Project no. 012105

CATIEMON

Catenary Interface Monitoring

Instrument: STREP

Thematic Priority: Coherent sensing technology for electrical railway infrastructure and rolling stock for interoperable cross boundary transportation

Final Activity Report

Period covered: from 2005-04-01 to 2009-01-31

Date of preparation: 2009-02-01

Start date of project: 2005-04-01

Duration: 2009-01-31

Project coordinator Dr. Henning
Project coordinator organisation SIEMENS AG

Revision [final 01]

Publishable executive summary

See annexes “2010_04_15 SYNOPSIS_CATIEMON.doc” and “2010_04_15 Poster_CATIEMON.ppt”.

1 Project execution

1.1 Project execution summary

The partners of CATIEMON are all aware of the **big picture** that forms the background for the project: Creating a competitive or even a decisive advantage for the European Union in the fast moving process of globalization.
The big picture is first made up of the interest of each single partner for his own well justified stake in the project then by the interest that all partners have together as members of the railways in Europe in competition to other means of transport further by the customers of the railways to have a comfortable, best price and high performance transportation and traveling system and finally by the interest of the European Union to be able to rely on a high efficient travel and transportation network when competing with the other big global players in the world.
The European Union is in the unique position to already possess a tight network of railways. The power that lies in this system is just not yet unleashed to its full extend. CATIEMON touches exactly this issue and enables the railway system to work as a whole. The outcome of this process will be more than the sum of the combined networks and is likely to form a real innovation in traveling and transportation.
The big picture of a profitably growing European Union in return will provide the partners of the CATIEMON project with the necessary frame for new orders, new business and increasing revenues.
With the big picture in mind it becomes clear that CATIEMON has the potential to not only become a good system but a great system with great benefits for all its stakeholders: The involved partners, the railways, the travel and transportation customers and the European Union.

During the meetings held so far for CATIEMON it was pointed out again especially through the dialogues with the operators that the foremost aim of the project is to enhance the **availability** of rail-operation. When the operation of the individual rolling stock or track-system goes without interruptions the interoperability within Europe will be reached faster. This also gives a competitive advantage to the rail-transportation in comparison to road, air or water borne transportation systems increasing the market share of the rail.

As the rail-traffic does not depend on a primary energy source such as oil but on a secondary energy source in the form of electric current, it can be easily switched to environmentally friendly sources such as nuclear energy or wind power. Therefore CATIEMON is placed on the **cutting edge** of the development towards a climate- and pollution-friendly transportation policy within Europe.

Wherever beneficial in CATIEMON there will be applied **fiber-optics** in order to further develop the Bragg sensing technology in the rail-area. This brings a big opportunity to create innovations on this field and thus derive a competitive advantage with the devices that will result from the project.

After all the costs for the operators shouldn't increase in sum. There will be some investment on the CATIEMON devices to be installed on the pantographs and on the overhead contact lines, but the costs that can be saved through the increased availability will by far exceed the first investment into the new technology of CATIEMON and bring significant **revenues and profits**.

On EU-level there could be an **initiative** to start thinking about condition dependent user fees deriving from the area-wide installation of CATIEMON.

The pantograph and the overhead contact line can be monitored in respect to their whole life cycle. This **Life Cycle Monitoring** (LCM) opens totally new opportunities in the operation of rails especially regarding the increased traffic in a more deregulated market. Not only permanent monitoring of the catenary is possible through hit detection on the current-strip but also indirect permanent monitoring of the carbon-strip. Therefore the zig-zag of the catenary can be used in combination with a periodic analysis of the hit-detection-signals for permanent condition-monitoring of the carbon-strip. Within one zig-zag the major part of the carbon-length will be scanned by the contact wire. If hits periodically repeat this is a signal that the fault is located on the carbon-strip rather than on the catenary.

There might be an outcome of the project to take influence on the Technical Specifications for Interoperability (**TSI**s).

The detection of light arcs is unsuitable from infrastructures point of view as it indicates damage, which has occurred already. The hit detection and contact force measurement is a tool to indicate exceeding of the limits, which will, if not corrected, lead to damage – causing light arcs.

High speed trains might give new aspects to the measurement techniques since the physical behavior at speeds of 350 km/h are different than those for conventional speeds.

The **value** that will be created for the European Union is to strengthen its competitiveness in the globalization-process with the other big economic areas around the globe. Only with a strong exponentially and profitably growing economy the European Union can keep a leading competitive position in the world. The products of CATIEMON, the inspection-gate and the sensor-pantograph, decisively facilitate this exponential and profitable economic growth by enabling a highly efficient European rail-network. As all partners are also stakeholders in the railway sector, its increased importance would also lead to growing orders, revenues and profits for the CATIEMON-team.

The **vision** of the CATIEMON project is to define different steps to be crossed over in order to evolve from the current rail system/organization ("multiple national rail networks") toward the new targeted one ("**high quality rail network**"). The partners keep that vision already during the research and development phase in mind to be able to meet the target of CATIEMON in the implementation phase of the project. Therefore it's important to make out already at this early stage of the project the Key Performance Indicators and to create synthetic figures (mainly linked to regulation and standards), to identify the lack of standards (common harmonized qualification criteria and inspection procedures) and to participate and be directly involved in standard works.

In laboratory tests the behavior of the carbon-strips with the fiber optic sensors directly glued to them was examined. It was found that there will be a possibility to distinguish between vertical (from top) and **horizontal** (frontal) **hits**. As the sensors are located in small grooves that were milled into the carbon they are as close to the interface between contact-wire and carbon-strip as possible. The deformation that horizontal (frontal) hits cause to the current-strip can be clearly detected.

During the project the smart current collector (SCC) fiber optical Bragg-system was proofed in several test runs in 2007 in Austria, Switzerland, Slovenia and the Netherlands on two different locomotives namely the ÖBB-Rh1216 with AC- and DC pantograph and the BLS-Re465 with AC pantograph with a sum of approx. 3000 km test runs. The SCC system has the potential of an adaptable and adjustable system on all types of pantographs. The system showed an inherent information level for soft impact detection as well as a release level for hard impacts. An impact level characterisation is feasible in comparison with the type of the catenary system, speed, pantograph configuration and environmental conditions including informations as time of the event, GPS-position and the vehicle´s condition. A preinformation of the infrastructure´s and pantograph´s condition will be available before the automatic lowering level appears and also with a small number of equipped vehicles, running on the whole network.

In addition to the SCC system an Inspection Gate (IG) at a fixed location was developed. While CC-Monitoring contributes to a vehicle specific type of network scan the IG contributes to a quality monitoring of all trains passing.
In a field test in Spiez the possibility of performing a hit-detection on the inspection gate through fiber optic sensors that are glued directly to the anchor-arms of the contact-wire was examined and later on transferred to final inspection gate location. The advantage of this smart steady arm is that no additional devices will have to be integrated into the catenary system. Later on in the project the inspection gate was build up in Heustrich near Spiez. For the measurement of the displacement of the contact wire a 1-dimensional laser triangulator for measuring the contact line uplift was installed. In addition also a 2-dim and a 3-dim displacement measuring technology was developed, tested and installed. Finally for the derivation of a representative contact force of passing trains a high number of fiber optical strain sensors were placed directly onto the catenary wire using a specially developed gluing protocol.
The IG monitored various types of vehicles from various countries equipped with different pantograph types in about 600 runs in 2007 and 2008. IG-Monitoring ensures that trains pantographs are adjusted with respect to TSI that means contact force is not exceeding the maximum or minimum allowable value by means of uplift. IG-Monitoring detects horizontal displacement originating from poor aligned pantographs, cracks or breakouts in the contact strips. Track blocking due to overhead line destruction because of faulty pantographs followed by repair works, compensatory actions, re-commissioning and renewal of accreditations shall be avoided by the installation and operation of Inspection Gates.

The CATIEMON project gathered a **high momentum** that enables it to spread its outcomes with high speed across the European Railway system. The quality of the CATIEMON system, i.e. the inspection gate and the sensorized current-collector-strips, is very high. This is true in terms of technical achievements as well as with processes and people-building.
The main target of the project is to gather experience with the application of CATIEMON in a real life environment including the integrated approach that is necessary for this. The application and testing of CATIEMON technologies under real life conditions will deliver the full information that enables a functioning of the european railway system as a whole. The experience with the system will lead to new insights and ideas that can be inspired only by actually acting in that field.

CATIEMON can be adapted highly flexible to the needs of the different users in regard to the resolution-level of the measurements. This applies to both systems, the inspection-gate and the fiber-optics equipped carbon-strip of the pantograph. Through this nearly **open scalability** in its measurement-capacity the varying demands of the Infrastructure-Managers and of the Rolling-Stock-Operators can be met individually.

CATIEMON deals with both systems that are relevant for the interface between carbon-strip and contact-line, i.e. the loco with its pantograph (SCC CATIEMON Smart-Current-Collector) and the catenary with an inspection gate (SOCL CATIEMON Smart-Overhead-Contact-Line). Through this integrated approach **both systems “learn” from each other** and are optimized to the needs of the operators on both sides: the infrastructure-manager and the rolling-stock-operator.

During test runs in Slovenia and Croatia with fiber-bragg-grating equipped carbon strips faulty spots could be made out on the overhead contact line that were not known to the operators before. During the operation of the inspection gate the standard traffic could be monitored identifying clearly newly introduced single carbon pantographs by their structure in the strain measurement data plots. This shows that the CATIEMON system is ahead of the current state-of-the-art.

Several innovative electromagnetic immune optical FBG sensors and two interrogators suited to railway applications have been developed and intensively tested during the CATIEMON European research project. In addition to in-lab design and tests, these sensing equipments have been installed for several field tests on commercial lines dispatched over an eighteen months long period. FBG sensors, able to sustain High Voltage at railway infrastructures as well as outdoor conditions, and efficient installation procedures have been developed and validated. Data acquired during the course of the project have shown that FBG-based sensing is a promising approach in order to characterize the pantograph/catenary interactions. This technology provides new diagnosis tools to the end-users in order to improve railway infrastructures' management procedures, to increase safety and thus availability. It may now benefit to all railway stakeholders in order to face the increasing demand for railway transportation, in particular in Europe.

The project website can be found under www.catiemon.info.

1.2 Smart Current Collector - Impact Monitoring

1.2.1 Concept of impact sensing using fibre-optic Bragg gratings (FBG)

Wavelength changes in a FBG sensor reflection signal can be caused from strain and/or temperature changes. Frictionally coupled FBG sensors change their Bragg wavelength with strain. Characteristic dependencies between force, strain, and Bragg wavelength will be calibrated.

Sensing principle:

Embedment of fibre Bragg grating sensors in current collector
Cabling between current collector and sensor system in loco
Sensor system with spectrometric measurement of Bragg wavelengths, their correlation to calibrated strain.

A variety of methods for the discrimination of both measurands strain and temperature was investigated. But all of them have the disadvantage, that the accuracy of the measurement was decreased. That‘s why for strain sensing usually a temperature reference (electrical or fibre optical) measurement is used. For the hit detection in our task, the low frequency components from temperature changes do not play such an important role, because the measurements can be taken in shorter times than the temperature can change.

