NDT for Need Based Maintenance of Bridge Cables, Ropes and Pre-Stressed Elements

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Abstract. Infrastructure is subject to continuous aging. This has given life cycle management of infrastructure an increasingly important role. Reliable inspection and monitoring tools are therefore in demand. A reliable prognosis of the condition and behaviour of a structure is an important basis for an effective service life management. Furthermore, traffic loads and loads due to changing environmental conditions increased during the last years and will increase in the future. Repair and maintenance have to be performed which requires reliable concepts and measurement of data, which is preferably gained through non-destructive methods. Furthermore, infrastructural constructions often have to be reconditioned when they are in use i. e. they cannot be torn down and rebuilt. Therefore, reliable diagnosis of the state of ‚hot spots' is required.

Within the frame of the Franco-German project FilameNDT steel wires of external tendon ducts and prestressing strands, prestressing rods, and stay cables are investigated. With regards to this field of application, practical relevance can only be gained when easily applicable and long ranging methods are used. The evaluation of extended structural elements using non-contact movable systems (bulk wave and guided wave application (Piezo, Electromagnetic Acoustic Transducers (EMAT)), Magnetic Flux Leakage (MFL), Micromagnetic methods) and those of localized elements based on elastic guided wave propagation – are complementary since they can be applied according to the various accessibility conditions of the tested objects. Inspection and monitoring scenarios were developed, hot spots were identified, and lab tests as well as field tests were carried out. A real cable stayed bridge in the Saarland region is available for monitoring within the frame of the project.

Results from local investigations using guided waves and from monitoring field tests with micromagnetic sensors are presented and discussed. The results show the scenarios where the non-destructive methods are applicable and how the results can be used for structural health monitoring and maintenance concepts.

Keywords: NDT of cables and wires, ultrasound, guided waves, micromagnetics, monitoring

1. Introduction

1.1 Background and NDT methods

Civil engineering infrastructures are ageing and slowly deteriorating resulting in a continuous increase of replacement costs. In most of these structures, cables and other pre-stressed elements are probably the most critical structural members requiring special attention. These metallic load carrying elements undergo degradation primarily due to corrosion and fatigue mechanisms which turn out to be a local loss of the cross-sectional area. The durability and structural safety of these members is thus strongly dependent upon the ability of inspection and the monitoring methods used to detect these degradations «in time». Regarding non-destructive testing (NDT), an important distinction is commonly made between the accessible parts of the structure to be tested and the non-accessible parts. The accessible parts concern the zones, where the metallic elements to be inspected, are directly visible and physically easy to access, whereas the non-accessible parts concern the hidden parts of the structure. If the current state of the art in the accessible parts, evaluation condition, relies on visual [1] and magnetic inspection [2-5], and acoustic monitoring [6-7], the one concerning the non-accessible part evaluation condition is still lacking, since numerous structural factors can significantly complicate the evaluation. Some of the main factors are:

- the different material layers and multiple interfaces of the protection systems (concrete, duct, grout) for the embedded strands configurations
- the anchorage zones which concern all bridge technology (cable-suspended, cable-stayed, and pre-stressed concrete bridges)
- the collar attachments in suspended bridges

Moreover, inspection and monitoring of the non-accessible parts is a major concern, as it is often considered as the weakest zones of the structure, where fatigue mechanism and corrosion (due to water ingress/accumulation) exists. Among the diverse investigated techniques, ultrasonic guided waves (particularly for anchorage zones) [8-9], magnetic flux leakage inspection, micromagnetic methods, and acoustic emission monitoring appear to be suitable [10-11]. High–frequency electromagnetic methods (ionizing method as radiography [12-13], or non-ionizing as radar or time-domain reflectometry) were rejected in this case due to the time-consuming nature, radiation hazards and low material portability of the first one, and the screening effect of metallic pieces of the two last ones [14].

MFL is a standard NDT method for the regular inspection of ropeways and bridge tendons [15]. MFL can be applied for inspection of open as well as embedded load carrying elements. By means of MFL the following rope defects can be detected (local faults in terms of wire breaks, pitting corrosion and local abrasion and loss of metallic area due to generalized corrosion or rupture) [16,17]. However, contrary to the surface ones, internal flaws are difficult to detect.

