A Fibre Optic Sensor Instrumented Pantograph As Part of a Continuous Structural Health Monitoring System for Railway Overhead Lines

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A FIBRE OPTIC SENSOR INSTRUMENTED PANTOGRAPH AS PART OF A CONTINUOUS STRUCTURAL HEALTH MONITORING SYSTEM FOR RAILWAY OVERHEAD LINES

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ABSTRACT

This article presents the project SAFE onLine (Pantograph for fibre-optic based recording and online evaluation of the catenary condition) funded by the Austrian Research Promotion Agency (FFG). The goal of this project is to develop a measurement system based on a commercial pantograph, that a regularly railway engine can be equipped with. We will give an overview on the different aspects and further course of the project and present first measuring results with the system obtained during integration tests at the pantograph test-bed.

KEYWORDS : *Optical Fibre Sensor, Fibre Bragg Grating, Monitoring, Railway, Overhead Catenary System*

INTRODUCTION

The catenary is a vital part of the railway infrastructure. The vertical and horizontal position as well as the tension of the overhead contact lines needs to be in certain limits that comply with international standards. For the moving electric train, that establishes contact to the catenary via his pantograph, this ensures minimal losses, limited wear, tear and a reduced risk of disruption of the current transmission to the train engines power unit. Irregularities need to be detected in time to avoid severe damage. A measure for the quality of the catenary is the contact force [1] between pantograph and the high voltage overhead contact wire (Figure 1a). An inspection of this condition needs to be done periodically and is currently done by single, limited specially equipped recording cars. Due to size of the electrified railway network intervals and track occupation the maintenance intervals are relatively long, vary and tend to increase. Sudden changes in the condition that might threaten normal operation are detected too late. The goal of the project SAFE onLine (Pantograph for fibre optic based recording and online evaluation of the catenary condition) funded by the Austrian Research Promotion Agency (FFG) is to develop a measurement system for the contact force based on a commercial pantograph, that a regularly railway engine can be equipped with.
A main requirement was to do measurements within a high voltage environment of 15-25 kV. Measuring systems with conventional electronic techniques have often failed on the high efforts to cope with isolation issues on the roof of a railway engine. Therefore the decision to use fibre optic sensors based on fibre-bragg-grating (FBG) technology [2] was made. Another advantage of FBG sensors is, that they can be connected in series and thus reduce the number of sensor cables. In recent research projects that used FBG techniques too, the sensory elements were placed in the contact strip ([3], [4]). This approach however does not give a direct measure of the actual forces acting on the contact strip, since only strains are measured. In order to achieve exactly this, HBM developed a new and unique

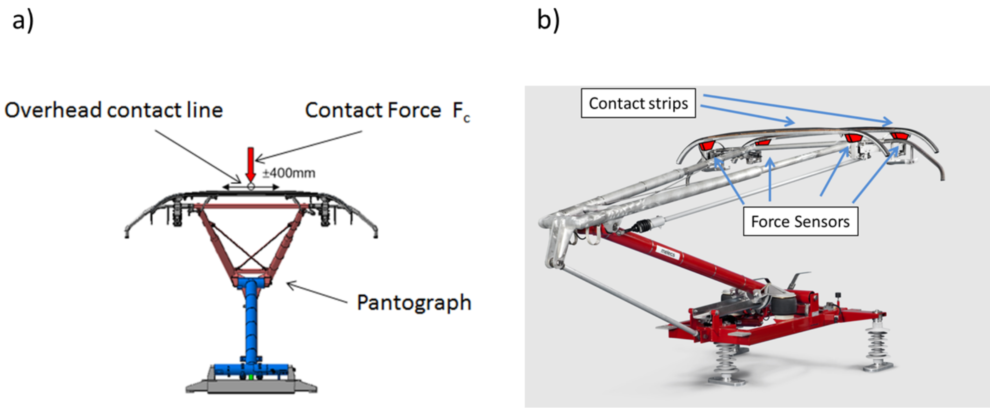

Figure 1 : a) Pantograph and contact force; b) Placement of force sensors on pantograph