1.2.2 Design and construction of load test facilities

Disturbances in the interface between CC and OCL usually occur as short time hits on the CC of the moving train. These hits occur in a dynamic response of the strain sensors, which have to be studied and characterised. For such studies, a test facility was needed, which can produce short time hits with the possibility of varying a lot of parameters like hit energy, velocity, position, etc.

One of such test facilities is available at the laboratories of Morgan inc. in Swansea. It uses as driving force the potential energy of a weight (mass can be varied) falling from different heights. With the potential energy of E_{pot} = m*g*h, which is completely transformed in kinetic energy E_{kin} = m / 2 * v^2 we get even with a 2 m long pendulum no higher velocities than 23 km/h. As long as we don't know the influence of the velocity, this is not fast enough for our investigations of impact strain responses on a CC of a driving train.

That's why we started to develop and manufacture a new test facility for very fast hits on the CC (see scheme in Figure 1.2.1). The hits were carried out by a free flying mass (projectile), which was accelerated by pressured air.

Energy *E* und velocity *v* of the projectile can be adjusted independently by choosing the parameters projectile mass *m*, air pressure *p* and acceleration length. For extending the energy ranges at given velocity, also different tube (and projectile) diameters *A* have been applied.

The kinetic energy of the projectile will be calculated with

$$E = \frac{m}{2} v^2 \qquad (1)$$

The energy of pressured air in a tube is given by

$$E = p \cdot A \cdot l \qquad (2)$$

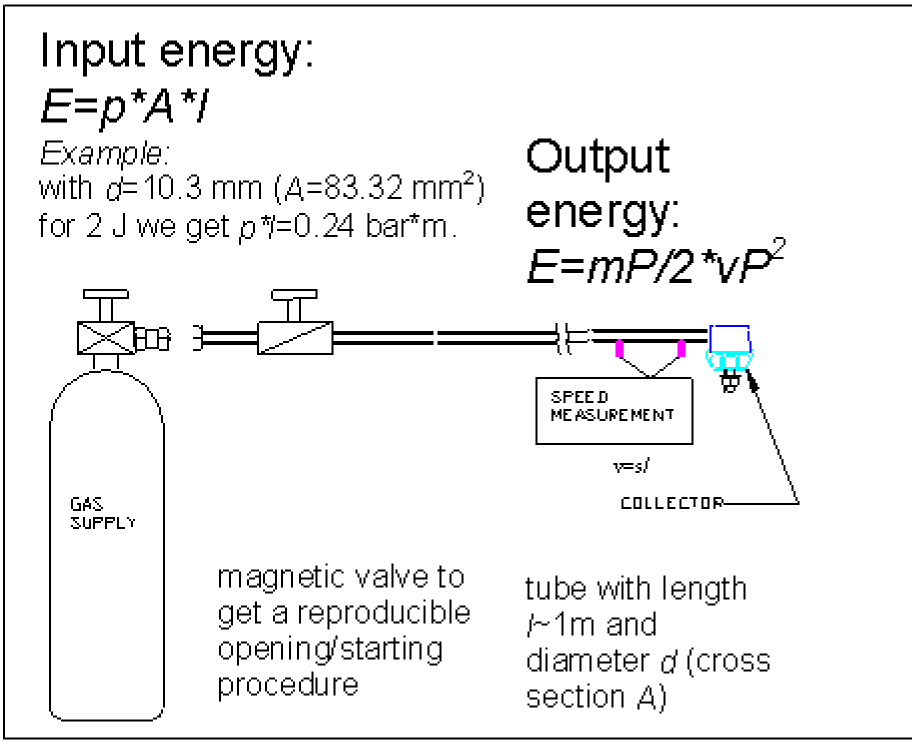
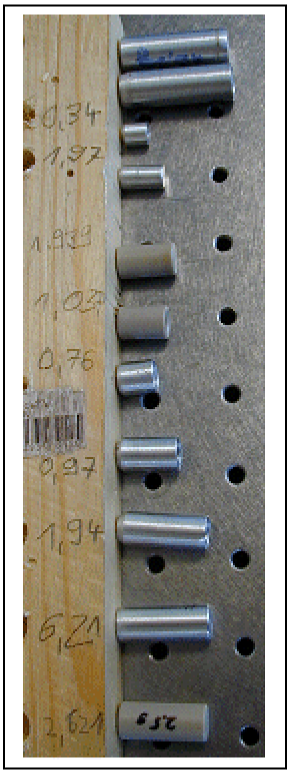


Figure 1.2.1: Scheme of the load test facility for high speeds, which was developed and manufactured.



We used projectiles with masses of 2 g up to 100 g, tube lengths from 0.25 m up to 1.2 m, air pressure from 0.2 bar up to 2.5 bar and tube diameters of 10 mm and 20 mm. So we got energies 1.5 to 80 J and velocities from 40 to 300 km/h. But of course a lot of parameter combinations show bad flying conditions for the projectiles, too low stability for the low mass projectiles or too high energies for ‘harmless’ hits on the carbon. So some special combinations are favored, for instance the 25 g mass over 0.5 m with 0.6 bar got a velocity of 50 km/h with an energy of about 2.3 J.

The CC is fixed on its pan-head to get a similar dynamic behaviour like on the loco. The velocity of the projectile is measured with a pair of light barriers ((the same, which will be used for the inspection gate. Description see Chapter 1.3) For safety reasons the whole area, where the mass can fly free is covered in a box (safety box).

Figure 1.2. 2:
Some projectiles which was investigated. We varied material, hitting area, mass and length. For other tube diameters additional projectiles was necessary.

Lab tests have been performed firstly at low energies (about 1..2 J) to find dependencies on parameters like hit position, hitting material, shape of the hitting area etc. The low energy levels avoid strong changes or destructions in the material, which would hinder to compare the results.

The full parameter range of the impact test facility covers impact energies of 0.1 .. 50 J, and velocities of 30 .. 400 km/h.

In a first step, we could apply very short hits (energy transfer during time periods of ~ 20 µs), which are typical hits from loose droppers or from sharp steps in the line adjustment. In order to simulate slower impacts, like such ones from inclining kinks in the contact line, also spring-loaded projectiles have been developed, which allow for slowing the projectile energy transfer time to periods of 1..4 ms.

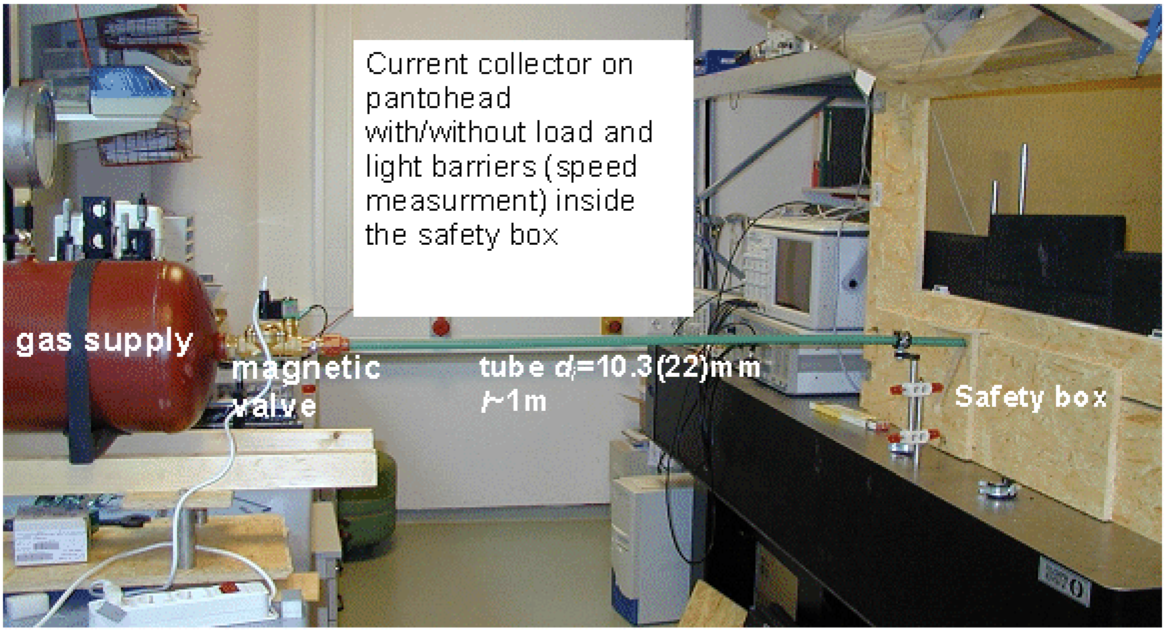


Figure 1.2.3 Impact load test facility at IPHT Jena

This test facility was demonstrated during a meeting to the other partners in June 2006 and used for a big amount of load test during the whole time. Some test results are published in /1/. So here only one example, which demonstrate the reproducibility of experiment and detection of the answer of the SCC (Figure 1.2.4).

Beside the test facility in Jena a similar facility was produced in the laboratories of Morganite in Swansea. This was done in cooperation between Morganite and IPHT. A photograph of this second test facility is given in Figure 1.2.5.

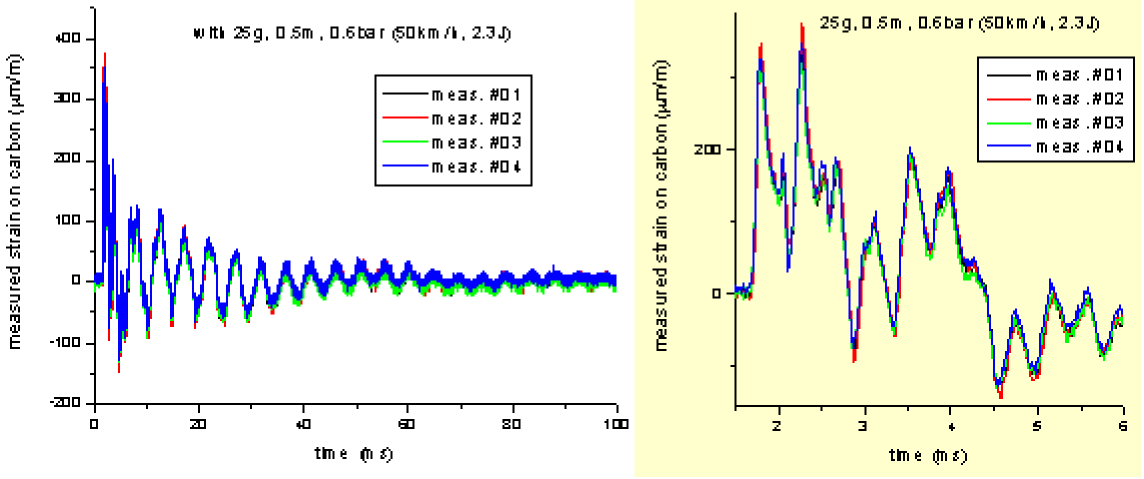


Figure 1.2.4: Four times the same hit on the SCC was carried out. The measurement result (right side graph is a zoom in the beginning of the graph on the left side) show the very good reproducibility of experiment and measurement.

Figure 1.2.5: Photographs from high velocity test facility in Swansea. Left side: Set up with open safety box and without a CC or pan-head. Right side CC in the safety box, destroyed from a hit.