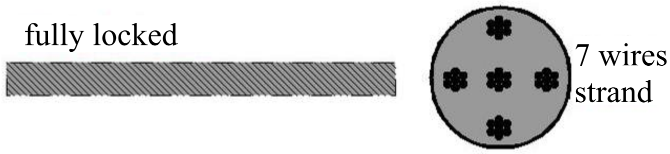
With regards to the investigations presented here guided ultrasonic waves were developed in two ways: modelling and experimental investigations at a laboratory scale. This work deals with propagation into cylinder or cylinder-like structures, civil engineering strands, using mono-elements magnetostrictive- and/or piezoelectric -based devices in pulse-echo and through-transmission mode [18-20]. The ultrasonic guided wave~~s~~ method generally combines the ability to inspect, in a single measurement, the whole width of the structure over an appreciable length along the guiding direction. It is potentially applicable for the inspection of hidden parts. The technique is continuously improved by an active

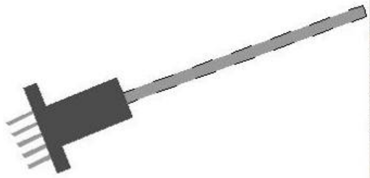
community in the world and is used in industry for tube and pipeline inspection, mainly in refinery fields as well as for cylinders and plates [21-22] e.g. for fuel tanks.
Micromagnetic methods are based on analogous interactions between the microstructure and Bloch walls on one hand as well as dislocations on the other hand. The magnetic and mechanical properties of ferromagnetic materials are strongly correlated [23]. Several micromagnetic testing devices were developed which allow the indirect non-destructive detection of changes of the mechanical hardness, hardening depth, and many other properties based on this analogy. In addition, the influence of the 1st, 2nd, and 3rd order residual stresses on the magnetic properties, most of all the magnetic Barkhausen noise, is a well known phenomenon which is already being used for micromagnetic residual stress measurement.
The acoustic emission (AE) technique is based on the release of stored elastic energy as elastic waves due to sudden micro-fracturing in a rigid body. This phenomenon can be observed on different scales, ranging from earthquakes to micro-fractures. In the field of non-destructive testing (NDT), this technique is used in many industrial areas ranging from nuclear to petrochemical industries. Acoustic emission analysis generally allows the possibility to identify and to localize active damaged source [24-25], but in many cases energy supply (forced vibration, [26]) is needed. Some developments concern the detection of wires rupture of suspensions, stay cables, and prestressing tendons [27-30].

1.2 Investigated configurations

Within the frame of the Franco-German project FilameNDT whose results are presented here, several relevant elements of typical constructions requiring special attention in form of inspections or monitoring were identified. The most relevant ones are summarized in Table 1. Results from inspections and monitoring tests will be discussed within the frame of this paper of the configurations 1 to 4, whereas the bridge shown in configuration 4 represents a realistic test scenario.

Table 1. Investigated configurations

Configuration	NDT Method
1. Bare cables of different diameters  	Ultrasound guided waves (EMAT (SH – torsional mode, L – longitudinal mode)) 3MA (7 wired strand)
2. Fully locked rope and 7 wire strand (pure rope only)  - fully locked rope: surface defects under coating and inner defects, artefacts due to magnetic particles from fretting fatigue - 7 wire strand: plastic duct outside, defects in wires	MFL 3MA (monitoring, first approach)

3. Anchorage Zone  	Ultrasound guided waves (EMAT (SH – torsional mode, L – longitudinal mode)) 3MA (monitoring) AE (monitoring)
4. Cable stayed bridge provided for inspection and monitoring (Saar river, Mettlach, Germany) 	Ultrasound guided waves (EMAT (SH – torsional mode, L – longitudinal mode)) AE (monitoring) 3MA (monitoring)

The NDT methods listed in Table 1 were first applied to specimens in the laboratory environment. Then inspection and monitoring tests were carried out at the real bridge shown in configuration 4 of Table 1. Within this paper the focus is on ultrasonic and micromagnetic methods,which can be used either for inspections or for monitoring purposes. In the next sections the chosen approaches and the results will be described.

2. Ultrasound guided wave inspection of wire ropes

2.1 Sensor design and modelling

Bridge cables, ropes and other pre-stressed wire like elements represent complex structures for ultrasound inspections. Due to the given geometry, guided waves were chosen for the investigations and especially here electromagnetic acoustic transducers (EMAT) with their ability to generate defined wave modes, which cannot be generated directly with piezoelectric transducers. Furthermore, EMATs do not require a couplant which is also an advantage for a variety of applications. To allow an optimal sensor design wave mode and optimal frequency range was modelled first and with this a priori information the appropriate sensors were built.