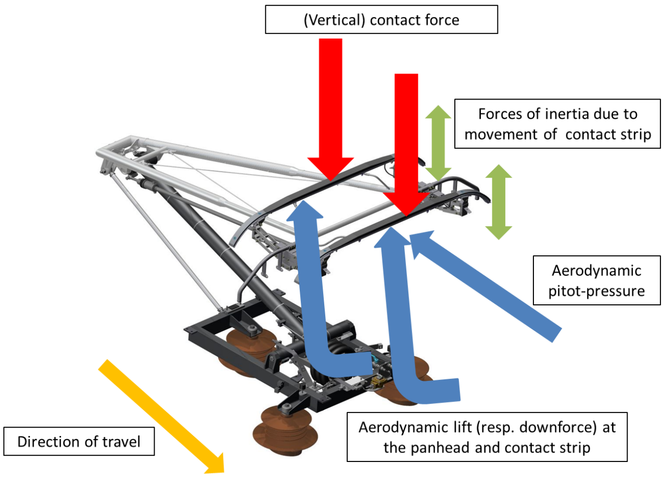

Figure 2 : Simplified illustration of forces acting on a pantograph

fibre optic force sensor, that complies industry standards and fulfils the requirement for operation in this harsh environment (all seasons, twenty-four-seven). The sensors are placed between pan head and contact strip and measure the force acting from the pantograph on the contact line (see Figure 1b).

Contact Force Measurement

The main forces acting on a pantograph are the combination of following components: the vertical contact force, the inertia forces of the contact strips and lift respectively down-forces caused by the aerodynamic of the movement of the train. Figure 2 gives an overview of the situation. The contact force can be calculated with the following formula, defined in EN50317 [5]:

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

Where:

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

The parameter $F_{Sensor,i}$ and $a_{Sensor,i}$ will be measured with fibre optic force respectively acceleration sensors. $F_{corr,aero}$ is a velocity dependant, characteristic value of each specific pantograph and is retrieved from a look-up table that has to be generated through calibration measurements.
From the measured values of the two force sensors on a contact strip, the position of the contact line can be calculated with the following relation:

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

With $F_{1,2}$ giving the force of the respective sensor on the contact strip and L as the distance between the two force sensors. The position x equals 0 when the contact line is exactly in the middle between the two sensors.

GENERAL SYSTEM DESCRIPTION

The measuring system has been designed to meet the following criteria:

- Measure the side way movement of the contact wire.
- Detect undesired peaks in contact force
- Detect contact force relief of the pantograph
- Localise the obtained results to position (+/- 1 m) on railway track record data autonomously, 24/7 operation
- Monitor thresholds and alarming of events and gives notice to operator in case a critical condition is detected immediately

The cost of the whole system for a railway operator will be a fraction of the one imposed on him by a recording car. For proper mapping of the collected data to the exact locations on the track current standard GPS techniques turned out to be too inaccurate for the projects needs. Therefore a new corrected GPS is integrated, that uses a special infrastructure already provided by the Austrian Federal Railways (ÖBB). In Figure 3 we see an overview how the SAFE onLine-pantographs will be integrated in the network infrastructure of the ÖBB. Alarms are send out immediately to dedicated receivers through e-mail or text-message. The recorded data is stored on servers via ftp and can be accessed from there for in-detail post processing.
Once a certain number of engines are equipped with the test pantograph the catenary network is monitored at a regular basis, as by product of normal operation. The data can be collected in database and the development of the condition of the overhead contact line at specific locations can be monitored over time. In operation the developed pantographs thus forms a structural health monitoring system (SHM) for the railway networks overhead contact line network.

