High-voltage Pantograph Overhead-line Monitoring

USING A FIBER-BASED MEASUREMENT CHAIN

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- Master level degree in Engineering and Economics
- >15 years of experience, >10 years in test and measurement
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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
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
Fibre optic part

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

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

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

- \( F_c \) = contact force
- \( F_{\text{Sensor},i} \) = measured force at sensor \( i \)
- \( a_{\text{Sensor},i} \) = measured acceleration at sensor \( i \)
- \( k_f \) = number of force sensors
- \( k_a \) = number of acceleration sensors
- \( m_{\text{above}} \) = mass of the panhead located above the force sensors
- \( F_{\text{corr,aero}} \) = aerodynamic correction force (velocity dependent, retrieved from lookup table)
Force under zigzag actuation scenario

- Start zigzag actuation
- Raise of pantograph
- Pantograph down
Position of contact line

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

\[ x = \frac{F_2}{F_1 + F_2} L - \frac{L}{2} \]

With:
- \( x = 0 \) middle position
- \( L \) distance between force sensors
Optical 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)
Fiber Bragg Grating (FBG) technology

- **Bragg’s Law**
  \[ \lambda_B = 2n_{\text{eff}} \Lambda \quad \Lambda = \frac{\Lambda_m}{2} \]

- **Temperature**
  \[ \frac{\Delta \lambda_B}{\lambda_B} = (\alpha + \zeta)\Delta T = \beta_T \Delta T \quad \frac{\Delta \lambda_B}{\Delta T} = 10 \text{ pm/}^\circ\text{C} \]

- **Strain**
  \[ \frac{\Delta \lambda_B}{\lambda_B} = (1 + p_e)\Delta \varepsilon = \beta_e \Delta \varepsilon \quad \frac{\Delta \lambda_B}{\Delta \varepsilon} = 1.2 \text{ pm/\mu} \varepsilon \]

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
FS66HDL datasheet

<table>
<thead>
<tr>
<th>Sensor</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity1</td>
<td>pm/N</td>
<td>2.1</td>
</tr>
<tr>
<td>Measurement range</td>
<td>N</td>
<td>500</td>
</tr>
<tr>
<td>Maximum load</td>
<td>N</td>
<td>1000</td>
</tr>
<tr>
<td>Critical load</td>
<td>N</td>
<td>1250</td>
</tr>
<tr>
<td>Dependence of zero point on temperature</td>
<td>% / 10°C</td>
<td>0.3</td>
</tr>
<tr>
<td>Dependence of sensitivity coefficient on temperature</td>
<td>% /10°C</td>
<td>0.5</td>
</tr>
<tr>
<td>Linearity deviation2</td>
<td>%</td>
<td>0.5</td>
</tr>
<tr>
<td>Acceptable interfering moment: around y axis/ around x axis</td>
<td>N.m</td>
<td>40 / 25</td>
</tr>
<tr>
<td>Operation temperature range</td>
<td>°C</td>
<td>-20 ... 80</td>
</tr>
<tr>
<td>Storage temperature range</td>
<td>°C</td>
<td>-40 ... 85</td>
</tr>
<tr>
<td>Degree of protection3</td>
<td>n.a.</td>
<td>IP67</td>
</tr>
<tr>
<td>Dimensions</td>
<td>mm</td>
<td>112 x 20 x 30</td>
</tr>
<tr>
<td>Weight4</td>
<td>g</td>
<td>99</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inputs / Outputs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable type</td>
<td>n.a.</td>
</tr>
<tr>
<td>Cable length</td>
<td>m</td>
</tr>
<tr>
<td>Connectors5</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ordering Information</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>K-SYS-FSS</td>
<td></td>
</tr>
</tbody>
</table>

1 Typical value. Sensitivity defined as wavelength difference \((\lambda_2 - \lambda_1) / \text{force}\).
2 Referred to nominal load.
3 DIN EN 60529.
4 Without cables.
5 Other connector types available.
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
FS65HDA datasheet

### Sensor

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>42 pm/g</td>
</tr>
<tr>
<td>Nominal acceleration</td>
<td>±20 g</td>
</tr>
<tr>
<td>Cross axis sensitivity</td>
<td>&lt;1 %</td>
</tr>
<tr>
<td>Frequency range</td>
<td>0 to 350 Hz</td>
</tr>
<tr>
<td>Resonance frequency</td>
<td>700 Hz</td>
</tr>
<tr>
<td>Operation temperature range</td>
<td>-20...80 °C</td>
</tr>
<tr>
<td>Storage temperature range</td>
<td>-40...85 °C</td>
</tr>
<tr>
<td>Maximum acceleration</td>
<td>±100 g</td>
</tr>
<tr>
<td>Degree of protection</td>
<td>IP67</td>
</tr>
<tr>
<td>Dimensions</td>
<td>54.5 x 49.2 x 15.5 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>34 g</td>
</tr>
</tbody>
</table>