2.2 Modelling of guided waves in wire ropes

The goal of this subsection is to improve the theoretical understanding of guided wave propagation at the periphery of fully closed spiral ropes. As a first step, a single simplified z-shaped wire has been modelled (Figure 1).

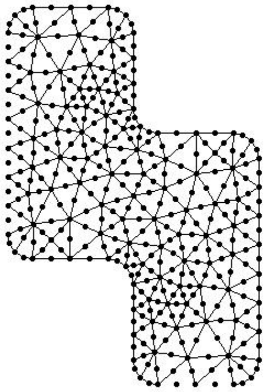


Figure 1. Finite-element mesh for a simplified single z-shaped wire geometry

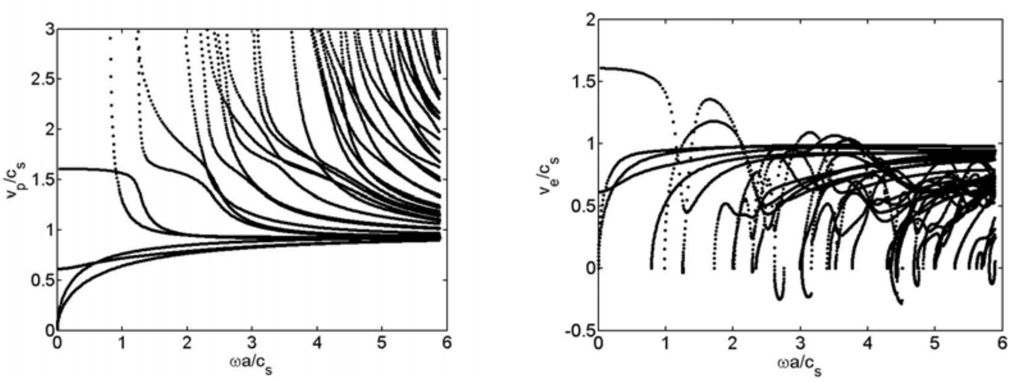


Figure 2. Calculated dispersions curve of guided wave modes in single z-shaped fiber (left: phase velocity; right: group velocity; a = 3 mm, c_s = 3.2 mm/µs)

No coupling with adjacent wires has been considered. Due to the geometrical complexity, a numerical method must be used. Here the method is based on the so-called semi-analytical finite element technique, which aims in reducing the problem to the cross-section only, thanks to a spatial Fourier transform performed along the axis. With a Semi-Analytical Finite Element (SAFE) method, the only assumption required is that the structure must be translationally invariant, which is the case for a single z-shaped wire. The problem to be solved, is initially three-dimensional, hence can be reduced to a two-dimensional. The curvature of the helical axis has been recorded to be based on the use of a specific curvilinear coordinate system, corresponding to a twisting system, recently developed at IFSTTAR. Results have shown that the curvature of the axis can be neglected for the structure and the frequency range be considered. Some theoretical dispersion curves are presented in Figure 2, which plots, respectively, the dimensionless phase velocity and group velocity with respect to the dimensionless frequency for each propagating mode. The dimensional frequency range considered corresponds to the range [0 - 1 MHz]. It can be observed that many modes are propagating in this range. Typical for prismatic waveguides, compressional, torsional, and flexural modes occur. At this stage, additional information is needed for a proper identification of branch modes that are mainly excited with the experimental device (frequency, wavenumber and direction of excitation). Interestingly, future works would include taking into account the excitation in the numerical model and plotting the corresponding dispersion diagrams.

2.3 EMAT measurements

7-Wire Strands

For the experiments on 7-wire strands EMAT probes were built up for the excitation and pick up of longitudinal and torsional guided wave modes. The principle design of the probes and the relevant ultrasonic inspection parameters are shown in Figure 3, respectively Table 2. The EMAT probes were applied to prestressed and differently prepared 7-wire strands. The set of specimens contains coated strands with grease, concrete and free ones. In addition, a few wires were modified with artificial pitting or crack like defects.

During the experiments it was found that the transduction efficiency of longitudinal wave modes in 7-wire strands is much higher compared to torsional wave modes. Therefore, the following examinations are concentrated using longitudinal modes. The artificial defects can be detected via an ultrasonic echo signal over several meter~~s~~ distance in all uncoated strands (see Figure 4). The ultrasonic signals are damped extremely by a coating layer of grease or grout. Under these conditions the ultrasonic signal extinguishes during a sound path of about one meter.

