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# High-voltage Pantograph Overhead-line Monitoring

## USING A FIBER-BASED MEASUREMENT CHAIN

Dietmar Maicz

HBM Brüel & Kjær

PUBLIC

# Presenter

## Dietmar Maicz

- **Railway Monitoring Specialist**
- Master level degree in Engineering and Economics
- >15 years of experience, >10 years in test and measurement
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**Dietmar Maicz**

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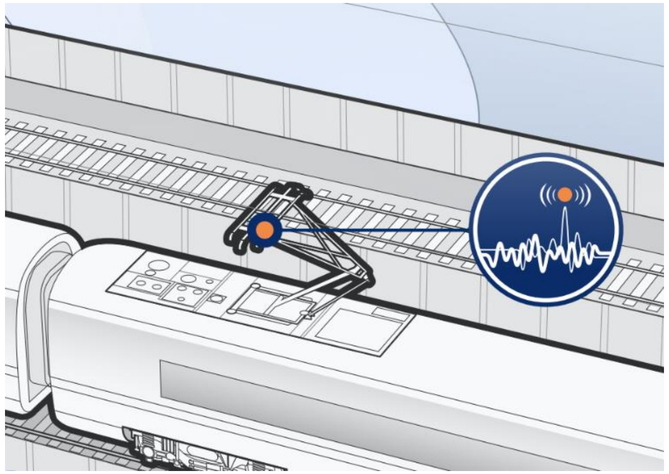
# Solution overview


Bringing light to measurement

# Typical applications for fiber based sensors

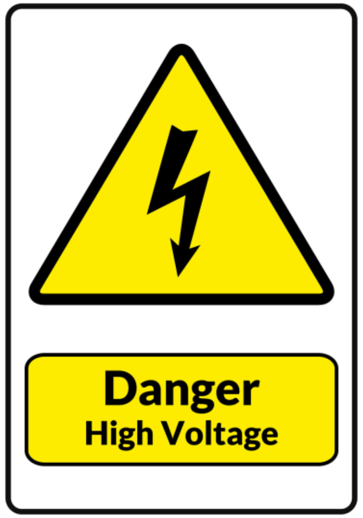
- Predictive overhead line maintenance
- Force- and acceleration measurement for overhead line inspection
- Homologation and testing of pantograph (EN50317)
- Dynamic contact force control

- Measured and computed values
  - Vertical contact force
  - Vertical acceleration
  - Sideway position computed from contact forces

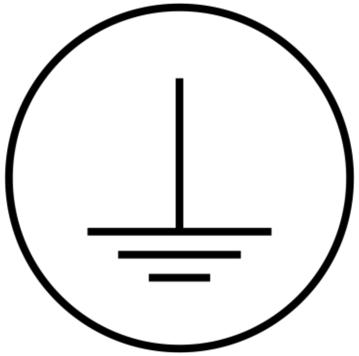


# Specifics

- Purely optical measurement chain
  - No electromagnetic influences
  - Force transducer and accelerometer design results in high accuracy
  - Allows easy and flexible integration with adapter holding plates
  - Very good long-term results
  - Patent pending



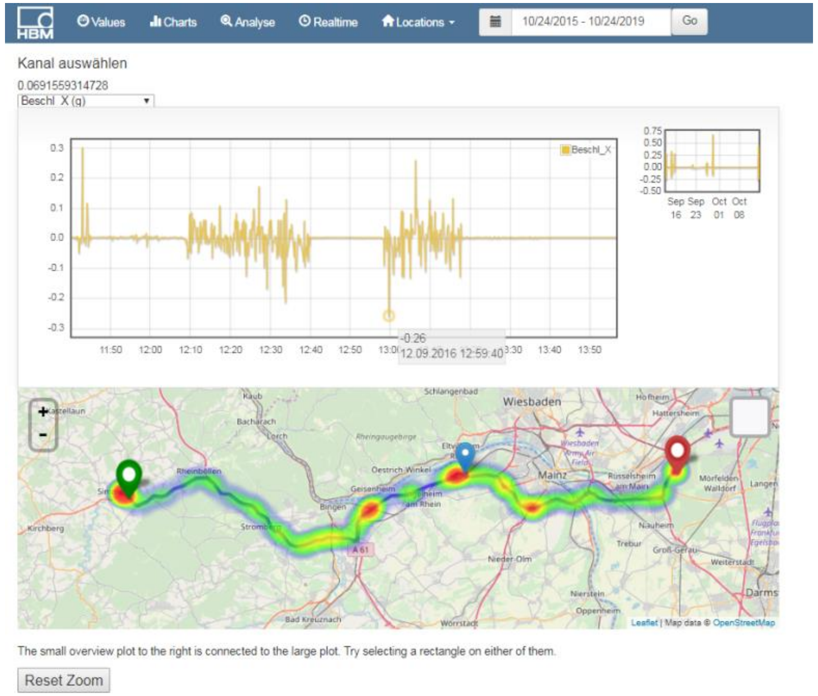

- Vehicle data and GNSS information
  - Wide range of physical and digital inputs
  - High data quality
  - Time-synchronized data (also with optical measurement chain part)



# Application example

# Example - Predictive overhead line maintenance

- 24/7 monitoring through standard trains
- A measurement pantograph incorporating a fiber optic sensing system, based on a regular, tested and certified standard model, can measure with suitable accuracy in the high voltage environment
- diagnoses the overhead contact line and automatically sends error reports via wireless technology if predefined limit values should be violated



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# Motivation

- The catenary is a vital part of the railway infrastructure
- Electric trains establish contact to the catenary via their pantographs
- For safe and reliable operation, vertical and horizontal position as well tension of the overhead contact lines needs to be within certain limits
- Contact force between pantograph and the high voltage overhead contact wire is a reliable and useful measure for its condition
- Irregularities need to be detected in time to avoid severe damage