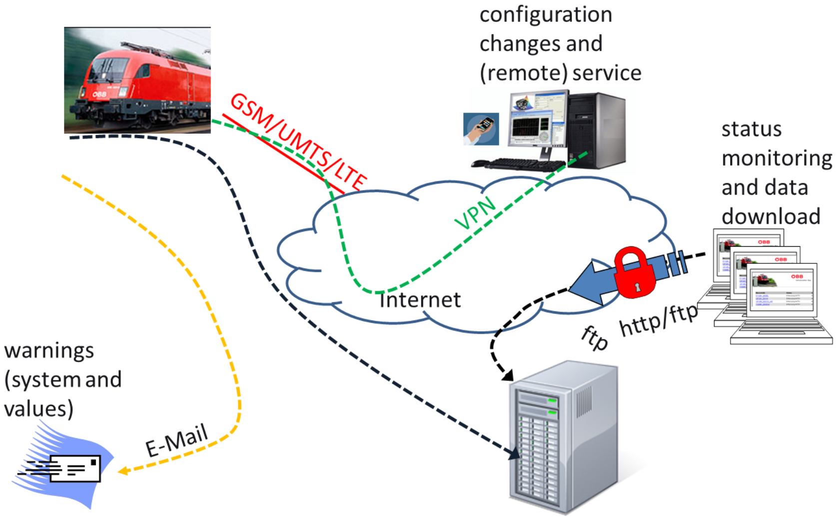

Figure 3 : SAFE onLine Network System Overview

Figure 4 : Fibre Optic Force Sensor FSTA131021-500N

SENSORS

Fibre Optic Force Sensor

For the project HBM developed a new and unique fibre optic force sensor *FSTA131021-500N* (Figure 4), that complies industry standards and fulfils the requirement for operation throughout the year in harsh railway environment. The main features of the *FSTA131021-500N* are:

- Measuring range: $+/-500N$
- Sensor consists of 3 FGBs (one in positive, one in negative strain direction, one for temperature measurement)
- One connection cable housing two optic fibres; so sensors can be connected in series
- Termination with 2 FC/APC-Connector
- Optical fibres completely save in the inside of the sensor
- Sensing zone protected and covered with silicon and aluminium

The force to be measured shall be passed as F_z by the center of the sensor (see Figure 5a). Deviations from this direction act on the transducer as parasitic forces or moments and are absorbed by the sensor

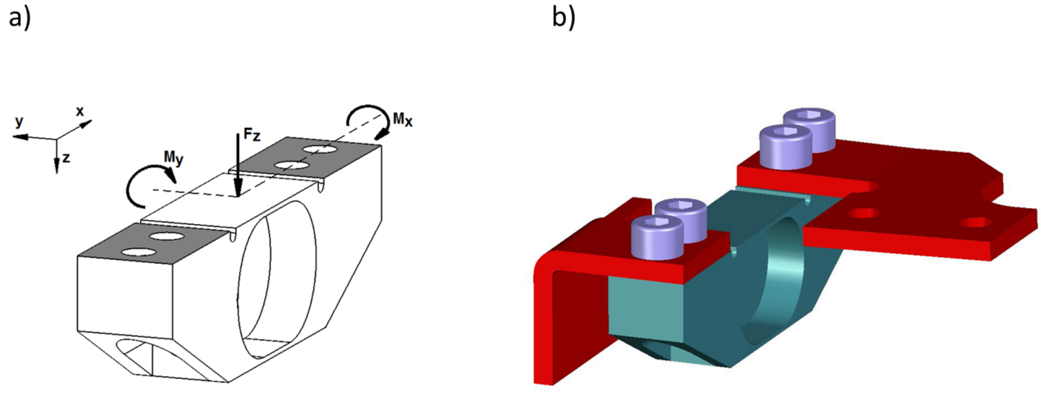

Figure 5 : a) Direction of measured force; b) Force sensor and assembly components

as long as they are in a reasonable range. For The pantograph the application of force is realized through special assembled (see Figure 5b)components.
Each of the sensors FBG'S yields a strain ($\mu m/m$) value according the following equation:

$$s = \frac{1}{0.78}\frac{(\lambda_c - \lambda_0)}{\lambda_0} \tag{3}$$

Where λ_c is the measured current wavelength and λ_0 is the nominal wavelength for the given FBG. The Force is then derived from the strain values by following relation:

$$F = A(s_2 - s_1) \tag{4}$$

Where A is the sensor sensitivity of dimension $[N/\mu m/m]$, that is provided for each sensor. The strain-FBGs in the sensor are arranged such that temperature effects act in opposite direction and cancel out when the values are subtracted (Eq. 4). This makes the force measurment robust against changes in temperature. Nevertheless the third FBG in the sensor is reacting to temperature only and can be used, in case a refined temperature compensation has to be done.

