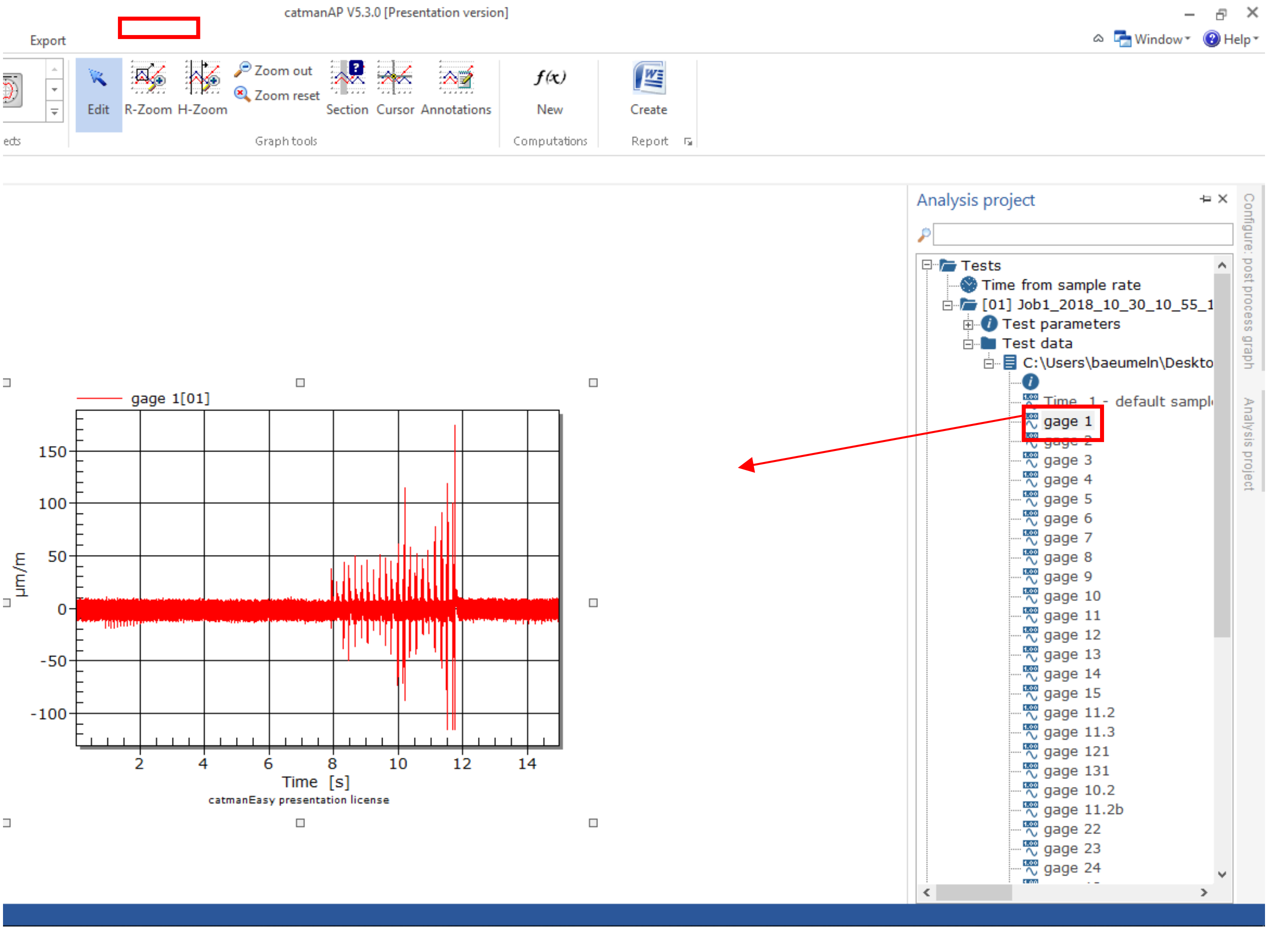
- To analyze the test data, open a new *'Analyze'* Project in catman®.