### Inputs / Outputs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable</td>
<td>n.a.</td>
</tr>
<tr>
<td>Huber + Suhner Radox</td>
<td></td>
</tr>
<tr>
<td>Cable length</td>
<td>8±0.05 m</td>
</tr>
<tr>
<td>Connector</td>
<td>n.a.</td>
</tr>
<tr>
<td>Huber + Suhner Q-ODC-2</td>
<td></td>
</tr>
</tbody>
</table>

### Ordering Information

<table>
<thead>
<tr>
<th>Information</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>K-SYS-FSS</td>
<td></td>
</tr>
</tbody>
</table>

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1. Typical value. Sensitivity defined as wavelength difference (λ₂ - λ₁) / acceleration.
2. DIN EN 60529.
3. Not considering cables.
4. Other connector types available.
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)
# MXFS – QuantumX datasheet

## Specifications MXFS

<table>
<thead>
<tr>
<th>General specifications</th>
<th>High speed mode</th>
<th>Slow speed mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inputs</td>
<td>n.a.</td>
<td>9</td>
</tr>
<tr>
<td>Connector types</td>
<td>n.a.</td>
<td>FC/APC</td>
</tr>
<tr>
<td>Transducer technologies</td>
<td>n.a.</td>
<td>Fiber Bragg Grating (FBG)</td>
</tr>
<tr>
<td>Optical wavelength measurement range</td>
<td>nm</td>
<td>1500 to 1600 [100]</td>
</tr>
<tr>
<td>Number of channels per optical connector</td>
<td>n.a.</td>
<td>16</td>
</tr>
<tr>
<td>Data rate(^1)</td>
<td>S/a</td>
<td>2000</td>
</tr>
<tr>
<td>Resolution(^2)</td>
<td>pm</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Stability(^2)</td>
<td>pm</td>
<td>5</td>
</tr>
<tr>
<td>Peak detection method</td>
<td>n.a.</td>
<td>SPD(^3)</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>dB</td>
<td>&gt; 20</td>
</tr>
<tr>
<td>OSA(^4)</td>
<td>n.a.</td>
<td>Yes</td>
</tr>
<tr>
<td>Max. Optical Output Power</td>
<td>dBm</td>
<td>-3</td>
</tr>
<tr>
<td>Active filters</td>
<td>Hz</td>
<td>Bessel, Butterworth, linear phase 0.01 ... 20 (-3dB), filter OFF</td>
</tr>
<tr>
<td>Supply voltage</td>
<td>V</td>
<td>10 ... 30 (24 V nominal [rated] voltage)</td>
</tr>
<tr>
<td>Power supply interruption</td>
<td></td>
<td>Max. 5ms at 24 V</td>
</tr>
<tr>
<td>Power consumption</td>
<td>W</td>
<td>&lt; 30</td>
</tr>
<tr>
<td>Ethernet (data link)</td>
<td></td>
<td>100Base-T/100Base-TX</td>
</tr>
<tr>
<td>Protocol/addressing</td>
<td></td>
<td>TCP/IP (direct IP address or DHCP)</td>
</tr>
<tr>
<td>Connection</td>
<td>n.a.</td>
<td>SRI plug (RL-45) with twisted pair cable, Streaming (CAT-5)</td>
</tr>
<tr>
<td>Max. cable length to module</td>
<td>m</td>
<td>100</td>
</tr>
<tr>
<td>Synchronization(^5)</td>
<td>FireWire</td>
<td>n.a.</td>
</tr>
<tr>
<td></td>
<td>Ethernet</td>
<td>n.a.</td>
</tr>
<tr>
<td>IEEE 1394b FireWire (module synchronization, data link, optional supply voltage)</td>
<td></td>
<td>IEEE 1394b (HB modules only)</td>
</tr>
<tr>
<td>Baud rate</td>
<td>MBaud</td>
<td>400 (approx. 50 Mbytes/s)</td>
</tr>
<tr>
<td>Max. current from module to module</td>
<td>A</td>
<td>1.5</td>
</tr>
<tr>
<td>Max. cable length between nodes</td>
<td>M</td>
<td>5</td>
</tr>
<tr>
<td>Max. number of modules connected in series (daisy chain)</td>
<td>n.a.</td>
<td>12 (±1Hops)</td>
</tr>
<tr>
<td>Max. number of modules in a IEEE1394b Firewire system (including hub(^6) backbone)</td>
<td>n.a.</td>
<td>24</td>
</tr>
<tr>
<td>Max. number of hops(^6)</td>
<td>n.a.</td>
<td>14</td>
</tr>
</tbody>
</table>
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
Detected problem in overhead line

- Sum force per contact strip in red and blue

Bigger impact followed by lose of contact (force ≤ 0)
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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