- *Work developed in the framework of a ÖBB/FFG R&D project*

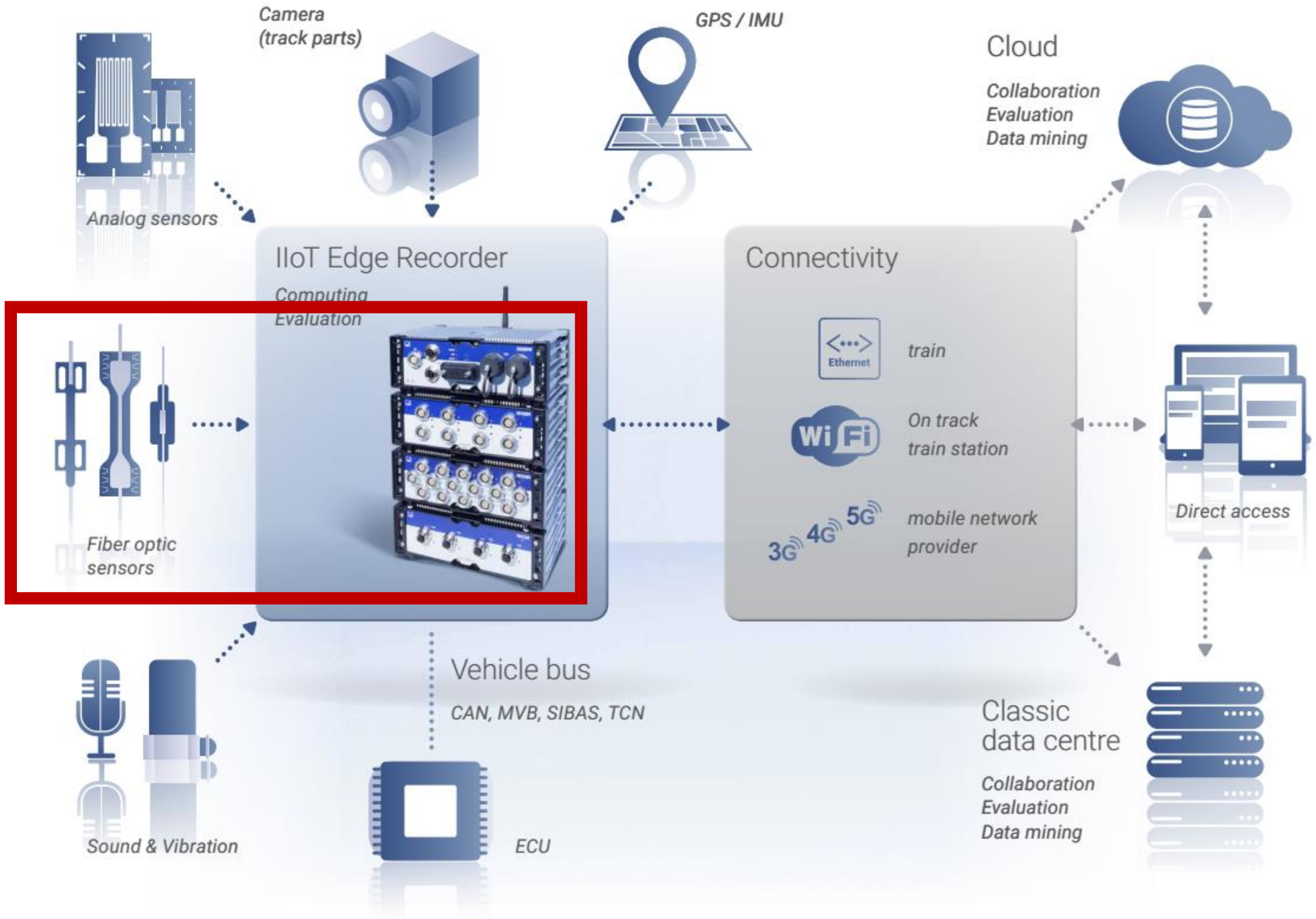
# Requirements (excerpt)

a measurement pantograph incorporating a fiber optic sensing system must…

- … detect contact force relief of the pantograph
  - … measure the side way movement of the contact wire
  - … detect undesired peaks in contact force
- … localize the obtained results on railway track (via GPS, +/-1 m position accuracy)
- … monitor thresholds and give alarm immediately to operator in case a critical condition is detected
- … ensure continuous 24/7 operation
- … be in compliance with EN 50317 (standard for measuring the pantograph-contact line interaction)
- … have minimum influence in vehicle maintenance (standard contact strips)

# System general architecture

# Vehicle integration



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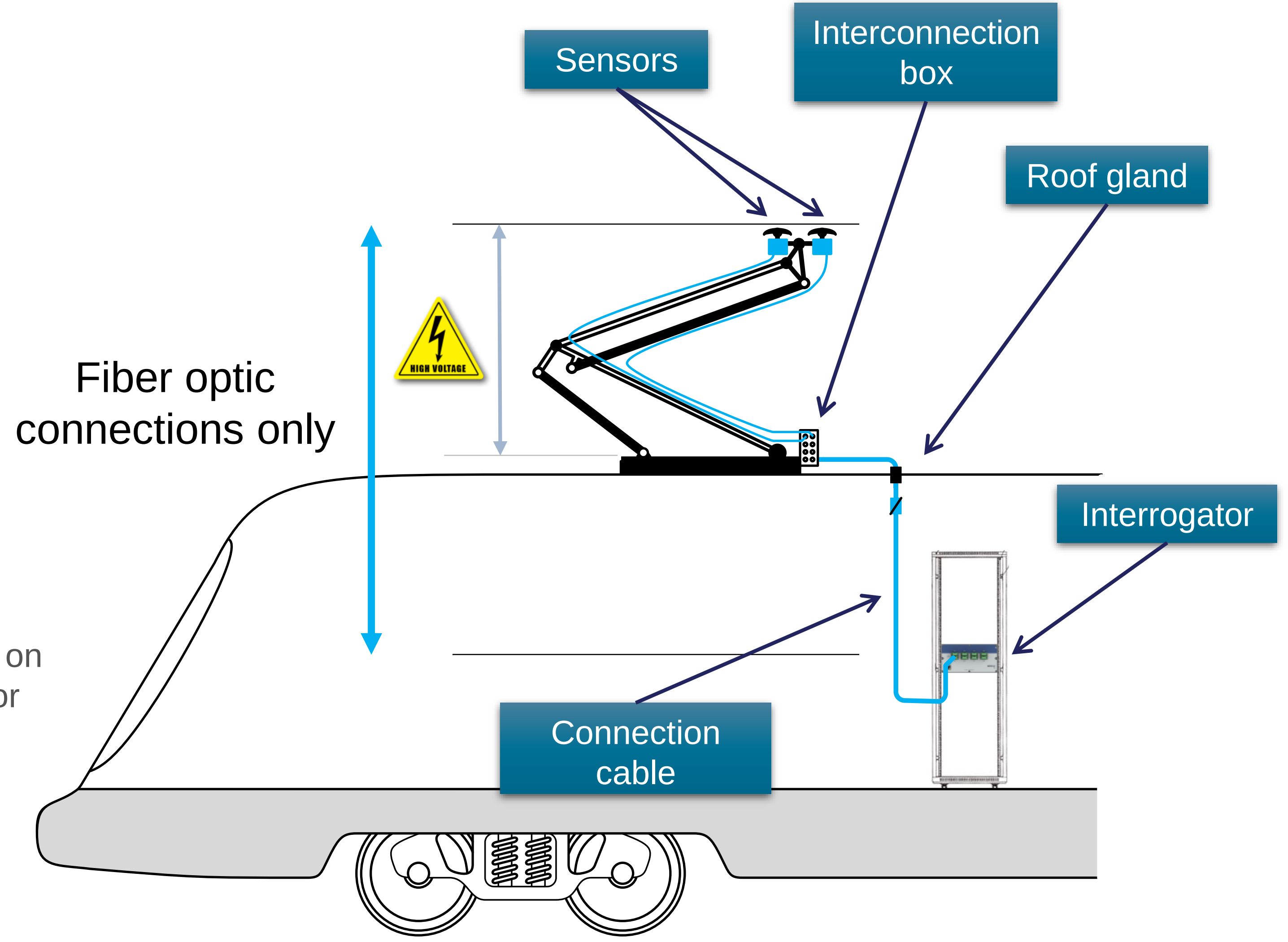
# Fibre optic part