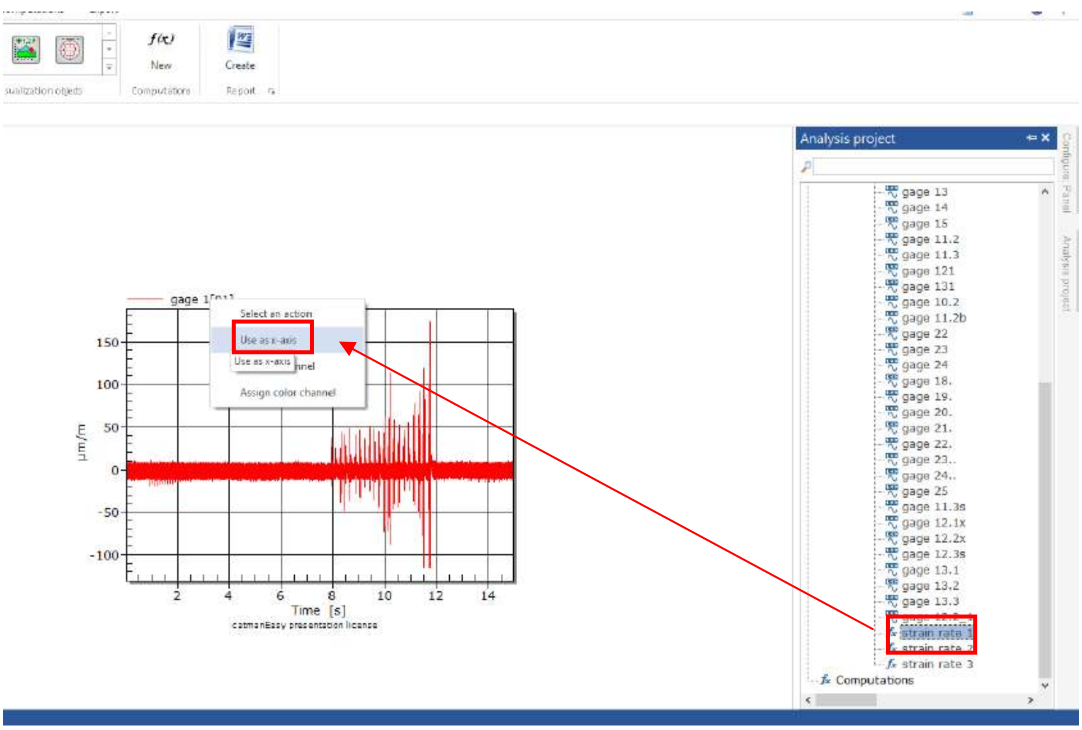
- Search for the test data and drag & drop it to the column on the right hand side.



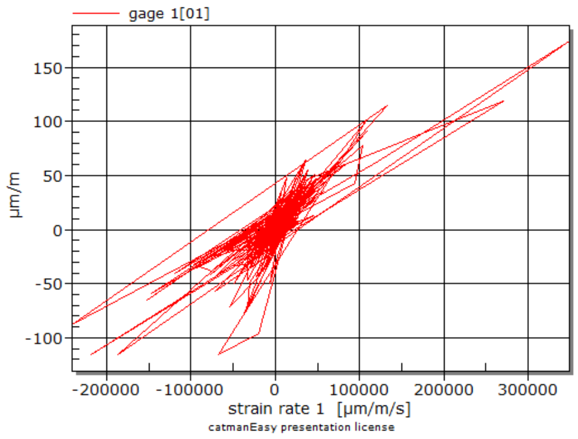
- Now, change to the '*Visualization'* panel. Create a graph by dragging & dropping the test data of *gage 1* to the empty surface.