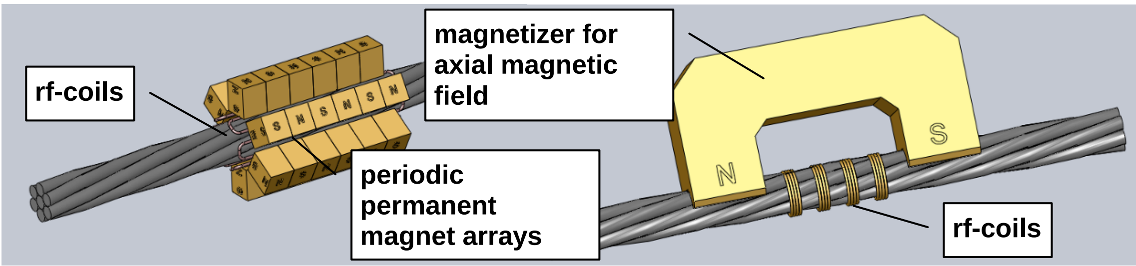


Figure 3. The principle design of EMAT probes for rod waves
(left: torsional wave modes, right longitudinal wave modes)

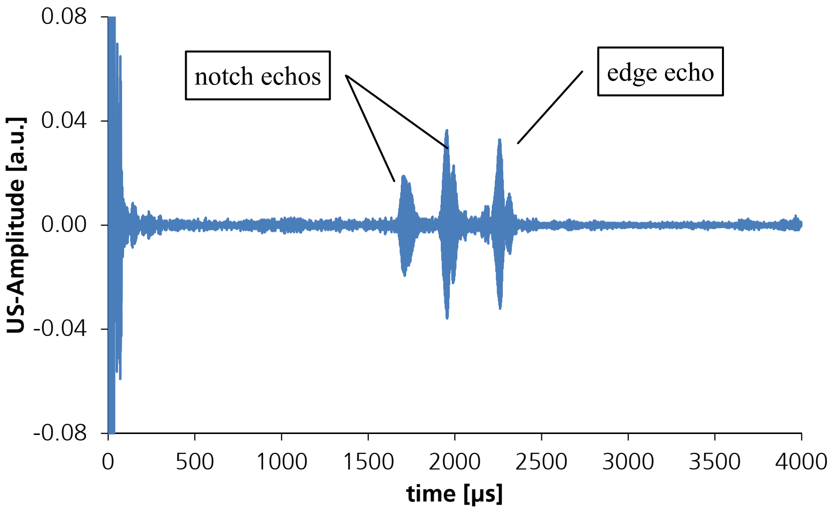


Figure 4. Ultrasonic A scan of a 7-wire strand with artificial defects, partially coated with concrete, the total length is about 5 m

Table 2. Ultrasonic inspection parameter

wave mode	trace wave length of transducer	operation frequency
Torsional	14 mm	~240 kHz
Longitudinal	12 mm	~410 kHz

Fully Closed Spiral Rope

For a single fibre of a z-shaped fully closed rope, the dispersion diagram was calculated (see section 2.2). Due to the results of the dispersion curves EMAT probes were designed and built for shear and longitudinal guided wave modes running in a single z-shaped fibre of a fully closed rope. Several EMATs with different trace wave lengths and corresponding frequencies were applied. The ultrasonic inspection parameters are shown in Table 3.

The ultrasonic through transmission signals are effected by a very high damping of 22 up to 28 dB/m (!). Therefore it is very difficult to receive defect or edge echoes with an evaluable amplitude. Due to the selected operation point it is not possible to excite pure longitudinal wave modes. The different modes interfere with each other resulting in variations of the spatial amplitudes. An evaluation of these variable amplitudes is not reliable enough for any defect detection.

Table 3. Ultrasonic inspection parameter

wave mode	trace wave length of transducer	operation frequency
shear (SH)	6 mm	~500 kHz
shear (SH)	14 mm	~200 kHz
shear (SH)	32 mm	~80 kHz
Longitudinal	12 mm	~240 kHz

2.4 Piezoelectric measurements in wire strands

A bench of 5 m length including 3 prestressing 7-wire strands was used for the experiments (Fig. 5). All the 3 strands are 5m long are grouted over 2.5 m length with cement grout in a polyethylene high density (HDPE) duct. The strands are prestressed at 80% of the ultimate strength.