1.2.3 Transducer design and its realisation

The main task for the sensors in the CC is the detection of disturbances in the interface between CC and OCL. Especially disturbances, which can be dangerous for this interface. In this project we solved the task in that way, that we measure the forces on the CC and document the positions along the track, where unnatural high forces appear. So a system can be developed, which weight the danger in different levels:

- everything normal

- slightly higher forces than natural (no action necessary, but have a look on this place)
- high force on the CC (inspection of CC and OCL as soon as possible)
- very high force on the CC (repair OCL immediately)

For the detection of the force on the CC we use the bending of the CC because of the force and measure the strain in a position of the CC where possibly high strains occur because of bending. This is as far from the neutral line or as much on the outer site of the CC as possible. Figure 1.2.6 demonstrate the bending (exaggerated) and the sensor positions for a force in vertical direction. For forces in the horizontal direction this works similar.

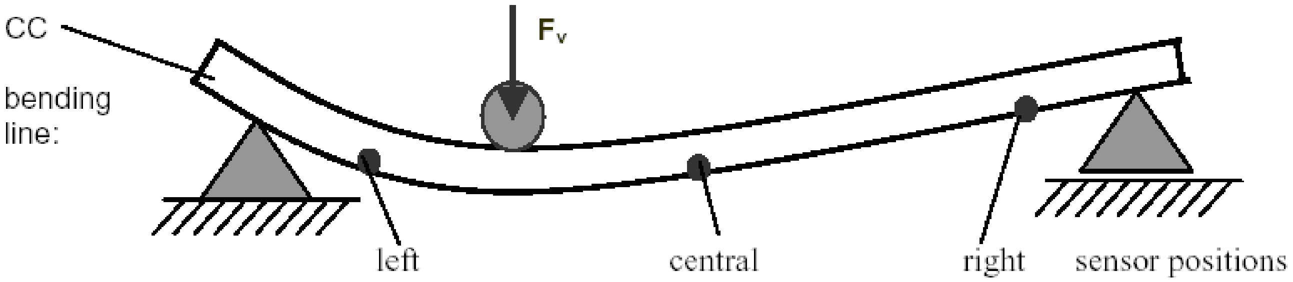


Figure 1.2.6: Principle of the transducer: the force to be measured cause a bending of the CC, which can be detected by strain measurement.

To discriminate between forces in horizontal and vertical direction, it is necessary to position the strain sensors in the neutral plane for the bending in the unwanted direction. Figure 1.2.7 demonstrate this sensor positioning: The vertical plane is the neutral plane for forces in horizontal direction. Sensors ε_{ml}, ε_{mc} and ε_{mr} are situated in this plane and measure the bending in vertical direction. The horizontal plane is the neutral plane for bending because of forces in vertical direction. Sensors ε_{nl}, ε_{nc}, ε_{nr} positioned in this plane measure the bending in horizontal direction.
To realise this, the ε_n-sensors are positioned in the interface between Al and Carbon. Here they are attached on the carbon, to avoid strain distribution losses because of the attachment material in this interface. For a good attachment technology between Carbon and Al the fibre optic sensors and cables has to be attached in a groove. This groove should be as narrow and as flat as possible, that the strength of the carbon itself and the strength of the carbon – Al attachment will not be influenced negatively. So the groove design was developed, designed, tested, redesigned and retested and now found to be good. An example of the grooved carbon piece is given in Figure 1.2.8.

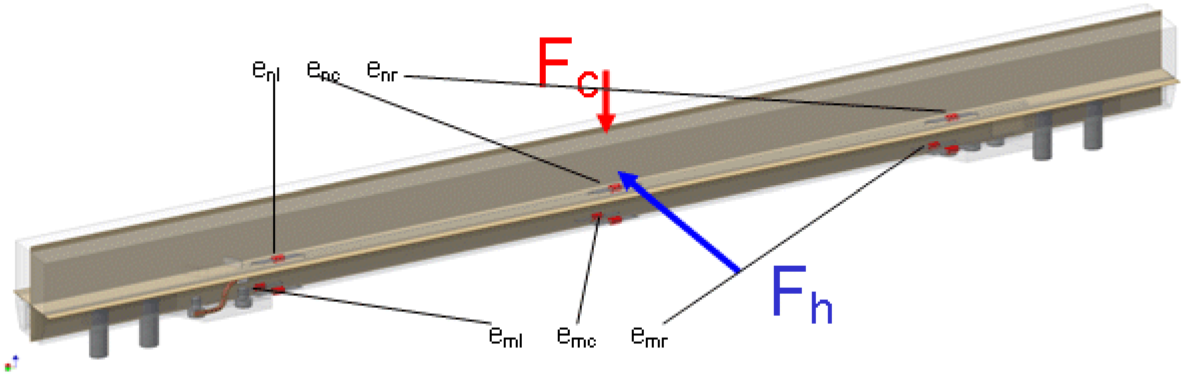


Figure 1.2.7: Scheme of a SCC with force directions (main forces), neutral planes for this forces and sensor positions.

Because of the carbon wearing during the use of the CC, the neutral plane for vertical forces is not constant over the life time of the SCC and there are times with more or less cross sensitivity to the vertical force.

The sensing of vertical forces is realised in that way, that the sensors are attached in the inside of the Al-profile in the middle line. Here the sensors are well protected from rough environment and show a good sensitivity.

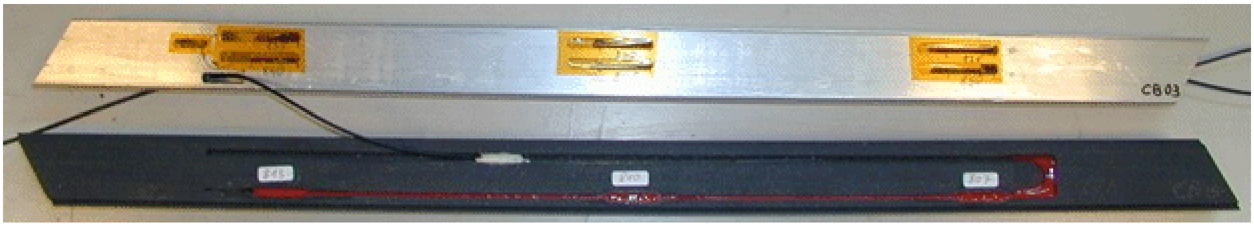


Figure 1.2.8: Carbon bar and Al profile with attached sensors before assembly. Grooves in carbon with old design. Grooves are refilled with silicon to save the sensors in the assembly process.

The detection of interface disturbances over the measurement of bending of the CC has beside a variety of advantages the disadvantage, that the transformation factor or transformation characteristic is dependent on the CC design and its fixation (pan-head). In this project we investigated three different designs of CC and in two in principle different constructions of pan-heads. The following table gives a rough overview, which strains can be expected by a special stationary force of ~ 43 N for the different CCs in their pan-heads.

Measured strain at sensor positions	**43 N in horizontal direction**	**43 N in vertical direction**
ÖBB AC	~ 20 µm/m	~ 45 µm/m
ÖBB DC	~ 10 µm/m	~ 22 µm/m
BLS	~ 19 µm/m	~ 24 µm/m

Table 1.2.1: Transducer sensitivity for different CC – types. Measured strains for a force of about 43 N in horizontal and in vertical direction, respectively.

This results can be understood well from the different dimensions of the CC: the DC-CC is broader and a bit thicker than the ÖBB AC – CC. The BLS CC is much shorter than the ÖBB AC – CC.

The disturbances in the CC – OCL interface, which we detect with this system are usually short hits. So we have to measure the forces with a high time resolution, this means with a quite fast measurement system. Such a measurement needs a special evaluation unit (will be described in the deliverable reports for WP06) and fibre optic strain sensors with high reflectivity, because of the short measurement time. The need of high intensity of the reflected light makes it necessary to design the fibre and cable combination between sensor and interrogation unit very carefully to get the optimal signal to noise ratio for the measurement.

For lab tests and test drives a variety of sensorized CC was manufactured with adapted sensor configurations. In this report we can give only short overview about this SCC (see table 2). In the sum this will 26 SCC with 129 FBG sensors.

1.2.4 Measuring limits and conditions

Environment (signal processing unit):

operating temperature T = -50 .. +70 °C,
storage temperature -50 .. +70 °C;
relative humidity 0 .. 60%

Bragg wavelength has to be corrected in dependence on operating temperature.
Measured sensor wavelengths have been corrected from SPU temperature influences by:

$\lambda_{Bc} = \lambda_B - TC1 \cdot (T - Tc) - TC2 \cdot (T - Tc)^2 - TC3 \cdot (\lambda - \lambda c) \cdot (T - Tc)$

Correction parameters have been determined empirically as follows:

TC1 = temperature correction (TC) linear shift = - 5.5 pm/K,
TC2 = TC quadratic shift = 30 fm/K²;
TC3 = TC spectral dispersion = 10 fm/nm/K
Tc = SPU temperature during calibration (approx. 30 °C)
T = actual temperature
λc = Central Wavelength = 840 nm

For validation of operation, active temperature cycling SPU was performed, in ambient temperature range from -40 °C to +50°C:
2 SPU modules that passed successfully all acceptance testing procedures were randomly selected and subjected to cycling within -40 °C to +50 °C in 10 K steps of temperature change.

Example for SPU 75
SLD current : 145 mA

Ambient T (degC)	Pigtail output, mW	Bragg wavelength, nm
-40	0.49	856.110
+25	0.52	856.114
+50	0.56	856.116

Bragg wavelength data revealed maximum deviations after temperature correction as given above, of 5 pm, corresponding to a strain offset of 8 με. Height of Bragg wavelength changes at every temperature remained smaller than 0.5 pm at 100 pm step height.

Corresponding maximum error of impact forces is 2 N at impact force of 400 N.

Environment (sensors in CC):

operating temperature T = -270 .. +180 °C,
storage temperature -270 .. +200 °C;
relative humidity 0 .. 100%
maximum strain ± 0.5% (load weight)

Cabling/Routing:

Distance between SPU and FBG

1 .. 500 m fibre cable 3 mm outer diameter
distances between FBG: 1 cm .. 100 m;
minimum fibre bending radius > 15 mm

Fibre optic connectors

type E2000/HRL: # E2108.6/K (Diamond SA, Switzerland)
Optical power in sensor fibre max. 0.6 mW

Allowable power supply range

9 .. 18 V d.c. / max. current 1.3 .. 0.8 A

Data transfer Ethernet sensor data output:

1000.00 measurements/s of up to 25 sensors to PC
Ethernet data output: 10 Mbps, UDP protocol
max. number of lost data: 1 in 250,000; registered by quartz stable enumeration of data lines

Strain sensor readout repeatability:

rms 1σ noise of sensor peak position at full scale intensity $\delta\lambda_B = 0.6$ pm, corresponding to strain repeatability within $\delta\varepsilon = 1$ με

Resulting deviations of responses to equal impact forces < 2 N:

Hit energy influences on the strain peak amplitudes during the first ms after the impact, but not on the temporal shape of the strain response.
Shapes and distances are dependent on the hit position.
Shapes are dependent on the time period of hit excitation.
A carbon and fibre break after a too strong hit is clearly visible by the fact, that either no additional peaks occur after the initial strain peak, or that the distances between the first and the consequent peaks deviate from calibration data.