All cables, including on sensors, are rated for railway applications (manufactured by Huber+Suhner)

# Solution Components

## Sensors, Cabeling and Interrogator

- Force transducer (HBM design)
- Accelerometer (HBM design)
- Interconnection box (HBM design) with penetration cable
  - Box to connect all sensors – installed outside on train roof
  - Penetration cable with PTFE overlay – from connection box to inside train (roof gland)
- Connection cable – from inside train to interrogator
- MXFS – HBM QuantumX interrogator with 8 connectors

## Vehicle integration (non optical)

- GPS/IMU
- CAN, MVB, SIBAS, TCN
- HBM QuantumX amplifier and logger
- DAQ-Software
- Connectivity incl. Cloud



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# Contact force measurement



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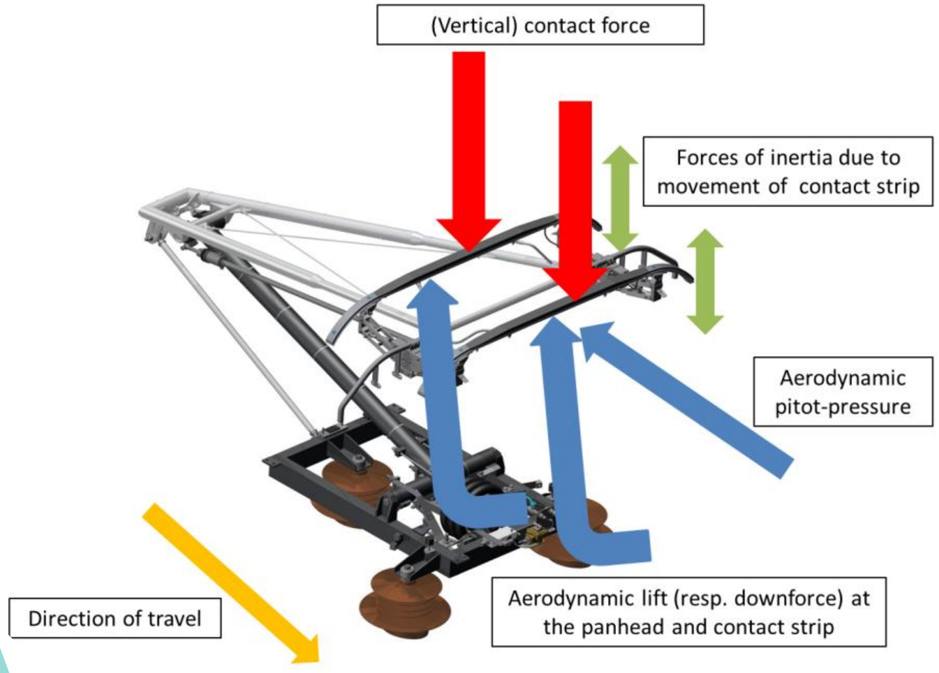
# Contact force measurement

- Force measurement on four positions of pantograph
  - Two for each panhead




FORCES ON PANTOGRAPH

$$F_c = \sum_{i=1}^{k_f} F_{Sensor,i} + \frac{m_{above}}{k_a} \sum_{i=1}^{k_a} a_{Sensor,i} + F_{corr,aero}$$

$F_c$ = contact force
$F_{Sensor;i}$ = measured force at sensor i
$a_{Sensor;i}$ = measured acceleration at sensor i
$k_f$ = number of force sensors
$k_a$ = number of acceleration sensors
$m_{above}$ = mass of the panhead located above the force sensors
$F_{corr;aero}$ = aerodynamic correction force
(velocity dependent, retrieved from lookup table)



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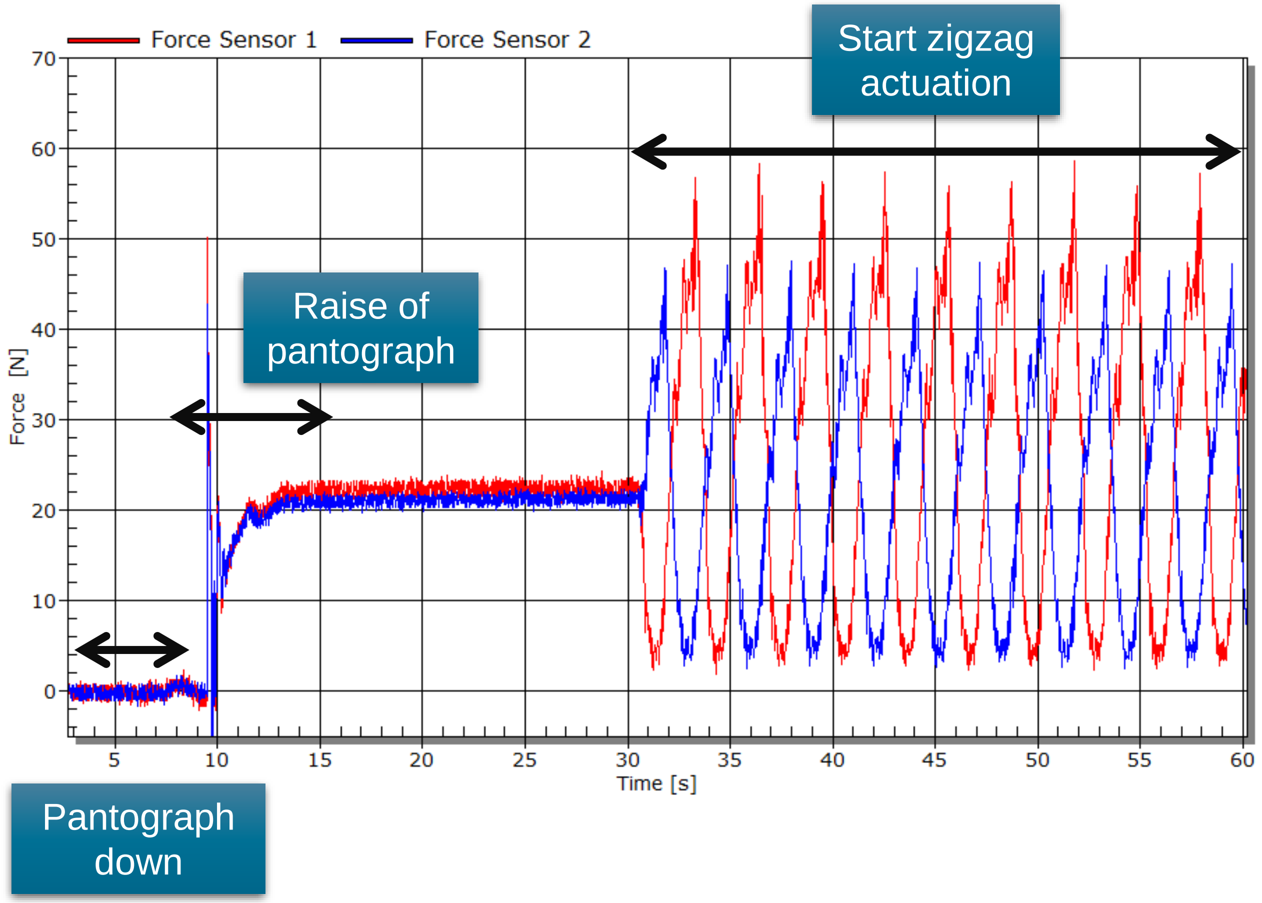
# Force under zigzag actuation scenario