Figure 5. 5 m bench for cement grouted 7-wire strand prestressed at 80% of the ultimate strength

Artificial saw-machined wire defects were performed to simulate broken wire for three different peripheral helical wires of one strand and at different distances from the excited end of the strand. The defects consist of two completely broken helical wires (square to the longitudinal axis of the strand) at 1.6 m (case 1) and 2 m (case 2) , respectively and one completely broken helical wire at 1.4 m with an inclination angle of approximately 45° (case 3).

Figure 6 corresponds to the 3 envelopes of the echo signal amplitudes relative to each damaged wire of the strand (case 1 to 3). It was observed that the straight broken peripheral wire is still detectable at 2 m. It can be concluded that 3 m distance of inspection range could be significantly reached. . Concerning, the case 3 damaged wire (with a broken wire whose ends are with an angle of 45°), it was observed that its amplitude is lower than the two farthest straight broken peripheral wire defects due to the lower reflectivity of a such defect.

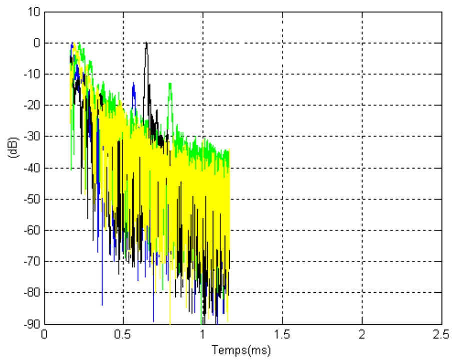


Figure 6. Time envelopes of echo signal for the damaged strand with 3 broken wires at 1.6 m case 1 (black curve), 2 m case 2 (green curve) and 1.4 m case 3 (blue curve). The yellow curve is for the central wire (undamaged wire).