High voltage tests of cabling:

test object: PFA fibre optical cable black (Fiberware GmbH Mittweida, Germany)
test length: 200 mm

dry cable: 55kV test voltage ok.
wet cable: 50kV test voltage ok.

Required sensor measuring rates:

Soft hit (200 Hz bending mode, Fig. 1.2.9 and Fig. 1.2.10, first event), can be detected also at medium-speed interrogation 1000 meas./s.
Hard hits (impact strain shock wave, Fig. 1.2.9 and Fig. 1.2.10, second event), are only to be resolved at fast interrogation of >= 6000 meas./s.

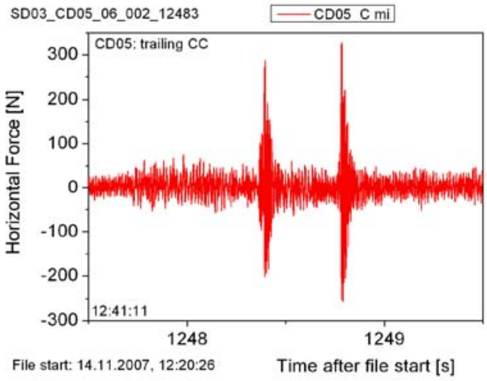


Fig. 1.2.9 Responses to soft (1st event) and hard (2nd event) hits at 20000 meas./s

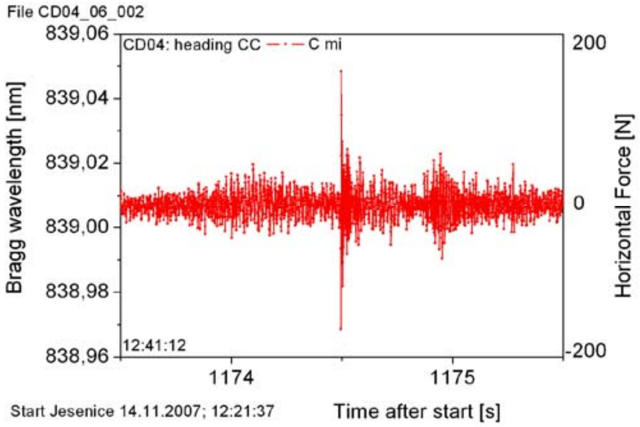


Fig. 1.2.10 Responses to soft (1st event) and hard (2nd event) hits at 1000 meas./s

Sensorised "Smart Current Collectors" with integrated fibre-optic strain have been mounted on the test locomotives. Fig. 1.2.11 shows loco RH1216 with dc current collectors as a practical example. The strain signals of the sensors have been calibrated to force using stationary test forces in the range 0..200 N.

The fibre-optic cables are connectorised at root of panto to fibre-optic connecting cables that are fed through the roof of loco to the interrogators (Fig. 1.2.12: interrogation units of different measuring speeds 1000 and 20000 meas./s, resp.) at the driver's platform.

Reason for the different force characteristics are the different types of "defects" - movable current separators with comparing smooth slopes generating soft impacts of usually low forces < 200 N; de-adjusted clamps with sharp edges giving rise to hard impacts, sometimes of destructive values F > 500 N.

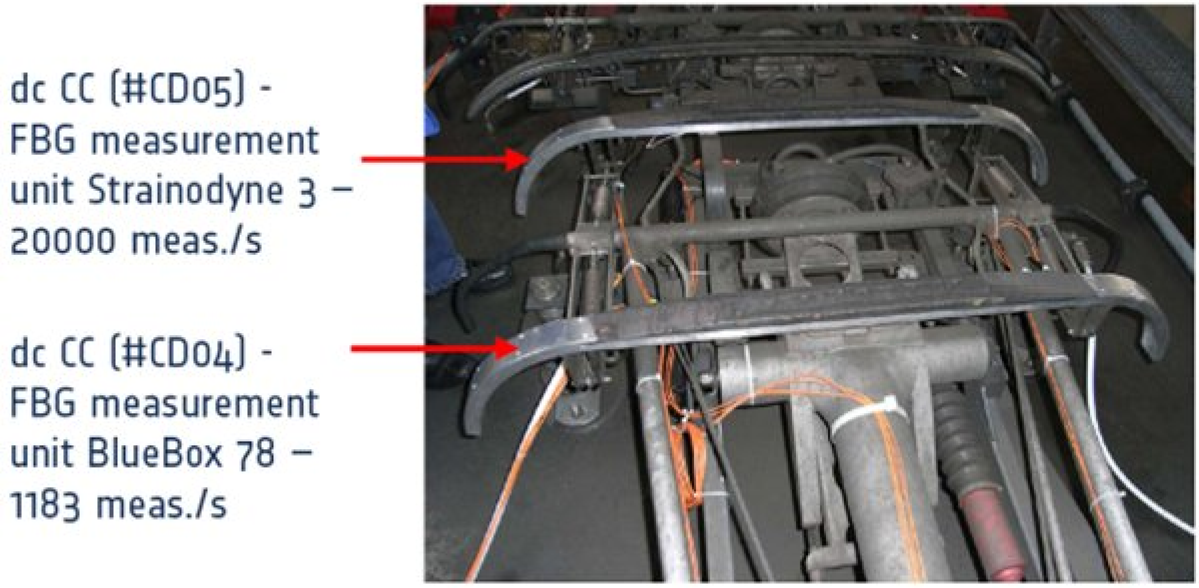


Figure 1.2.11: Smart Current Collectors installed in ÖBB RH1216-143 dc pantograph

During test runs, 2 different types of defects can be measured (example results in Fig. 1.2.13):

a) soft impacts of rise time >= 1 ms;
b) hard impacts of rise time <= 0.3 ms.

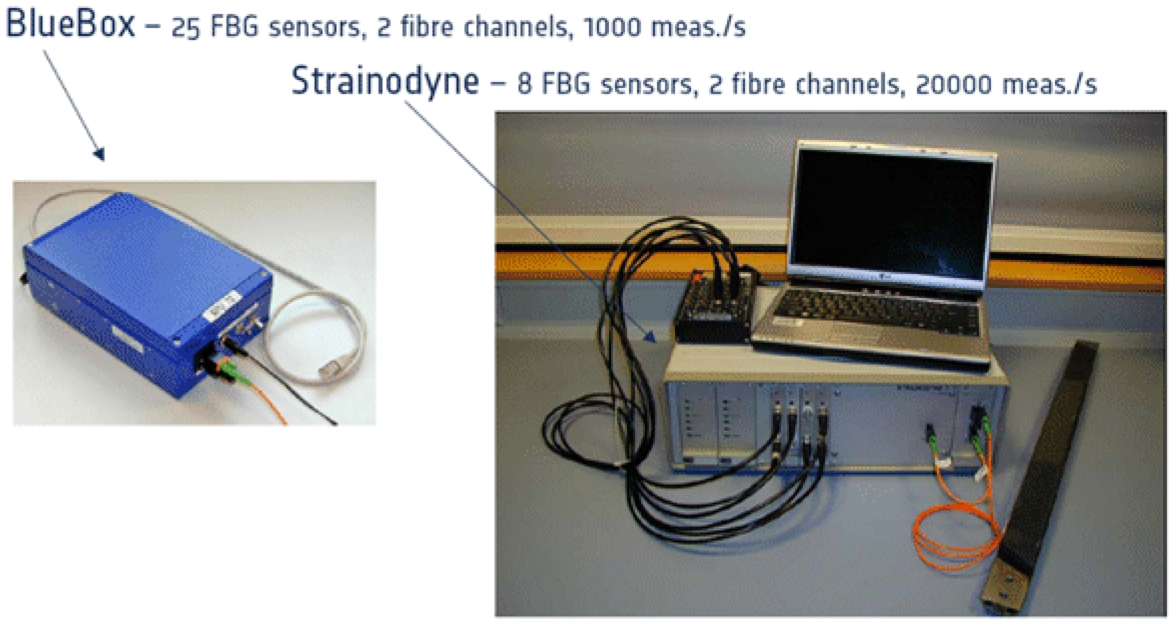
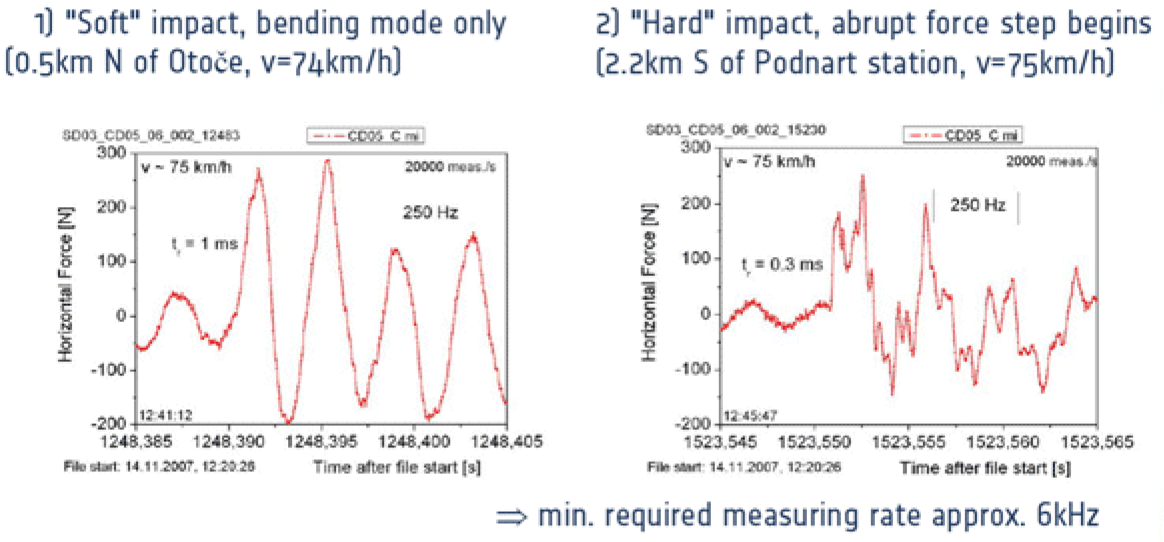


Figure 1.2.12: Sensor interrogation units of different measuring speeds



1) "Soft" impact, bending mode only (0.5km N of Otoče, v=74km/h)

2) "Hard" impact, abrupt force step begins (2.2km S of Podnart station, v=75km/h)