Fibre Optic Acceleration Sensor

When measuring the contact force the effects of inertia from the contact strip movements have to be taken into account (Eq. 1). Therefore measuring the acceleration is necessary. For this project 4 acceleration sensors that are based on the optic FBG technology, too are placed on the panhead to cope with this task. The sensors that have been selected are from type *AngleEye* from VanderHoekPhotonics (Figure 6). The operational range of the accelerometer is +/- 20g and since there are two active FBGs in the sensor temperature effects are similar compensated as in the force transducer.

EXPERIMENTAL RESULTS

Testsite

Extensive tests on laboratory level of the system have been performed on the pantograph test bench from the the project partner MELECS MWW GmbH & Co KG. The test facility comprises a large industrial robot coupled with an electrical linear motor and can simulate the entire dynamic operation

Figure 6 : Fibre Optic Acceleration Sensor AngleEye

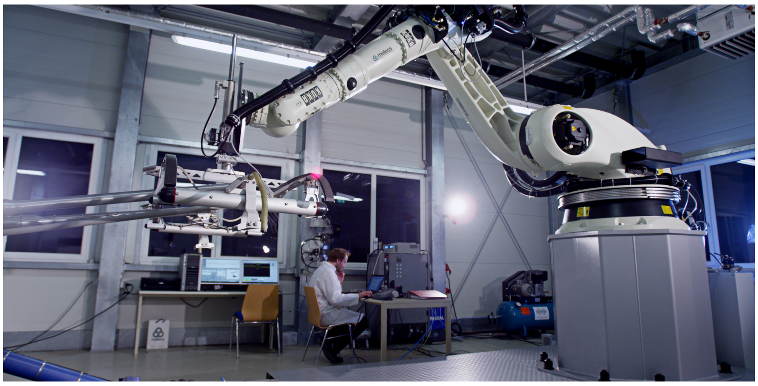

Figure 7 : The Pantograph-Catenary Interaction Simulator

range of most commercial pantographs. Figure 7 gives an impression of the test site. The main focus of this testing equipment is to be able to analyse the interaction between the pantograph and a simulated overhead contact line. The contact force between the two contact strips and a short rail, which functions as a replacement of the catenary, is measured continuously. The operating height of the pantograph (max.3300mm) and the momentary air pressure within the actuator that raises the current collector are also recorded. The train speeds that can be simulated on the test facility currently range from 0 to 400km/h.

Results

In the following we present some representative measurement results, that were collected at the Pantograph-Catenary-Intreraction-Simulator. In Figure 8 the recorded forces during various test stages are shown. First the Pantograph is down and therefore no contact force is measured (this state can be used to zero the measurement channels). Then the pantograph rises and the sensors each perceive a force of circa $20N$. The result is in good agreement with the total uplift force of around $80N$, that is equally split to the 4 force sensors on the panhead. Later a zigzag actuation with amplitude $965mm$ is started and one can observe the corresponding course of the forces, that act in expected diametrical direction.

The next plot (Fig. 9) shows the acceleration that occur during a test with a zig-zag actuation of amplitude 800mm.

Finally (Fig. 10) we have the result for measuring the contact point of the overhead contact wire. The values are calculated with equation 2. The distance between the two force senors is $1035mm$. The actuation amplitude of $400mm$ $(+/-200mm)$ is very good represented in the curve.