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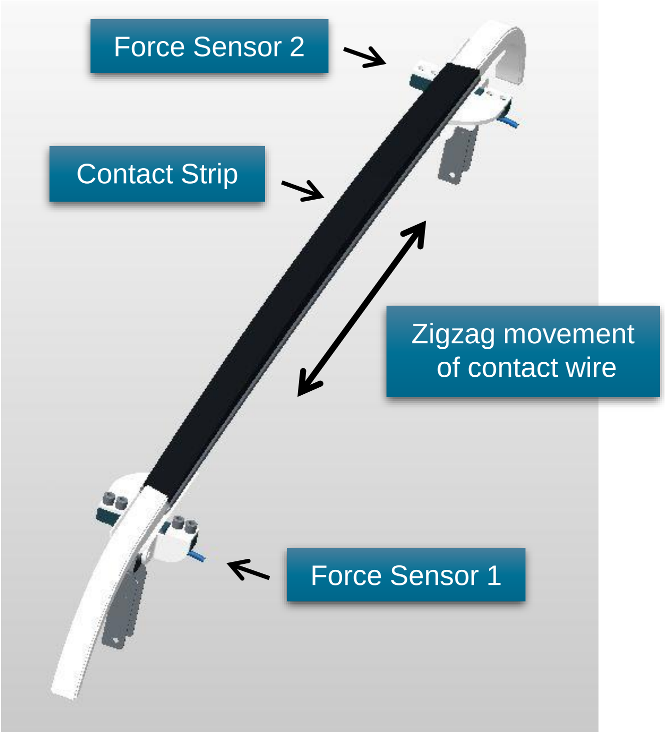
# Position of contact line

- Calculated from the force values the position of contact wire can be deduced

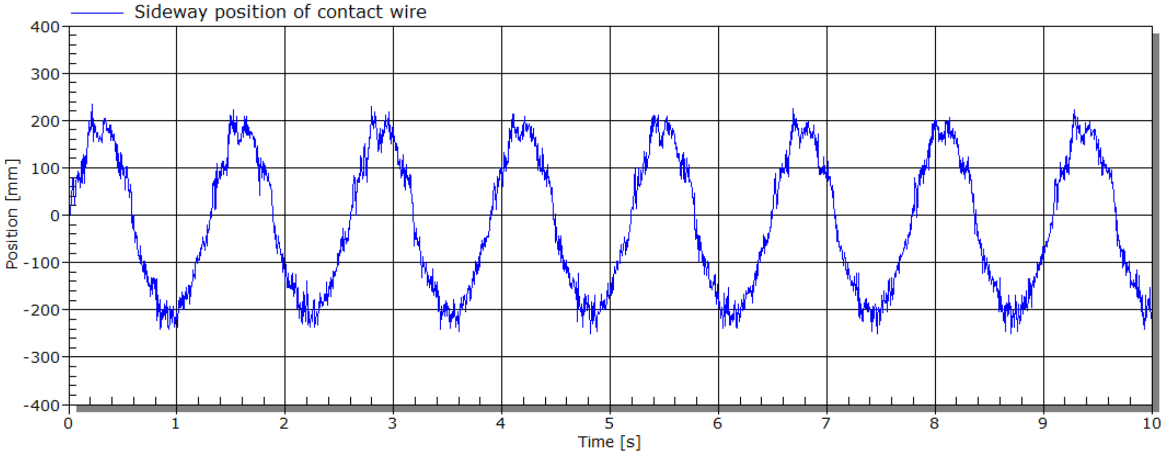
PANHEAD




$$x = \frac{F_2}{F_1 + F_2} L - L/2$$

With:

| | |
|---|---|
| x = 0 | middle position |
| L | distance between force sensors |