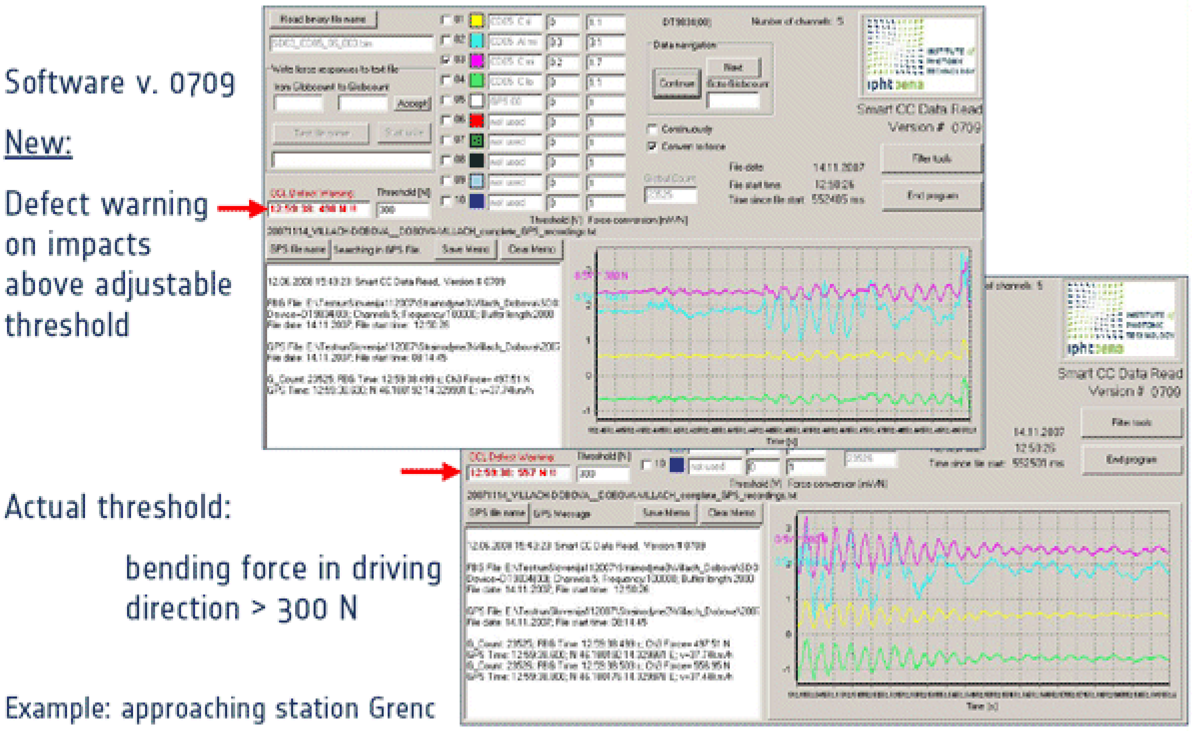
⇒ min. required measuring rate approx. 6kHz

Figure 1.2.13: Differentiation between 2 different defect types, causing "Soft" and "Hard" impacts

The interrogation software allows for online detection of such events (PC user interface in Fig. 1.2.14), which are higher than pre-set safety values. There are two adjustable thresholds implied:

a) event warning (with no immediate action required, events will be filed for identifying possible intensification over longer time); from test run experiences, this level could be adjusted to about 250 N in driving direction;

b) defect warning (in red, defect should be repaired); from destructive lab tests, this level should be adjusted to about 500 N in driving direction.



Software v. 0709

New:

Defect warning on impacts above adjustable threshold

Actual threshold:

bending force in driving direction > 300 N

Example: approaching station Grenc

Figure 1.2.14: PC user interface of impact detection software - recognition of impacts above safety threshold

Data fusion:
Smart Current Collector impact data are correlated with GPS positions (for identifying site of impact) and train velocity; the data are on-line available for train operator, and they are filed for later track status analysis.

1.2.5 Compilation of smart CC test run campaigns:

Sum of approx. 3000 km test runs without sensor system failure.

Evaluation of Smart CC Test Run Campaigns in Austria, Switzerland, Slovenia and the Netherlands during 2007 approx. 3000 km test runs

26.-30.03. Spiez <-> Kandersteg (Re465-001)

07.-16.05. Westbahn –42 x Pöchlahrn <-> Ybbs (RH1216-233) Nordbahn –38 x Angern <-> Drösing (RH1216-233, 1116-242) (repeated tests at different speed)

13.-14.08. Buchs-Spiez (RH1216-233)

15.-17.08. Inspection Gate Heustrich 60x (RH1216-233, Re465-001) (repeated tests at different speed, but without characteristic defects)

19.-20.08. Spiez-Buchs (RH1216-233)

12.-15.11. Jesenice <-> Dobova (RH1216-143, OeBB dc CC)

03.-06.12. Utrecht-Eindhoven-Venlo-Zutphen (special CC)

03.-06.12. 2007 Utrecht-Eindhoven-Venlo-Zutphen

In the following all collected data was thoroughly analysed. The analyses results brought about a huge amount of experience and knowledge which could be well used for further traditional comparative catenary inspections afterwards in order to repair the OCL – where necessary – for the reason of avoiding heavy damage in the future, for example, at Slovenian Railways. These analyses and comparative inspection results were treated in detail at a results presentation meeting in Ljubljana held on July 15th, 2008.

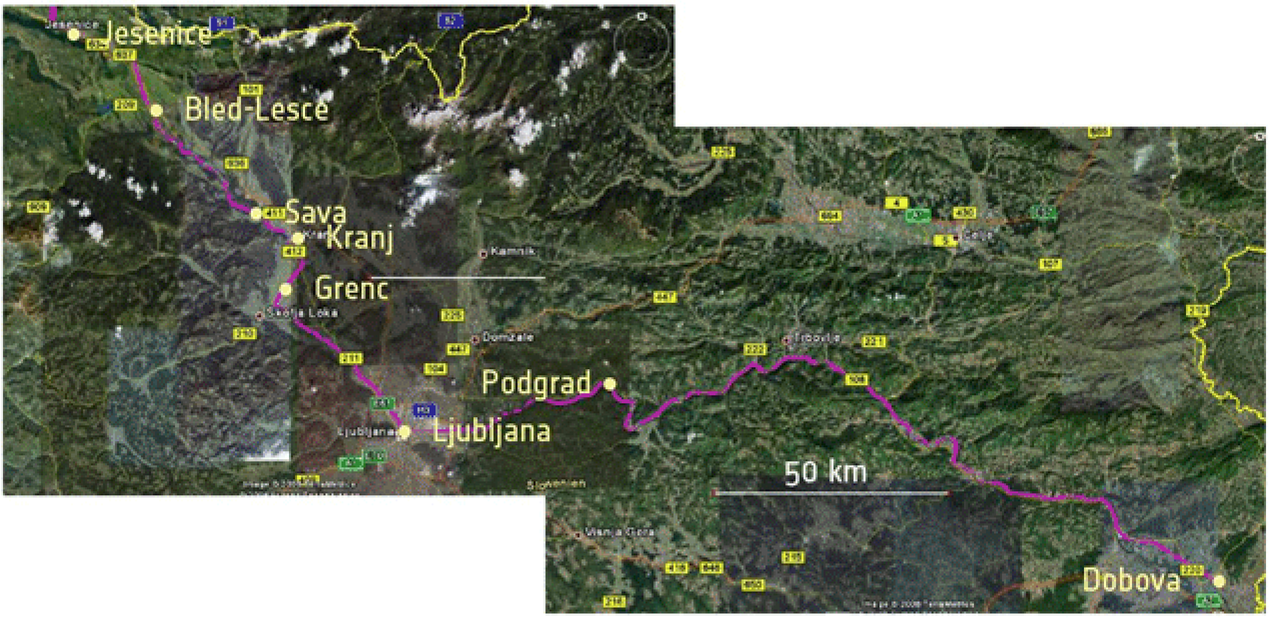
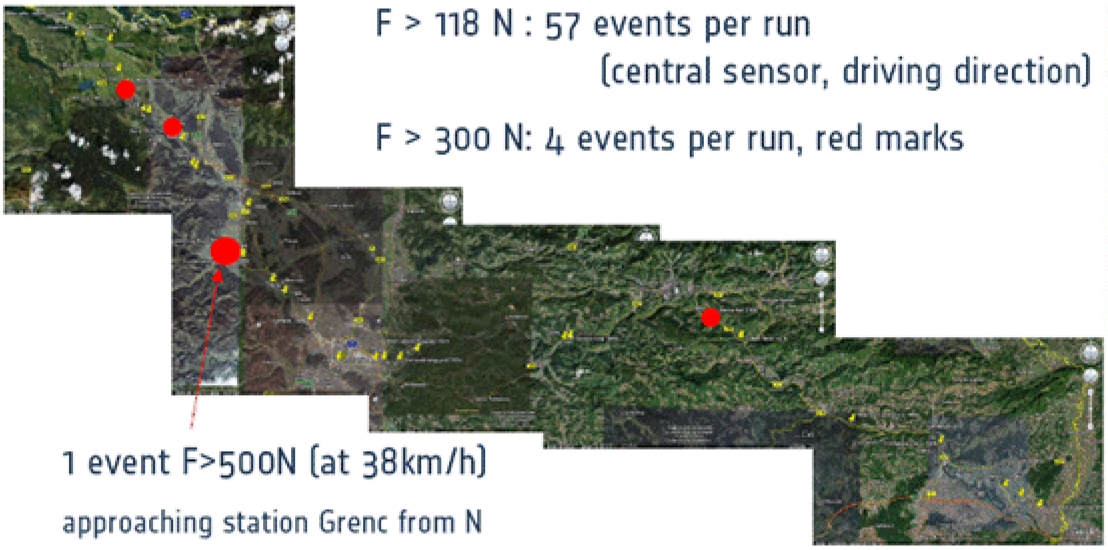


Figure 1.2.15: Slovenia Test Run Jesenice–Dobova, Track Overview

Average hit occurrence:

Horizontal force peak > 150 N: average 20 events/1.5 h
Horizontal force peak > 300 N 1 event/1.5 h

problematic hit (from lab simulations): peak force > 400 N (none detected)
undisturbed driving conditions ≈ 20 N; detection limit ≈ 5 N