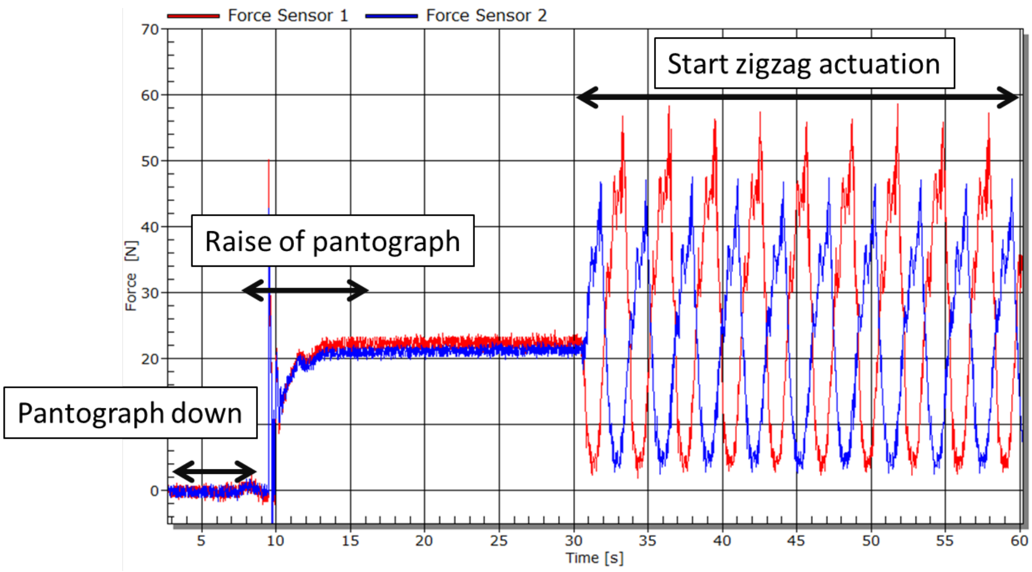

Figure 8 : Measured Forces on one contact strip; zig-zag actuation, amplitude 965mm

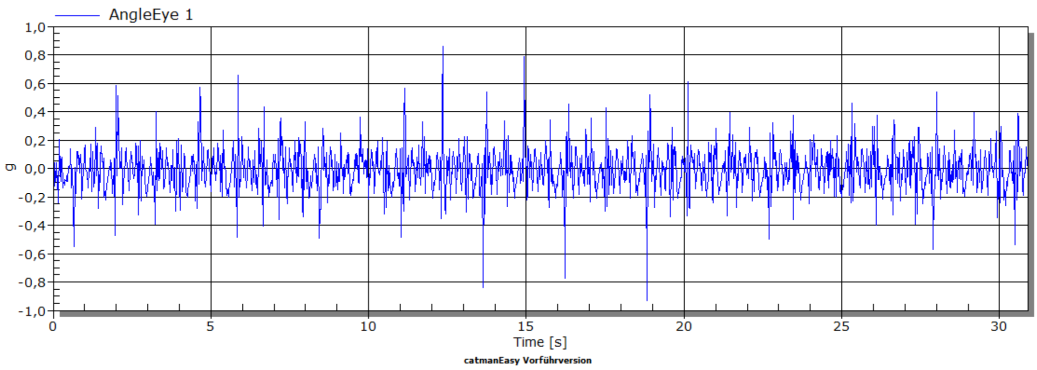

Figure 9 : Measured Acceleration on one contact strip; zig-zag actuation, amplitude 800mm

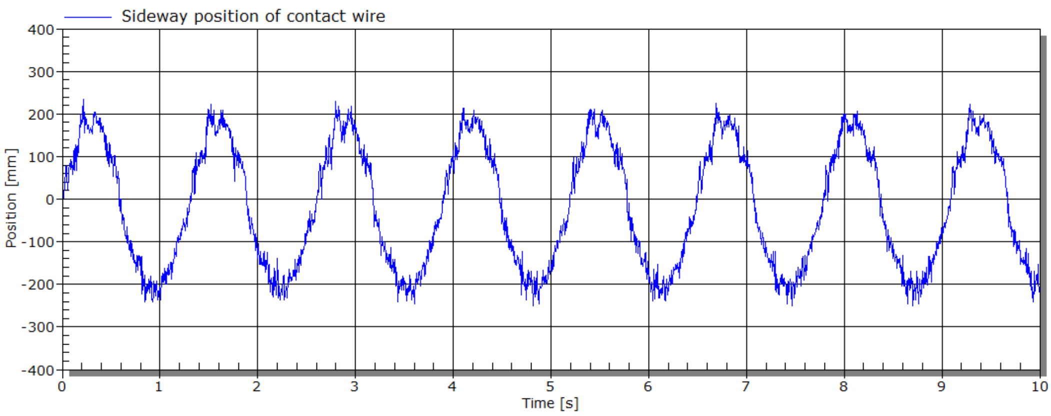

Figure 10 : Calculated position of contact line on panhead; zig-zag actuation, amplitude 400mm

CONCLUSION

The laboratory tests show good results and give an ample demonstration for the feasibility and functioning of the measuring system. In June 2014 the SAFE onLine pantograph and measuring system will be installed on a ÖBB railway engine of type 1116 from the series Taurus. From there on a stepwise integration in the information network of the Austrian Federal Railways will be realized, so that the system will reach its completion and make available its full capabilities.

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