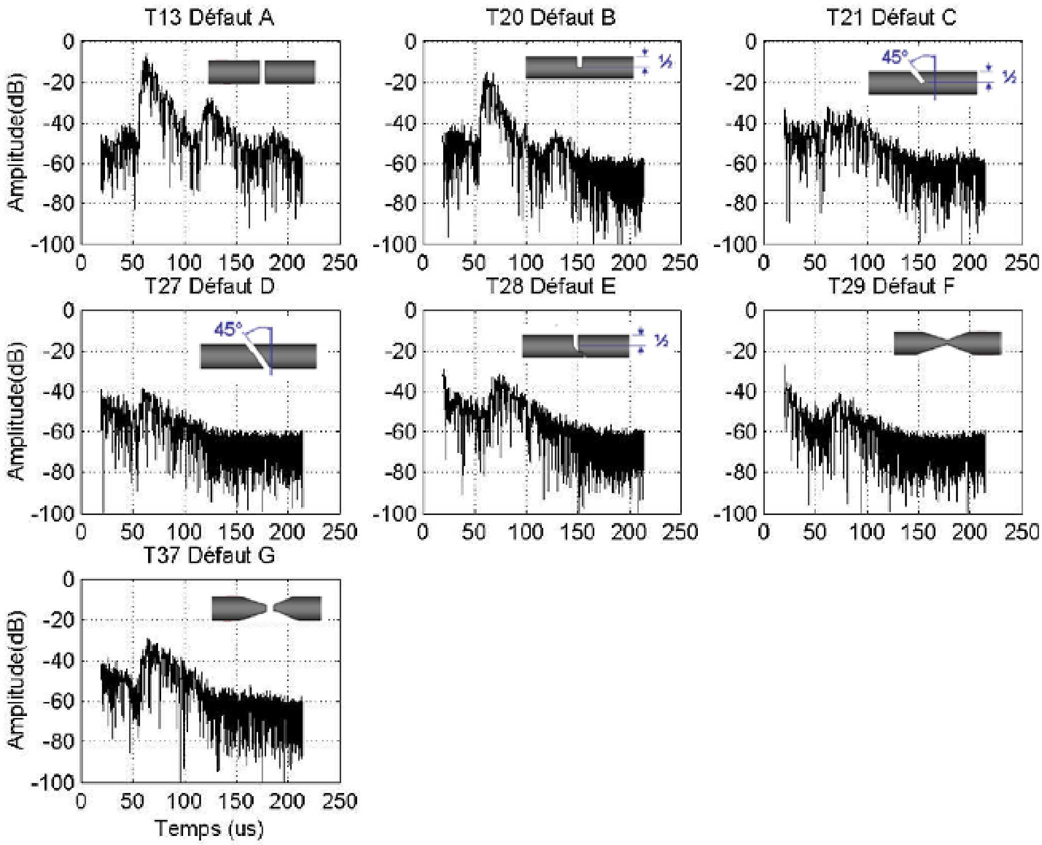


Figure 7. The time envelopes of the damaged wire of each strand

Another series of experiments were conducted on a separate bench from the one considered before. This is a 2.5 m-bench with individually HDPE coated greased strands prestressed at around 30% of the ultimate strength. Artificial defects were machined at short distance range (lower than 50 cm). Contrary to the measurement performed in the above part, high-frequency wideband excitation signals were used for the short-distance defect detection.

Various types of defects were machined to observe the influence of the defect shape on the echo signal amplitude. The same methodology as above was used.
Figure 7 represents the time envelopes of the investigations of each damaged wire of each strand. It is observed that all types of defects produce one (or more) distinguishable echo signal(s). For instance, it is possible to detect the complete straight broken wire defect echo (and associated multiples), as well as the mid depth straight notch echo signal (and its multiple) respectively. As expected, the more difficult echo signals to detect are those whose reflectivity is assumed to be low. This concerns the 45° inclined notch at mid depth case (T21 Defect C) and the tapered wire with no break (T29 Defect F).

3. Monitoring of bridge wire ropes

3.1 Monitoring test site and concept

Bridge cables, ropes and external pre-stressed elements are predestinated for applying monitoring techniques. They are significant load carrying elements of a construction and they often provide a limited accessibility. Within the frame of the investigations, presented in this paper, preliminary tests were carried out at the bridge shown in Table 1. These first investigations concentrated on the applications of micromagnetic methods for monitoring purposes of pre-stressed elements.
The bridge shown in Table 1 is currently under renovation. Inspection activities within the frame of this process started in autumn 2011. This period was used for the first monitoring tests. The main renovation phase began in late autumn 2012 and during this process the concrete deck was replaced by a much lighter one. Within the frame of these activities additional load tests are envisaged for this construction. Therefore, a micromagnetic monitoring at two anchorage zones and an acoustic emission monitoring at all 4 anchorage zones was planned. The bridge has eight wire ropes on each side as elements carrying the main load. Stress changes should be equally distributed over all the wires. Therefore, not all ropes have to be instrumented. Acoustic emission monitoring for the detection of wire breaks is a well referenced approach. This method will be used for validating the micromagnetic results and to have redundant measurements for the assessment of the results. Micromagnetic measurements rely on the fact that the magnetic properties of ferromagnetic materials are strongly correlated to the mechanical properties. Using this approach, monitoring stress changes is possible. The transfer of the micromagnetic technique from the application field of material characterization and quality assurance to structural health monitoring is a new approach. However, this application needs to be tested this was performed in a first field test at the described bridge.

3.2 Micromagnetic monitoring approach

The micromagnetic monitoring approach is based on the assumption that any loss of wire cross-section, e.g. due to cracked fibres, should lead to a redistribution of the tensile load over different measuring locations on a wire rope or a bundle of wire ropes. This load change should be detectable by means of stress-sensitive micromagnetic quantities, thus allowing for a remote detection of flaw occurrences.
The sensitivity of the micromagnetic method was tested in the form of a laboratory tension test using a typical steel strand. The results of this test, the maximum Barkhausen noise amplitude and the harmonic distortion factor, are shown in Fig. 8. The effect size for both

micromagnetic properties is about 50 % and therefore a significant signal due to the local traffic that is expected during the field test.