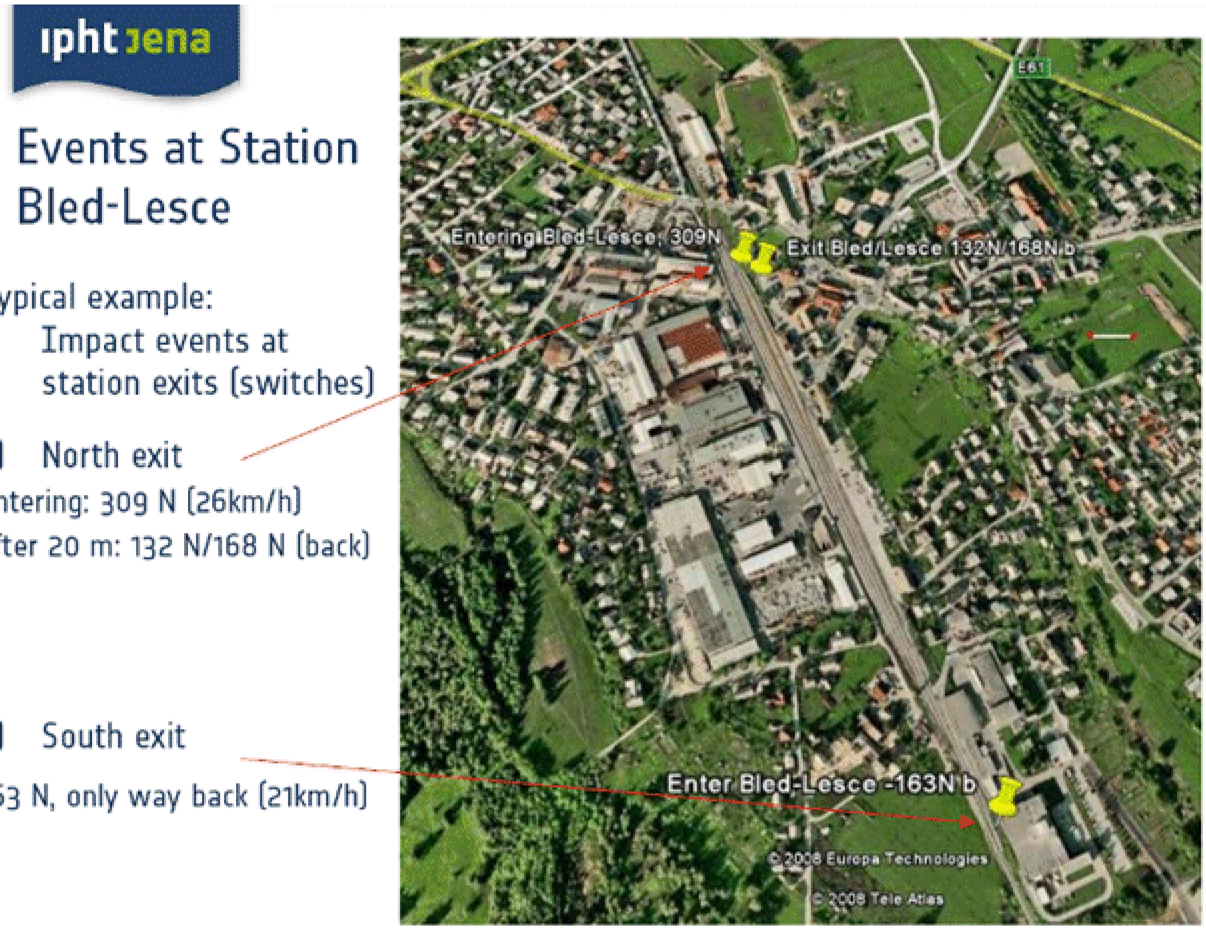


F > 118 N : 57 events per run
(central sensor, driving direction)

F > 300 N: 4 events per run, red marks

1 event F>500N (at 38km/h)
approaching station Grenc from N

Figure 1.2.16: Event summary on track Jesenice - Dobova.



iphtjena

Events at Station Bled-Lesce

Typical example:
Impact events at station exits (switches)

a) North exit
entering: 309 N (26km/h)
after 20 m: 132 N/168 N (back)

a) South exit
163 N, only way back (21km/h)

Figure 1.2.17: Event example Station Bled-Lesce: Soft impacts at station entrances (in and out), usually caused by movable voltage separators.

Figure 1.2.18: Events in Ljubljana: Station (East & West Exits) and Switchyard (East Exit)

1.2.6 **Summary of event detection**

- Smart CC sensor interrogation worked on test runs in period May – November 2007 without failure.

- Required sensor measuring rate - about 6000 strain meas. /s for "hard hits" of OCL defects.
- At peak level of horizontal forces > 400 N: event site needs inspection for possible repair.
- Threshold level for immediate repair (probable destruction of CC): probably > 600 N, to be confirmed from accompanying investigations at partner MOR.
- Primarily measured strain values of FBG sensors have to be calibrated to forces because of different sensitivity of different CC types. Conclusion: standardised sensor carrier to be developed for installation along any CC.

Smart CC sensor interrogation worked on test runs in period May –November 2007 without failure.

Systematic investigations of threshold levels for advisable/necessary OCL repair are now under way at Morganite, in cooperation with IPHT. IPHT sensor software allows evaluation and documentation of defect events, on-line as well as in post-processing, including GPS data of events.

OCL event sites detected during sensor test runs – as already done e. g. in Slovenia (see chapter 3 “test runs”) – can now be:
- visited for correlation of force characteristics to physical OCL defect type;
- repaired in order to avoid heavy damage.

Future activities should consist of:
- Standardization of impact measurements
- Implementation in operational guidelines
- Proof of significance at different pantographs

1.3 Overhead Contact Line - Train speed, intruder, and uplift sensors

1.3.1 Train speed and intruder monitoring

For the speed and direction measurements of the trains, a double light barrier v1in, v2in was installed at cantilevers at a pylon bridge (see Fig. 1.3.1, bottom). The light barrier distance is about 1.47 m. The light barrier will be interrupted when the roof of the loco enters the laser beams.

Input signals from light barrier receivers :
v1in from LB v_1 low active if v1 LB = dark, +24 V if bright
v2in from LB v_2 low active if v2 LB = dark, +24 V if bright Intru_in
from LB Intru low active if Intru LB = dark, +24 V if bright

When the second LB of v1in and v2in is passed, a synchronization signal Sync will be generated by the light barrier control unit in the container.

Sync BNC socket <TTL Low 20..40 µs>, impedance 47 Ohms, will be generated after completion of v1in, v2in difference measurement

In addition, a third light barrier Intru_in was installed at a bigger height for intruder monitoring (see Fig. 1.3.1, top). Operating pantographs will interrupt the third light barrier. Counting and measuring of position of operating pantographs is possible using this third light barrier.
The measurement results of the 3 light barrier sensors are transmitted as +24 V signals to a converter box in the container where these signals are converted into TTL levels for transmission to a PCI-bus timer card ME1400C in the IPHT computer. The default polling rate for speed (Δt (v1in - v2in)) and pantograph position measurement (Δt(Intru_in-Sync)) is 500 samples per second. The corresponding

maximum error of the speed measurement is speed dependent (+-3.8km/h @ 100 km/h and +-0.01 km/h @ 5km/h).

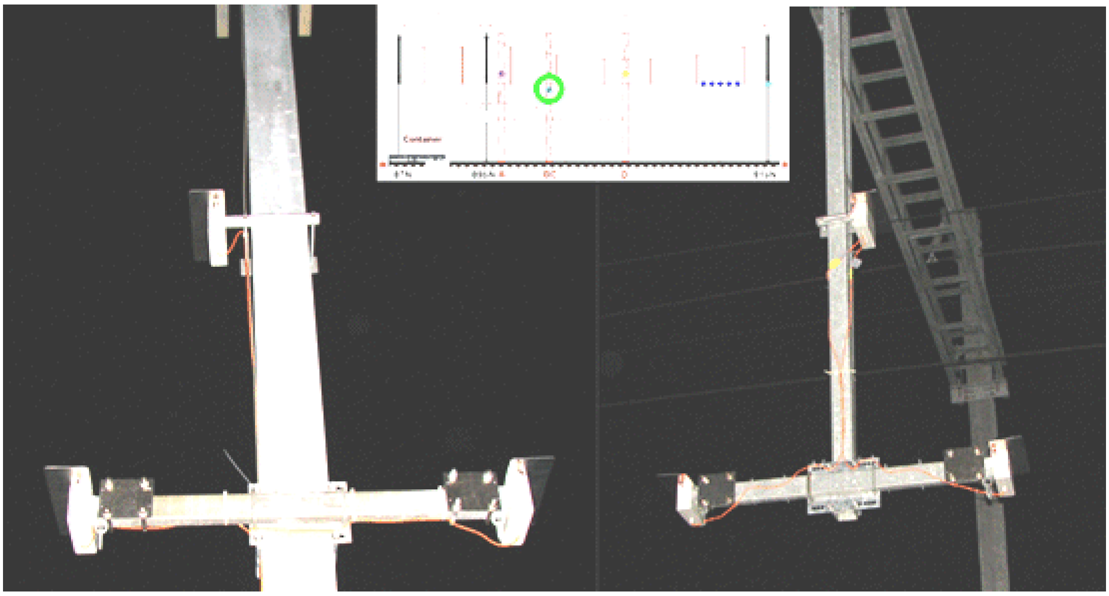


Fig. 1.3.1 Laser barriers for intruder detection, pantograph counting and synchronization

Installed equipment:

- 3 pcs. laser light barriers type WLS-D90 (WELOTEC GmbH, D-48366 Laer)
- Laser sender module OWTL 4999 at 670 nm, cw; laser power < 1 mW, laser safety class 2 (eye-safe up to 0.25 s duration)
- Laser light barrier receiver modules OWRL 4999 including corresponding optical filters for 670 nm
- Each module in housing Aluform #00.04.14.22.070 (Rose GmbH) including cylindrical tube apertures for shielding scattered ambient light
- Connecting cables ZWK-m8/3-w-5 (6 pcs., WELOTEC GmbH)
- Field cable: length100 m, capacity 8 twisted wire pairs, SubD25 socket connector at cable end
- Electronic converter box (24V to TTL)
- PCI bus ME1400C timer card (Meilhaus Electronic GmbH, D-82178 Puchheim)
- Connecting cable ME AK-D78 (Meilhaus)
- Computer with industry PC main-board (high-load PCI and ISA busses, Redlich edv Jena)

Available Functionality:

- Speed measurement
- 500 samples per second (i.e., max. time jitter 2 ms)
- Accuracy about +-3.8km/h @ 100 km/h and +-0.01 km/h @ 5km/h
- TTL synchronization output for SIE laptop
- Counting and position measurement of operating pantographs

1.3.2 **Laser uplift sensor**

The uplift sensor is based on a laser-optic triangulator type ILD1800-750 (optoNCDT Serie 1800, micro-epsilon Messtechnik GmbH).
This uplift sensor is embedded in a steel housing incl. external shielding aperture against scattered sunlight, and is placed on gate portal A, next to Pylon 89bN (see Figure 1.3.2).
The laser beam illuminates a PTFE scattering reflector on OCL (see Figure 1..3.2, bottom, 3).

The reflector covers OCL displacements in driving direction (caused by thermal expansion of the OCL) and in perpendicular (thermal and dynamic effects).