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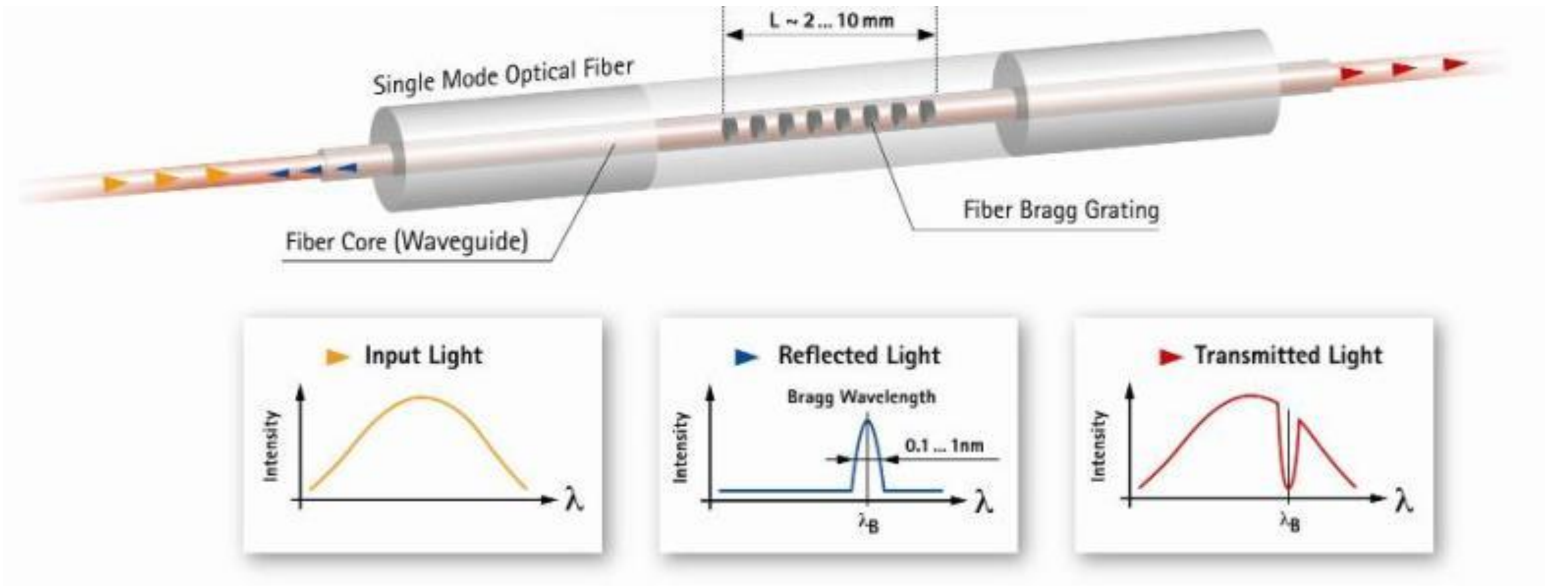
# Optical technology

# Fiber Bragg Grating (FBG) technology

- Fiber Bragg Grating (FBG) technology
  - Sensors can operate in HV environment (0.6 to 25 kV, up to 8000 A)
  - FBGs inscribed in optical fiber reflect light at certain wavelengths
  - Changes in strain or temperature alter FBG and affect reflected light
  - Measurements obtained from wavelength shifts in reflected peaks (nm)



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# Fiber Bragg Grating (FBG) technology

- Bragg's Law

$$\lambda_B = 2n_{eff}\Lambda \qquad \Lambda = \frac{\Lambda_m}{2}$$

- Temperature

$$\frac{\Delta\lambda_B}{\lambda_B} = (\alpha + \varsigma)\Delta T = \beta_T \Delta T \qquad \frac{\Delta\lambda_B}{\Delta T} = 10\ \mathrm{pm}/^{o}\mathrm{C}$$

- Strain

$$\frac{\Delta\lambda_B}{\lambda_B} = (1 + p_e)\Delta\varepsilon = \beta_\varepsilon \Delta\varepsilon \qquad \frac{\Delta\lambda_B}{\Delta\varepsilon} = 1.2\ \mathrm{pm}/\mu\varepsilon$$

**FBG**

$$\frac{\Delta\lambda_B}{\lambda_B} = 0.78 \cdot \Delta\varepsilon$$

**Strain gauge**

$$\frac{\Delta R}{R} = 2 \cdot \Delta\varepsilon$$

# Sensors, Cabling and Amplifier

# FS66HDL Heavy Duty Force Transducer

- New and unique development
  - newLight® technology*
  - High resolution
  - Low weight – 99g
  - Compact design
- Measuring range +/- 500N
- Forces measured via shear beam principle
  - Temperature effects cancel out
- One connector housing for two optical fibers
  - Possibility to connect sensors in series
- Rugged
  - Protected and covered, weather proof
  - Railway rated cables and connectors





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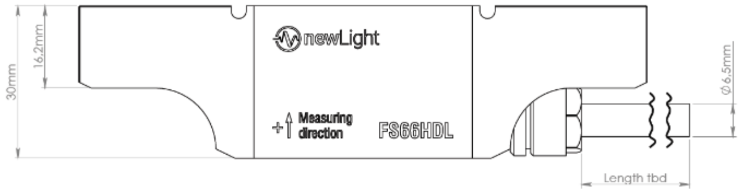
# FS66HDL datasheet

| | | |
|---|---|---|
| **Sensor** | | |
| Sensitivity[1] | pm/N | 2.1 |
| Measurement range | N | 500 |
| Maximum load | N | 1000 |
| Critical load | N | 1250 |
| Dependence of zero point on temperature | % / 10ºC | 0.3 |
| Dependence of sensitivity coefficient on temperature | % /10ºC | 0.5 |
| Linearity deviation[2] | % | 0.5 |
| Acceptable interfering moment: around y axis/ around x axis | N.m | 40 / 25 |
| Operation temperature range | ºC | -20 … 80 |
| Storage temperature range | ºC | -40 … 85 |
| Degree of protection[3] | n.a. | IP67 |
| Dimensions | mm | 112 x 20 x 30 |
| Weight[4] | g | 99 |
| **Inputs / Outputs** | | |
| Cable type | n.a. | Huber+Suhner Radox |
| Cable length | m | 8±0.05 |
| Connectors[5] | n.a. | Huber+Suhner Q-ODC-2 |

| **Ordering Information** |
|---|
| K-SYS-FSS |


[1] Typical value. Sensitivity defined as wavelength difference $(\lambda_2 - \lambda_1)$ / force.
[2] Referred to nominal load.
[3] DIN EN 60529.
[4] Without cables.
[5] Other connector types available.



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# FS65HDA Heavy Duty Accelerometer

- New and unique development
  - newLight® technology*
  - High resolution
  - Very low weight – 34g
  - Compact design
- Measuring range: +/- 20g
  - Acceleration measured via seismic mass principle
  - Temperature effects cancel out
- One connector housing for two optical fibers
  - Possibility to connect sensors in series
- Rugged
  - Protected and covered, weather proof
  - Railway rated cables and connectors




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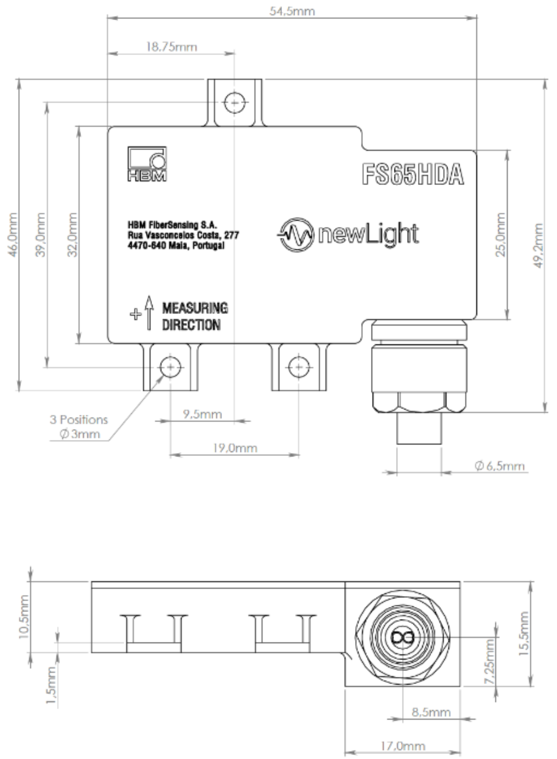
# FS65HDA datasheet