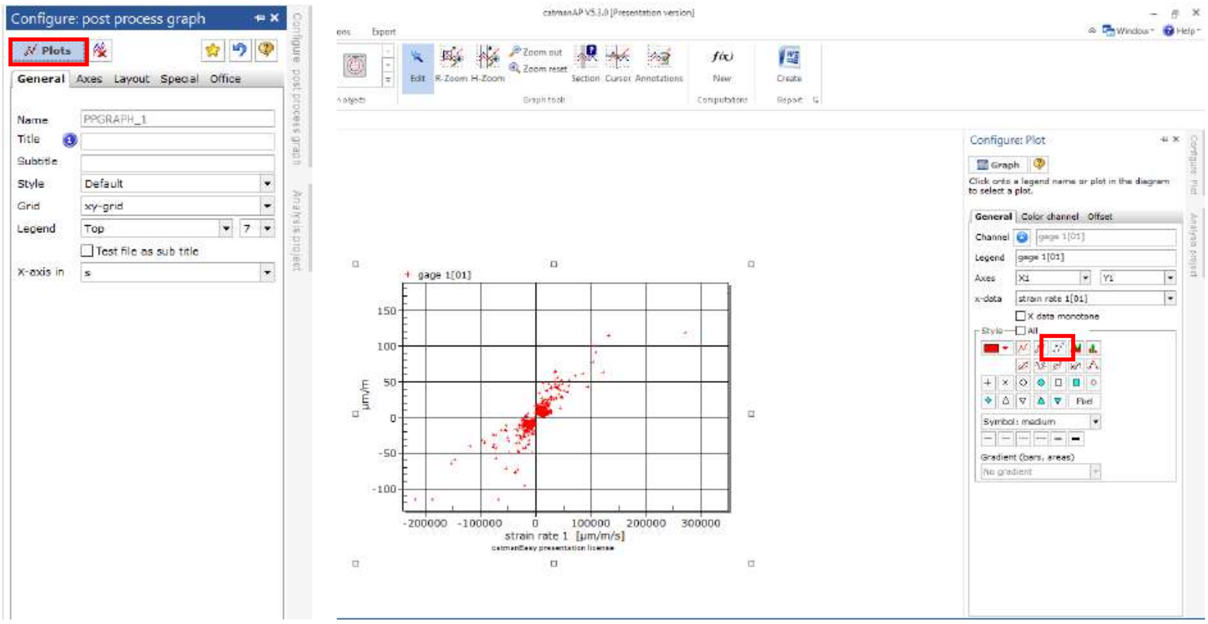
- Then choose the corresponding *strain rate 1* and drag it onto the text *gage 1[01]* in the graph explanations. Use strain rate 1 *as* the *x-axis*.



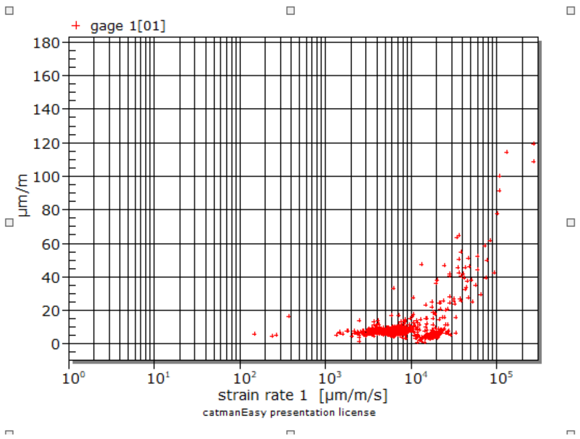
- The following graph will appear.

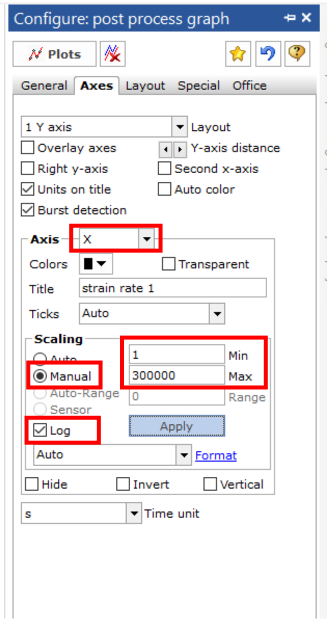


- As this is not the desired shape of the graph, configure the plot as follows (dotted-style).



- Adjust the x-axis by choosing a manual logarithmic scaling.





As a reminder: This is the target graph:

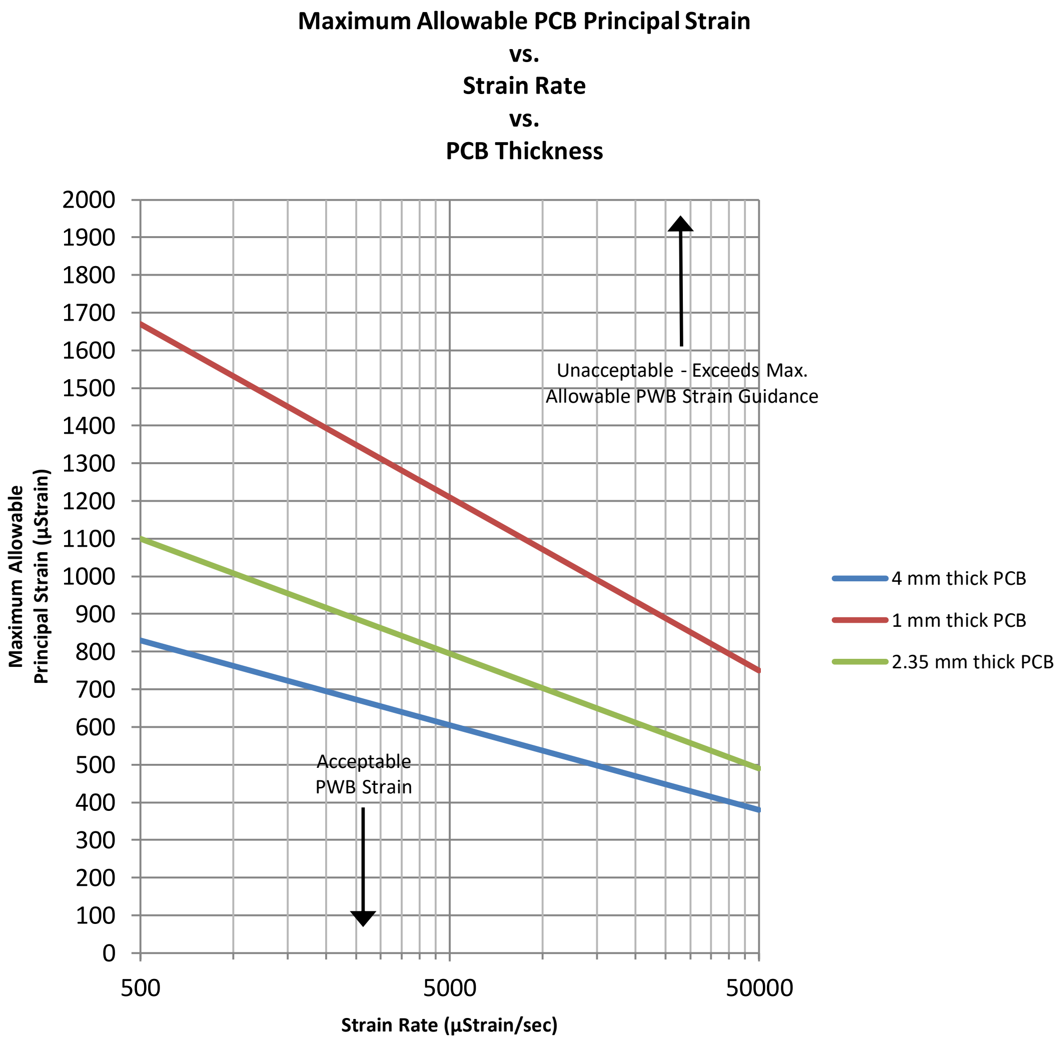
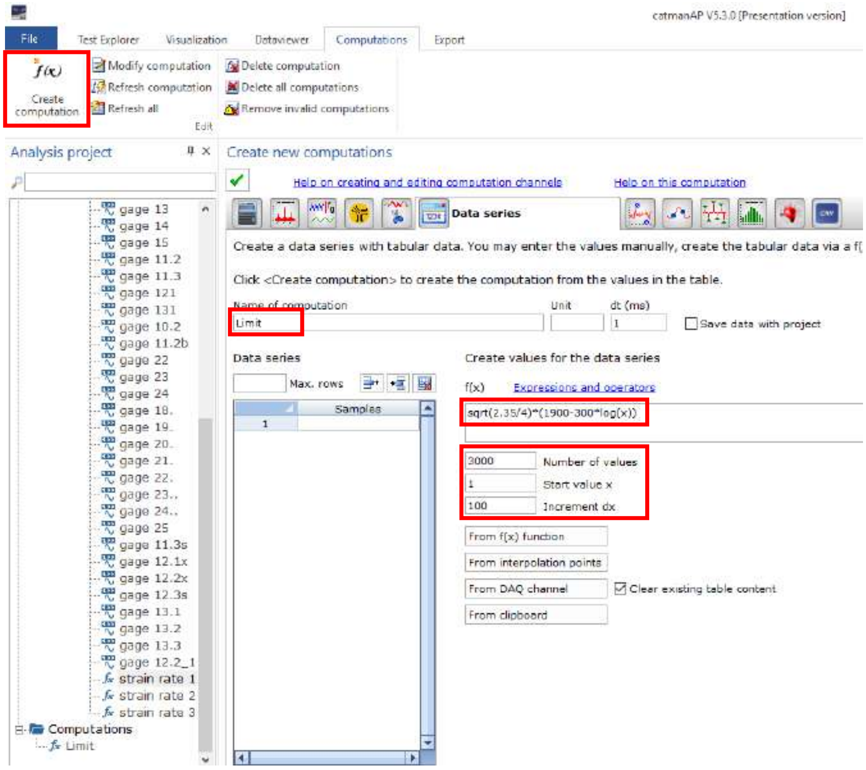