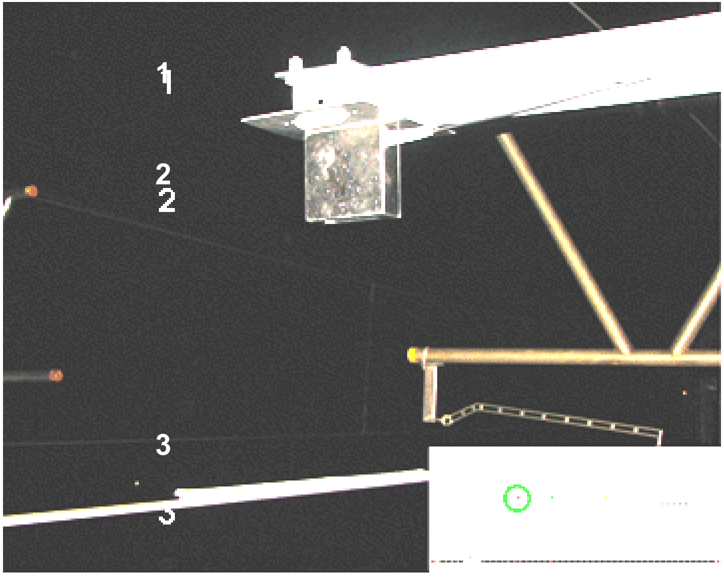


Fig.1.3.3 Laser uplift sensor for one-dimensional uplift measurement

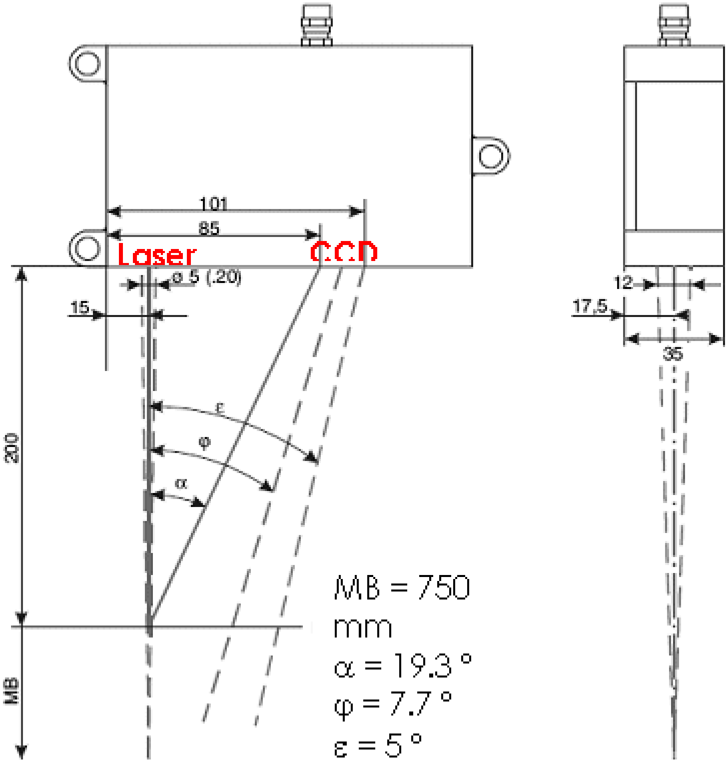


Fig. 1.3.3 Laser triangulator - principle of operation

The position of the backscattered laser light is detected by a CCD photo detector line. The peak position on the CCD line depends on the distance between back scattering object (200 .. 950 mm). The peak position is calculated from the intensity distribution over the CCD pixels. It is recalculated into the object distance, this distance value is transmitted to the PC, via serial interface RS422, at a measuring rate of 2500/s.

Installed equipment:

- Laser optic triangulator type ILD1800-750 (optoNCDT Serie 1800, micro-epsilon Messtechnik, D-94496 Ortenburg), EC confirmation according to EU 89/336/EWG

- Housing Serie 712 - Steel AISI 304, IP66 (rs electronic GmbH); with glass window directed to OCL
- 24 V power supply to triangulator
- Laser module at 670 nm, pulse modulated 2.5kHz; laser power < 1 mW, laser safety class 2 (eye-safe up to 0.25 s duration)
- CCD receiver module incl. corresponding optical filters for 671 nm
- Additional external optical filter Y43-191 671 nm, 50x50 mm²
- External shielding aperture around glass window of housing
- PTFE strip on overhead contact line
- RS422 connection from sensor to IPHT computer in the container
- Connecting cable PC1700-10 (micro-epsilon)
- Field cable of chapter 2.5 Light barriers
- IPHT electronic converter box (RS422 to RS232)
- RS232 data crosslink cable with SubD9 socket connectors
- Computer with industry PC main-board of chapter 2.5 Light barriers

Available Functionality:

- Uplift value (distance between sensor and Teflon strip on contact line)
- 1kHz standard measurement rate (max. 2.5kHz)
- Repeatability 30 µm peak-to-peak
- Reproducibility after on-site calibration 75 µm within 0 .. +50 °C
- Absolute accuracy over full measuring range of 750 mm depends on profile of scattering plate, it is estimated to about 1 mm
- Accuracy errors of relative distance changes within 50 mm has been determined to < 0.1 mm
- Max. distance measuring range is 200..950 mm (Δ = 750 mm)
- Zero position in the inspection gate in Heustrich at 670 mm
- Uplift measurement range from -470 mm to +280 mm

1.3.3 Running Tests of train speed, intruder, and uplift sensors

The train speed, intruder, and uplift sensors instrumentation was installed with respect to the following measuring tasks:

the time of train arrival
direction and speed of train
the number and position of operational pantographs

time response of uplift during train passage
the maximum dynamic uplift

Due to the research objective, a laser uplift sensor and a light barrier system have been installed and tested at the Catiemon inspection gate.
The sensors are covering 1-dimensional movement of the contact line using also different sensing technologies (see Fig. 1.3.1). In the reliability evaluation phase of the project, the accuracy, repeatability, and reliability of measurements have been investigated.

Fig. 1.3.4 Location of the Inspection Gate in Heustrich

A validation process has been performed in following steps:

Operational tests of integrated catenary
Integration of transducers, cabling and signal processing
Sensor re-calibration for use in catenary elements
Running test
Result evaluation
System optimisation

Available Functionality of speed and intruder detection:

Speed measurement
500 samples per second (i.e., max. time jitter 2 ms)
TTL synchronization output for SIE laptop
Counting and position measurement of operating pantographs

Following 3 light barrier components have been installed and tested:
Sender (3 x), Receiver (3 x).

Laser beam directions and positions are made adjustable, positions proven to be stable over Catiemon test period. Laser and receiver housings are made dust, water, and impact proof, IP65.

Characterisation of train detection and speed measurement::

Light barrier rise time 17 µs
Original design was for 40 µs interrogation cycles and interrupt controlled read-out of external counters. Correspondingly, velocity error would have been < 1% at 250 km/h.
Validity tests showed that interrupts went out of work under railway conditions (probably bad electrical ground conditions). New readout used polling of velocity counter states at 2 ms cycles only.

Speed errors of 0.2% at 5 km/h,
3.8% at 100 km/h.
Errors can be reduced to original values (max. 1 % error) by redesign of light barrier distance to 6 m (actual value: 1.46 m)

SYNC hardware signal on train detection to Siemens installation, position accuracy error maximum 2 ms = 5.6 cm at v = 100 km/h.

Measurement of pantograph positions relative to front end of train, position accuracy error maximum 2 ms = 5.6 cm at v = 100 km/h.
Double-armed structure of pantograph could be always detected. This results in an decision between detection of a pantograph and of an unwanted other intruder.

Available Functionality of Laser uplift sensor:

1kHz standard measurement rate (measuring rate can be adjusted up to 2.5kHz)
Max. distance measuring range is 200..950 mm (Δ = 750 mm)
Zero position in the inspection gate in Heustrich is 670 mm
Uplift measurement range from -470 mm to +280 mm

First test results showed influence to sunlight: uplift went out of work at bright sun illumination.
Following additional improvements resulted in undisturbed operation (details visible and marked in Fig. 4.3.1.3):

1. Additional 670 nm filter for higher contrast laser/sunlight
2. Narrow aperture against bright sunlight
3. White scattering plate on OCL

Deviations of uplift measurements:

Following experimental accuracy and repeatability values have been determined in lab investigations:

Repeatability 30 µm peak-to-peak
Reproducibility after on-site calibration 75 µm within 0 .. +50 °C
Absolute accuracy over full measuring range of 750 mm depends on profile of scattering plate, it is estimated to about 1 mm
Accuracy errors of relative distance changes within 50 mm has been determined to < 0.1 mm

Uplift errors will be caused mainly by angle variation of light scattering plate.

Data format of uplift measurements

On a note pad, following train parameters are automatically stored:

```
Timer analysis Version 07
Ready: 17.08.2007 23:02:26
Train arrived: 17.08.2007 23:23:52
Direction: backward
SYNC to external user: 17.08.2007 23:23:53
SYNC_OK
Speed in km/h:  5,00
Intruder 1 : 11,04 m
Intruder 2 : 11,32 m
Intruder 3 : 31,42 m
Intruder 4 : 31,63 m

Min -0.07   Max 3.80 cm
Measurement finished: 17.08.2007 23:25:39
```

Besides immediate uplift over time H(t), this data has been transformed to uplift over track path H(z), in a Delphi based file conversion algorithm.

There are 2 data files stored:

a) a ringbuffer file, starting always 60 s in front of SYNC
b) a succeeding measuring file, closed manually after train has passed

Measuring result examples

Fig. 1.3.5 shows the long-term stability, i.e., how the uplift returns to zero after train has passed for a sufficient long time.

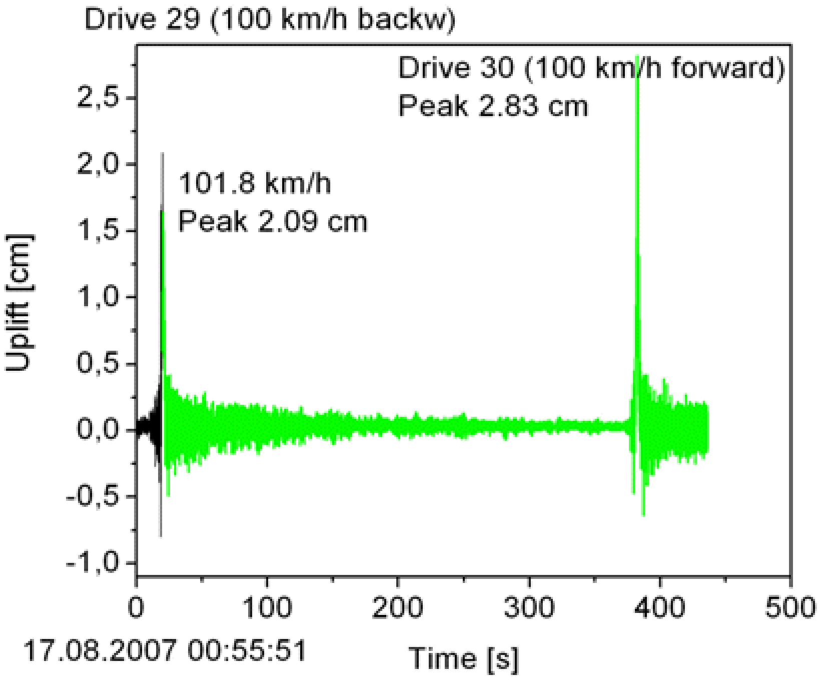


Fig. 1.3.5 Uplift trace over longer time (2 succeeding trains)

Repeatability is mainly determined by noise of uplift read-out. Fig. 1.3.6 shows a peak-to-peak value of noise under real field conditions (measured in the inspection gate Heustrich) of 300 mm, i.e., a 1σ deviation of uplift measurements of 60 µm.