| Sensor | | |
|---|---|---|
| Sensitivity[1] | pm/g | 42 |
| Nominal acceleration | g | ±20 |
| Cross axis sensitivity | % | <1 |
| Frequency range | Hz | 0 to 350 |
| Resonance frequency | Hz | 700 |
| Operation temperature range | °C | -20…80 |
| Storage temperature range | °C | -40…85 |
| Maximum acceleration | g | ±100 |
| Degree of protection[2] | n.a. | IP67 |
| Dimensions | mm | 54.5 x 49.2 x 15.5 |
| Weight[3] | g | 34 |
| **Inputs / Outputs** | | |
| Cable | n.a. | Huber+Suhner Radox |
| Cable length | m | 8±0.05 |
| Connector[4] | n.a. | Huber+Suhner Q-ODC-2 |

| Ordering Information |
|---|
| K-SYS-FSS |




1 Typical value. Sensitivity defined as wavelength difference $(\lambda_2 - \lambda_1)$ / acceleration.
2 DIN EN 60529.
3 Not considering cables.
4 Other connector types available.



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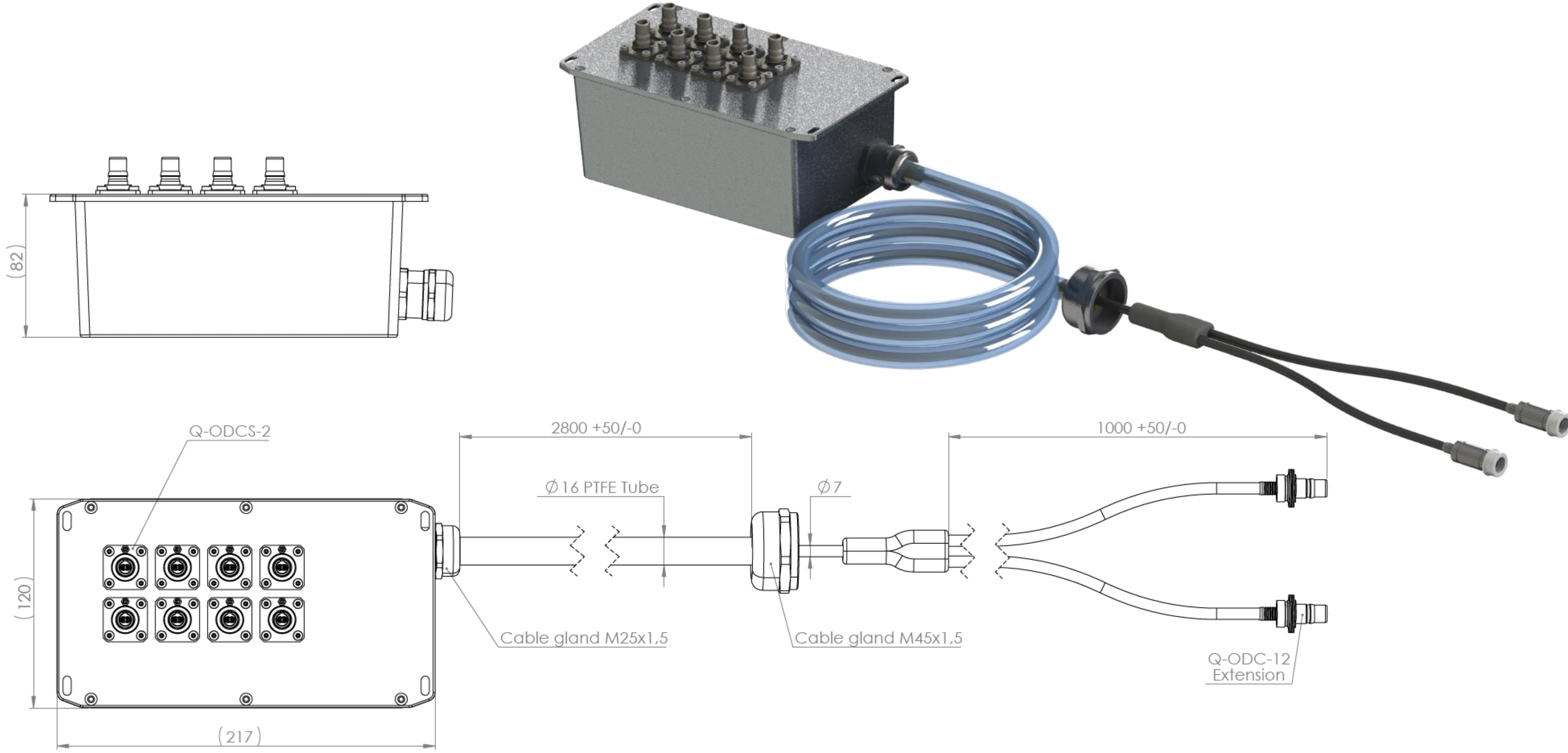
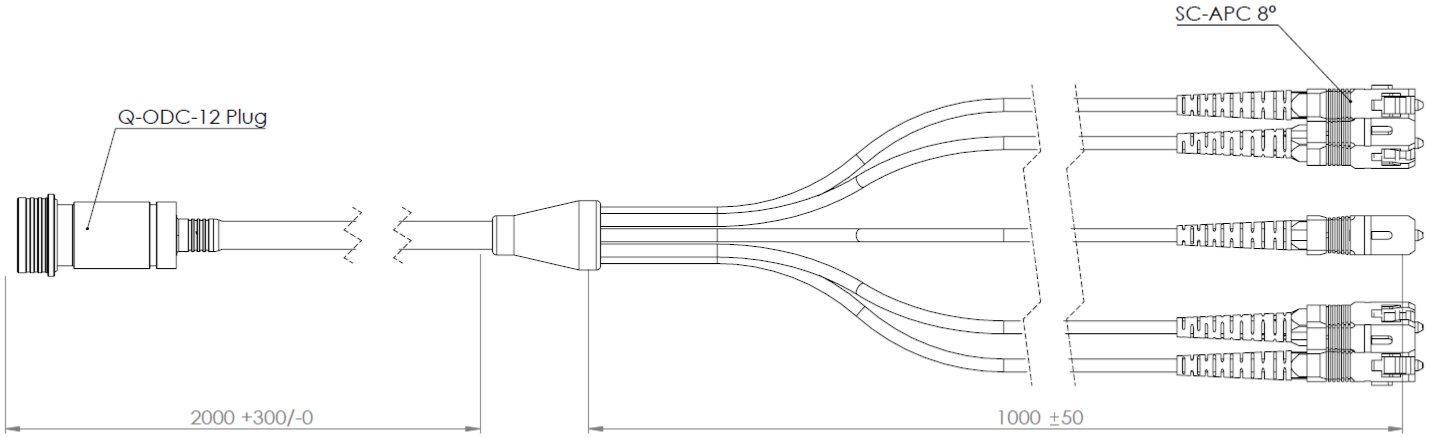
# Interconnection box with penetration cable