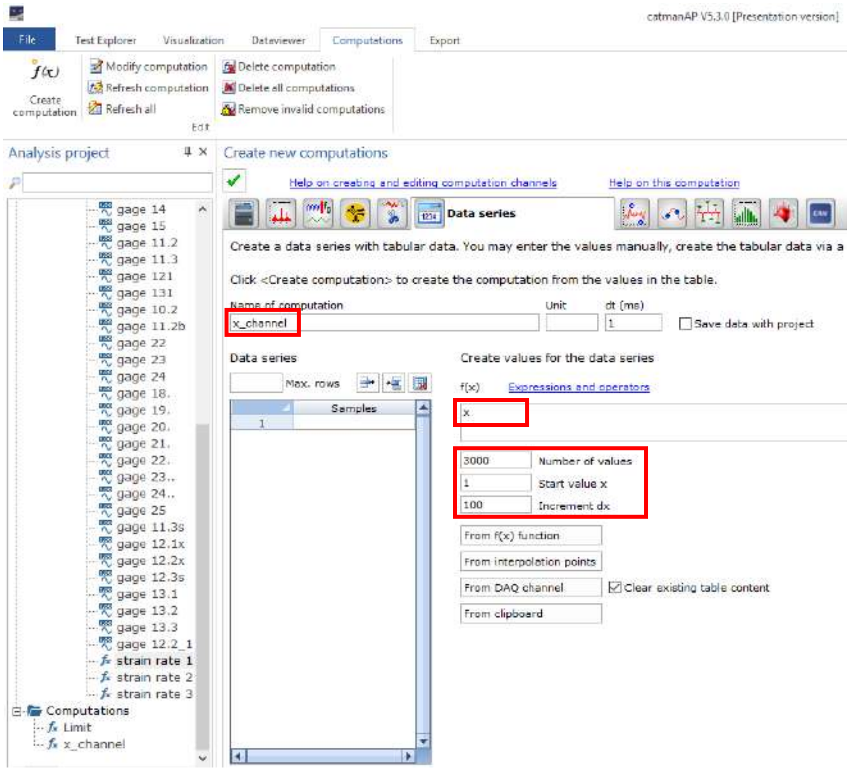
Figure 13: Maximum Allowable PCB Principal Strain based on IPC/JEDEC-9704

- To picture the limit line, define the following *data series* function (*according to IPC/JEDEC-9704*)