However, a train on the other (neighboured) track generates noise of ground movements, measured as uplift vibrations.
Under real Heustrich inspection gate conditions, this cross-sensitivity of neighboured traffic generates uplift noise of up to 4 mm peak-to-peak (Fig. 1.3.7)

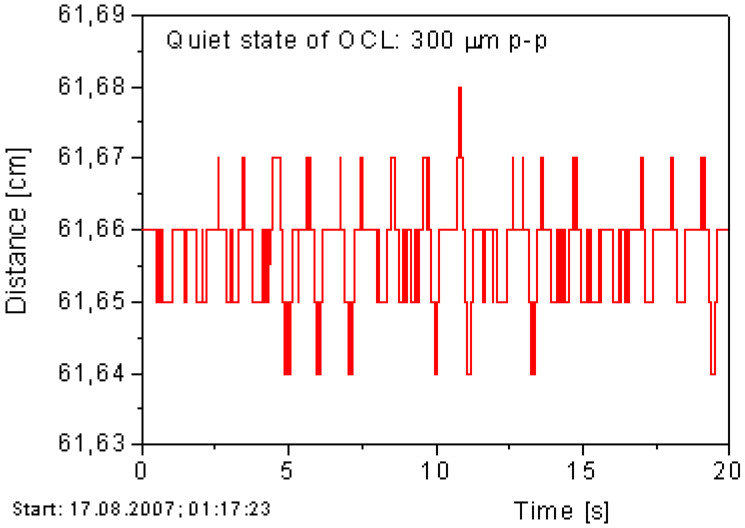


Fig.1.3.5 Uplift noise in quiescence state

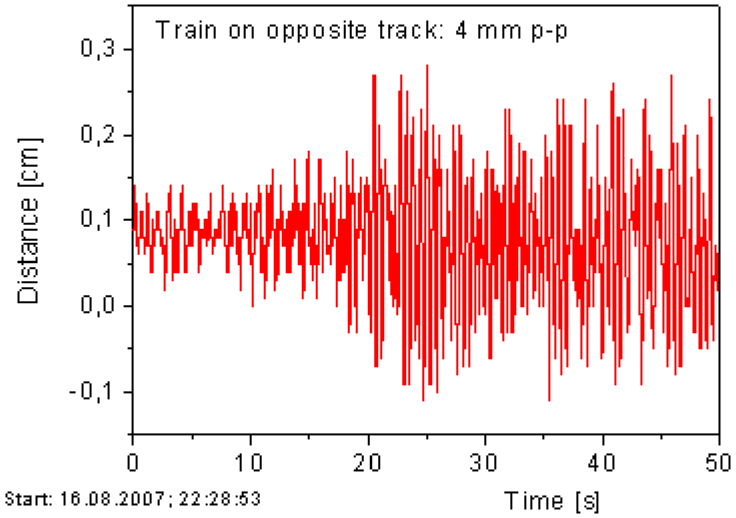


Fig. 1.3.6 Uplift noise caused by neighboured traffic

2 Dissemination and use

The CATIEMON Final Event took place on January 14, 2009 in Vienna where the project results were presented to a large audience with technical representatives from various railway related companies across Europe. For an overview on the technologies of CATIEMON see the public section (see below: **Section 3 – Publishable results**) of the final plan for using and disseminating the knowledge.

Section 3 – Publishable results

Exploitable result 3:

Result description:	3. OCL uplift device for the inspection gate (IPH)
Possible market applications; use in	on-line distance measurements in energy and transportation industry

further research:	
Stage of development:	lab demonstrator
Collaboration sought or offered:	Collaboration offered for further distance measurement applications on high-voltage devices
Collaborator details:	Dr. Kerstin Schroeder, IPHT Jena, D-07747 Jena, Germany
Intellectual property rights **granted** or published:	DE, PCT, and WO patents issued to IPH
Contact details:	kerstin.schroeder@ipht-jena.de; phone +49-3641-206220

Exploitable result 4:

Result description:	4. Smart carbons for hit detection current collector (IPH & MOR)
Possible market applications; use in further research:	Transportation industry: structural health monitoring, operational monitoring
Stage of development:	prototype
Collaboration sought or offered:	Collaboration offered for further force monitoring applications in electric railways
Collaborator details:	Mr. Simon Willet, Morganite Electrical Carbon Ltd., Swansea, Wales SA6 8PP, UK
Intellectual property rights **granted** or published:	PCT, and WO patents issued to MOR
Contact details:	Simon.Willett@mecl.co.uk; phone +44-1792-763 025

Exploitable result 5:

Result description:	5. High energy carbon testing machine (MOR)
Possible market applications; use in further research:	Testing of current collectors for railway or tramway end users.
Stage of development:	Complete.
Collaboration sought or offered:	End user customers.
Collaborator details:	Mr. Simon Willet, Morganite Electrical Carbon Ltd
Intellectual property rights **granted** or published:	None
Contact details:	Simon.Willett@mecl.co.uk; phone +44-1792-763 025

Exploitable result 6:

Result description:	6. Detection device for wavelength shift of fiber Bragg peaks (IPH)
Possible market applications; use in further research:	Energy and transportation industry: structural health monitoring, fatigue investigations
Stage of development:	prototype
Collaboration sought or offered:	Collaboration offered for further strain and force sensor applications in structural health monitoring
Collaborator details:	Dr. Kerstin Schroeder, IPHT Jena, D-07747 Jena, Germany
Intellectual property rights **granted** or published:	DE, PCT, and WO patents issued to IPH
Contact details:	kerstin.schroeder@ipht-jena.de; phone +49-3641-206220

Exploitable result 7:

Result description:	7. Laser-based 2D-profiler for OCL displacement measurement (CYX)

Possible market applications; use in further research:	Large market is reachable for applications where main characteristic would be high speed profile inspection on surfaces having a very low optical albedo; as an example: track ballast, tires, underwater monitoring. Main limitation is the applicability of the laser safety regulations to every possible business case.
Stage of development:	Functional rugged demonstrator, adapted to harsh environment.
Collaboration sought or offered:	Any further development toward a commercial product / application
Collaborator details:	
Intellectual property rights **granted** or published:	No IP rights are granted yet
Contact details:	Cybernetix Industry Business Unit 306, rue Albert Einstein - BP 94 13382 Marseille Cedex 13 - France eric.gautret@cybernetix.fr ; jocelyn.millet@cybernetix.fr

Exploitable result 8:

Result description:	8. Bragg sensor based 3d-OCL displacement measurement (CEA LIST)
Possible market applications; use in further research:	Any research/industrial sector requiring displacement measurement based on fiber optics, for instance to benefit of electrical insulation provided by fibers.
Stage of development:	Design upgrade in order to suit various displacement range specifications.
Collaboration sought or offered:	Possibility to pursue the developments of the Inspection gate prototype/product is a option to consider.
Collaborator details:	To be discussed. A collaborative contract, and/or a license to transfer the technology to industrial companies is also an option to consider
Intellectual property rights **granted** or published:	Principle already Patented. Some results published
Contact details:	CEA LIST Laboratoire de Mesures Optiques CEA Saclay Detecs-Syssc-Lmo Bât. 528 P120 F-91191 GIF-SUR-YVETTE France guillaume.laffont@cea.fr ; pierre.ferdinand@cea.fr;

Exploitable result 9:

Result description:	9. Fiber Bragg sensor based strain measurement for overhead line deflection (CEA LIST Institute)
Possible market applications; use in further research:	Protocol developed for the mounting of wavelength-multiplexed FBG sensing line will be used in all the sectors addressed by CEA LIST such as: Civil Engineering, Energy and Nuclear Industry, Oil and Gas, Transportation sector … This solution will be also re-used/improved as a follow-up of the Catiemon project for contact force measurement, hit detection and commercial traffic evaluation.
Stage of development:	Analysis of other sensors configurations/topology able to improve both the ability to detect damaged/worn current collectors and to measure the contact force.
Collaboration sought or offered:	To be discussed. It depends on decision to pursue the developments of the Inspection gate prototype/product. A collaborative contract, and/or a license to transfer the technology to industrial companies is also an option to consider
Collaborator details:	To be discussed with Catiemon's partners in priority
Intellectual property rights **granted** or published:	Some results already published

Contact details:	CEA LIST Laboratoire de Mesures Optiques CEA Saclay Detecs-Syssc-Lmo Bât. 528 P120 F-91191 GIF-SUR-YVETTE France guillaume.laffont@cea.fr ; pierre.ferdinand@cea.fr;

Exploitable result 10:

Result description:	10. Detection system for steady arm vibration measurement (CEA)
Possible market applications; use in further research:	Dedicated to the characterization of hits and sideward oscillations of contact lines on railway infrastructures. Detection of damages/worn current collectors.
Stage of development:	To be tested on a new Inspection Gate prototype in order to evaluate its potential for damaged/worn current collector detection.
Collaboration sought or offered:	To be discussed. It depends on decision to pursue the developments of the Inspection gate prototype/product.
Collaborator details:	To be discussed
Intellectual property rights **granted** or published:	Published
Contact details:	CEA LIST Laboratoire de Mesures Optiques CEA Saclay Detecs-Syssc-Lmo Bât. 528 P120 F-91191 GIF-SUR-YVETTE France guillaume.laffont@cea.fr ; pierre.ferdinand@cea.fr;

Exploitable result 11:

Result description:	11. Detection device for measurement of wavelength shift of fiber Bragg sensors (CEA)
Possible market applications; use in further research:	The FBG monitoring system will be used in forthcoming R&D and industrial projects in the railway market but also in all the industrial sectors addressed by the CEA LIST such as: Civil Engineering, Energy and Nuclear Industry, Oil and Gas, Transport …
Stage of development:	CEA's FBG monitoring system is ready to be transferred to an industrial for small-medium quantity manufacturing. Improvements are foreseen in order to integrate the system as a stand-alone unit, as it will be required for an Inspection Gate product.
Collaboration sought or offered:	To be discussed. It depends on decision to pursue the developments of the Inspection gate prototype/product.
Collaborator details:	To be discussed
Intellectual property rights **granted** or published:	Patented
Contact details:	CEA LIST Laboratoire de Mesures Optiques CEA Saclay Detecs-Syssc-Lmo Bât. 528 P120 F-91191 GIF-SUR-YVETTE France guillaume.laffont@cea.fr ; pierre.ferdinand@cea.fr;

Exploitable result 12:

Result description:	SIE: 13. Procedure for data fusion of location and hit measurement data of smart current collector system 14. Calibration device for overhead line sensors 15. Overhead contact line monitoring with integrated vehicle identification 16. Contact strip quality monitoring
Possible market applications; use in further research:	SIE: The particular results from the Catiemon project have a different stage of development. To reach a reasonable commercialization only a common product, an inspection gate with different sensors etc., may be reasonable. The choice of the applications for the right measurement and use of the data taking into consideration the particular stage of development will be the next step. Potential locations for inspections gates could be determined according to the different possible case of operation. One main focus is the prevention of disasters. Railway tunnels are naturally bottlenecks for transportation of persons and goods. Beside the availability of routes is the avoidance to bring people in danger one major focus, especially in tunnel routes. Consequentially one major case of operation for the inspection gate is in front of tunnel entrances. Different technical development implicated different handling of the interface between pantograph and contact wire, e.g. different contact forces. So very often the border between two countries is not only a changeover between two operators, also the interface between pantograph and contact wire could be different. And in special cases, the voltage level and other electrical data are different. So the second important focus for the inspection gate should be the border crossings. The process of separation between infrastructure networks and rolling stock operators will cause a stronger definition of the interface between both parties and the monitoring of these agreed conditions. The change of responsibility from one infrastructure operator to another could be an interesting location for the gates. Nevertheless during these days for the main routes very often the country border is identical with the infrastructure operator border. In all cases modularity depending on the case of application and country should be possible. With this construction set the special needs of different clients could be considered, further instruments for other measurements could be integrated and also a step-by-step enlargement of the inspection gate is possible.
Stage of development:	Analysis of current situation, market survey, business case with calculation of profitability as a basis for decision how to proceed
Collaboration sought or offered:	Depending on the decisions for further proceeding
Collaborator details:	See above
Intellectual property rights **granted** or published:	Patent application filing in progress
Contact details:	Siemens AG, Industry Sector, Mobility Division, Turnkey Systems I MO TK ED CL Solution Management 91052 Erlangen, Mozartstr. 33b, Germany mailto:jens.wackernagel@siemens.com