# Connection cable



# MXFS – QuantumX BraggMETER

- Optical interrogator for FBG (Fiber bragg grating) sensors
  - 8 parallel optical connectors
  - 2,000 S/s acquisition rate
- Full integration with QuantumX* platform
  - Small size and weight for mobile applications
  - Robust design for intensive operation
- Proven continuous swept laser scanning technology
- Continuous calibration with NIST traceable wavelength reference
  - Ensures system accuracy over long term operation
- High resolution
  - Assured by a high dynamic range and output power combined with SPD (Smart Peak Detection)

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# MXFS – QuantumX datasheet

**Specifications MXFS**

| General specifications | | | |
|---|---|---|---|
| | | **High speed mode** | **Slow speed mode** |
| Inputs | n.a. | 8 | |
| Connector types | n.a. | FC/APC | |
| Transducer technologies | n.a. | Fiber Bragg Grating (FBG) | |
| Optical wavelength measurement range | nm | 1500 to 1600 [100] | |
| Number of channels per optical connector | n.a. | 16 | |
| Data rate[1] | S/s | 2000 | 100 |
| Resolution[2] | pm | <2 | |
| Stability[2] | pm | 5 | |
| Peak detection method | n.a. | SPD[3] | |
| Dynamic range | dB | > 20 | |
| OSA[4] | n.a. | Yes | |
| Max. Optical Output Power | dBm | -3 | |
| Active filters | Hz | Bessel, Butterworth, linear phase 0.01 … 20 (-3dB), filter OFF | |
| Supply voltage | V | 10 … 30 (24 V nominal (rated) voltage) | |
| Power supply interruption | n.a. | Max. 5ms at 24 V | |
| Power consumption | W | < 30 | |
| Ethernet (data link) | | 10Base-T/100Base-TX | |
| Protocol/addressing | n.a. | TCP/IP (direct IP address or DHCP) | |
| Connection | n.a. | 8P8C plug (RJ-45) with twisted pair cable, Streaming (CAT-5) | |
| Max. cable length to module | m | 100 | |
| Synchronization[5] | | | |
| FireWire | n.a. | IEEE1394b (2 ports per device) | |
| Ethernet | n.a. | IEEE1588 (PTPv2) or NTP (2 ports per device) | |
| IEEE1394b FireWire (module synchronization, data link, optional supply voltage) | | IEEE1394b (HBM modules only) | |
| Baud rate | MBaud | 400 (approx. 50 Mbyte/s) | |
| Max. current from module to module | A | 1.5 | |
| Max. cable length between nodes | M | 5 | |
| Max, number of modules connected in series (daisy chain) | n.a. | 12 (=11Hops) | |
| Max. number of modules in a IEEE1394b Firewire system (including hubs[6] backplane) | n.a. | 24 | |
| Max. number of hops[7] | n.a. | 14 | |



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# Electric physical and digital inputs

**Universal Inputs**
Inputs > 16 transducers types
**MX840B, MX440B**

**High Speed Mechanical**
Universal, Torque, Speed
**MX410B, MX460B**

**Electrically Isolated Inputs**
Voltage, current, temperature
MX403B, MX809B

**High Channel Count Specialists**
Strain, +/-10V, 4..20 mA, Thermocouple
**MX1615B, MX1601B, MX1609KB, MX1609TB**

**High Accuracy Full Bridge**
Force, Torque, Weighing
**MX430B, MX238B**

# Freely scale your system

**Powerful Data Recorder**
Mobile DAQ, monitoring, test station
**CX22B-W**


**CAN / CAN FD digital vehicle bus**
Mobile recording (CAN / CAN FD, xCP),
CAN Bench integration (DBC generation)
**MX471B, MX471C**