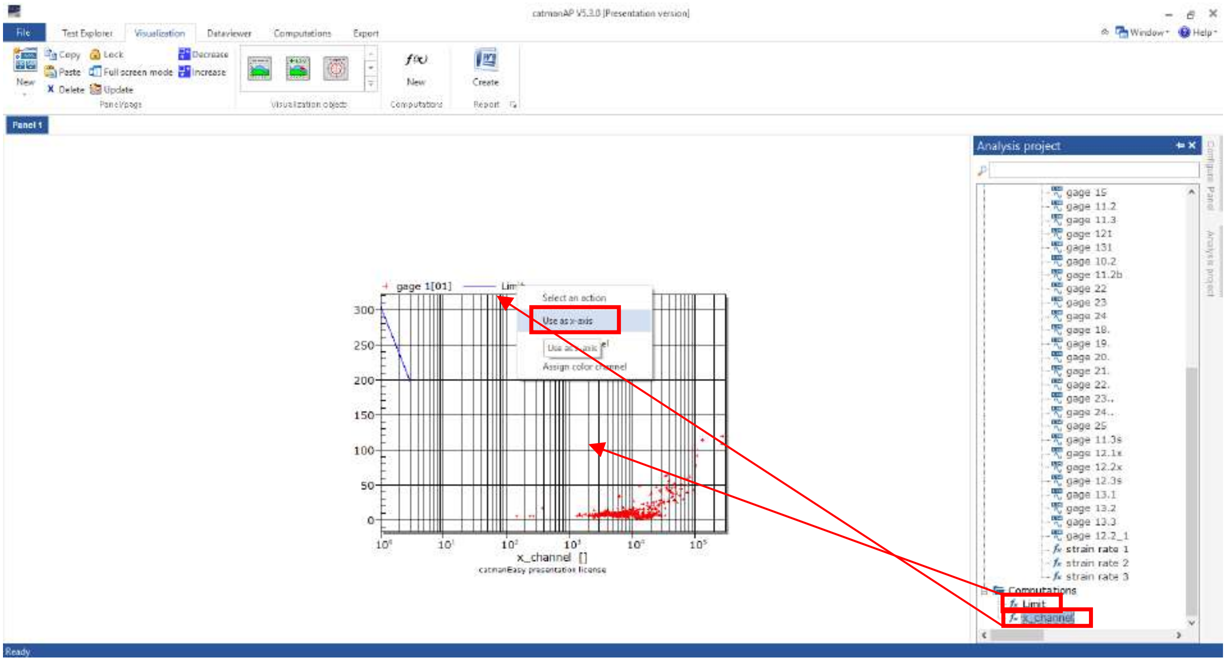
Max. allowable strain = sqrt[2.35/(*PWB thickness*)]*[1900-300*log(*strain rate*)]

and **x as function**.

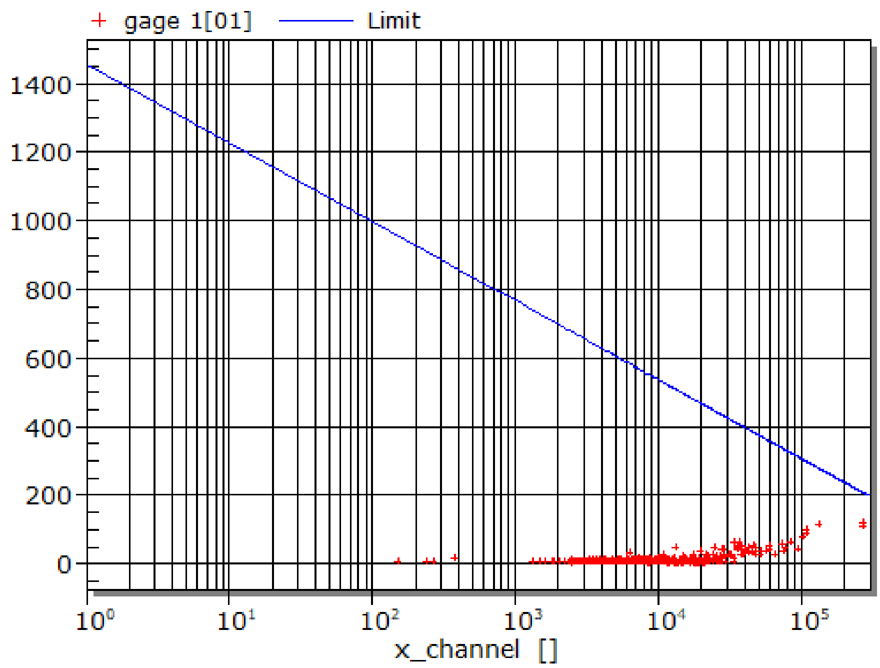




- Finally visualize the computed functions. Drag & drop the '*Limits'* computation to the displayed graph. Then drag & drop the '*x_channel'* computation onto the Limits in the graph explanations and *use as x-axis*.



The resulting graph looks as follows:



According to *IPC/JEDEC-9704 Printed Wiring Board Strain Gage Test Guideline*, the measured strain is within the acceptable strain range. The tested PCB is, then, not damaged during the manufacturing process.

QuantumX Measurement Amplifiers

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 an Ethernet interface and can be freely combined with each other. All channels work completely time synchronized - module to module with < 1 µs.

MX1615B – Strain gauge bridge amplifier

Every channel can be individually parameterized via software, supporting the following:

- Strain gauges in full-, half- or quarter-bridge (120 or 350 Ω)
- Standard voltage, PT100, resistor, potentiometer
- Individual data rates up to 20kS/s per channel, active low pass filter

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, you are only a few clicks away from starting your measurement. 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.

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