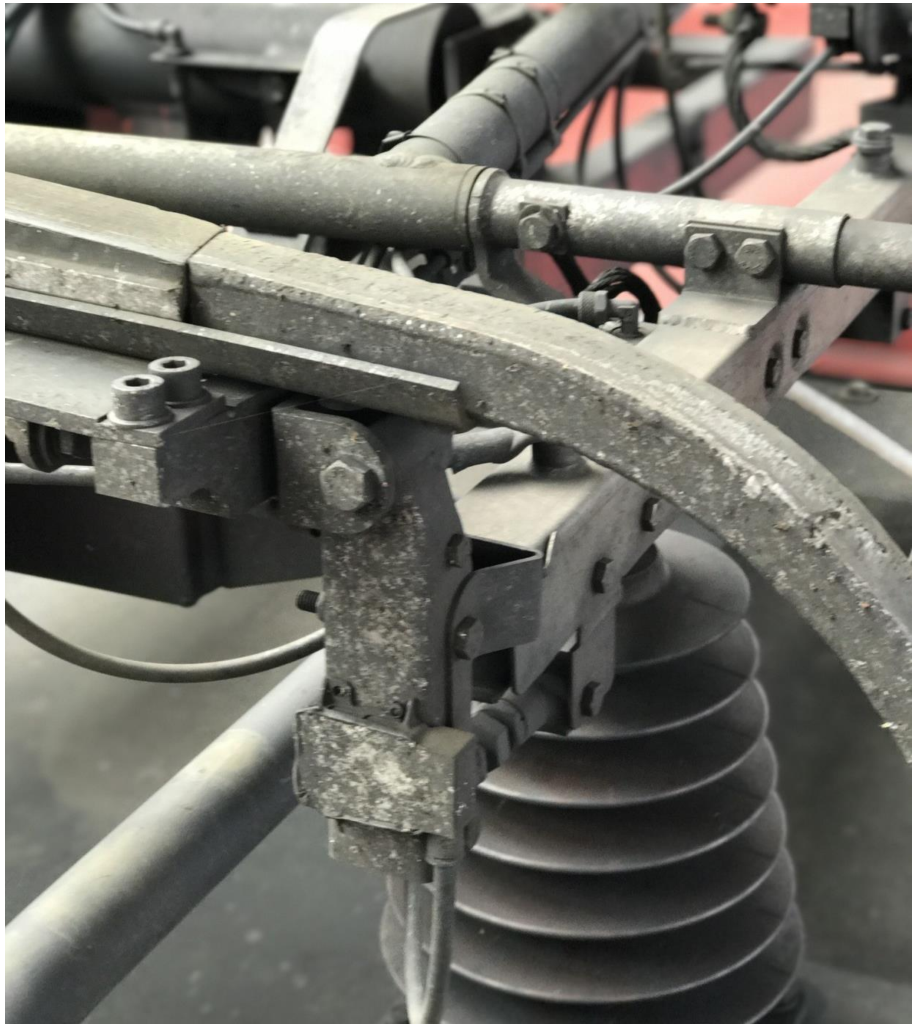

**Real-time bench test integration**
EtherCAT/PROFINET, + Ethernet gateway
**CX27B, CX27C**

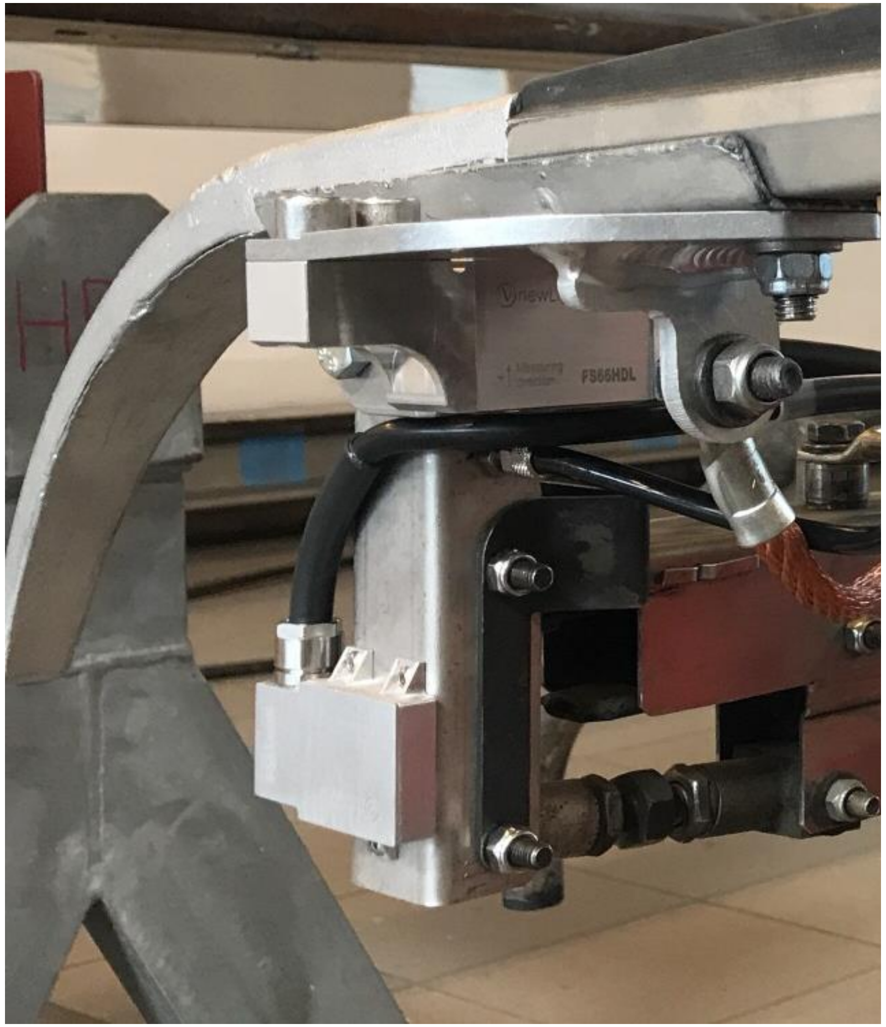
**Small Scale Lab Automation**
Analog voltage output, Multi IO
**MX878B, MX879B**

# since 2015 in 24/7 operation

Pictures taken after one year operation

# 4 years in 24/7 operation vs new







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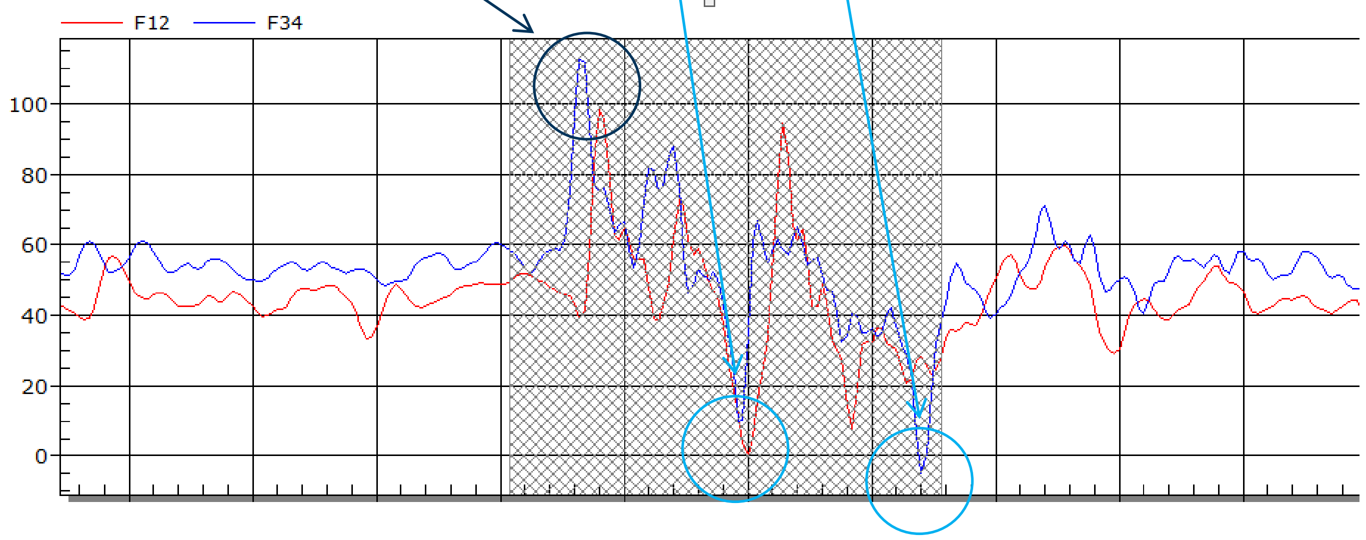
# Detected problem in overhead line

- Sum force per contact strip in red and blue

Bigger impact

followed by lose of contact (force ≤ 0)



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# Questions..?

# Additional questions..?

- If you have any questions, please do not hesitate to contact us: webinar@hbm.com

- Or email the presenter directly: dietmar.maicz@hbm.com

# Thank You

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