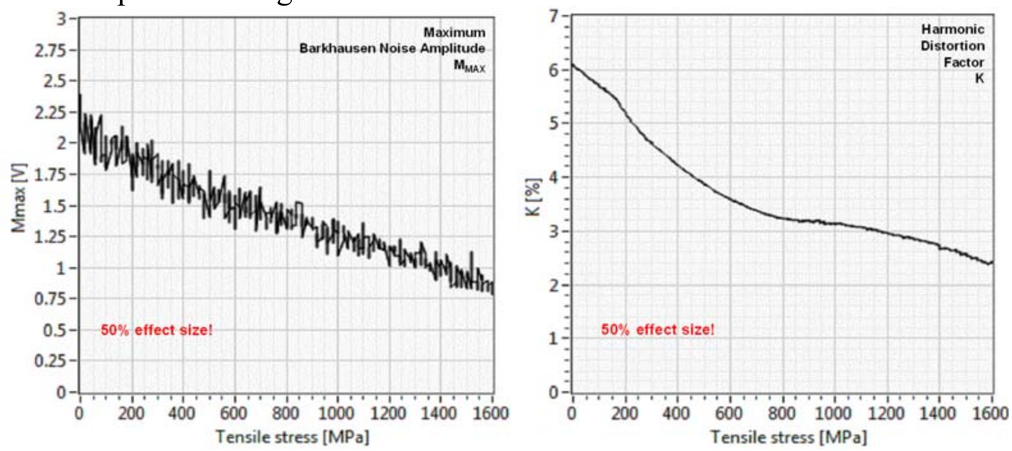


Figure 8. Results from laboratory tensile test on a strand which was provided to study the sensitivity of the approach. T15.7 strand: Young‘s modulus = 202 Gpa, Yield strength (0.02%) = 1750 MPa, UTS = 2020 MPa

Based on the laboratory results, a first on-site test of the micromagnetic monitoring approach was performed at the bridge over the Saar river in Mettlach (Germany). The applied measurement setup is shown in Figure 9. In order to test the remote detection of stress changes a set of three rugged micromagnetic devices was built, and an appropriate software for the long-term control of several devices with a single PC was created. A netbook PC, a USB hub for controlling the devices, and the power supplies were placed in a weather-proof box. The unit was connected to the 230 V mains line, available at the construction site. Two devices were strapped on loaded bridge ropes, and one device was strapped on an unloaded fully locked wire rope of similar design which was used as a reference cable during this test. In order to monitor the environmental conditions (temperature, humidity) and the traffic load, a time lapse camera and a weather logger were installed as well.

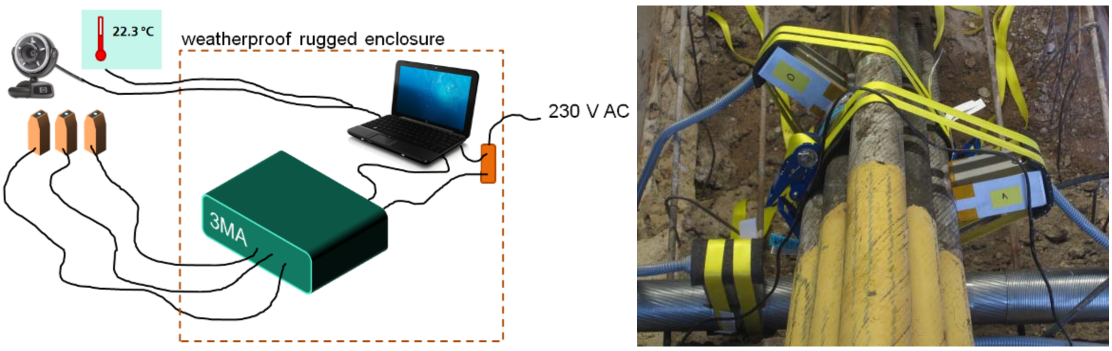


Figure 9. Schematic representation of the monitoring equipment tested in Mettlach and photo of three installed devices (two on the loaded ropes and one device on an unloaded similar rope located below the loaded ropes)

The system was set to record approximately one sample per minute. Although the devices were installed for a few days only within the frame of this first test, the expected essential information for a full monitoring experiment was obtained:

- All measured parameters showed no detectable reaction to the traffic load. Since the stress in a single rope, due to a 30 t traffic load, is approximately 15 MPa only, this small effect probably was below the detection limit. Moreover, the measuring rate of only one sample per minute made it difficult to correlate the results to the traffic load.

Further tests indicated that improvements to the devices and averaging of several measured values might even allow for traffic load detection to be performed in the future.

- A small, but significant correlation between the measured values and the ambient temperature was found (Figure 10). Further lab tests were performed which have shown that the effect is related to the temperature of the material, rather than the temperature of the device. A remarkable observation is that the temperature coefficient of the values measured on the loaded ropes had opposite sign and a smaller magnitude than the one in case of the reference rope. This suggests that the effect might be at least partially related to the thermal expansion of the wire and the related variations in tensile stress.
- Of course, no sudden changes in the measured values which would indicate a partial wire break were detected throughout the short experiment.

In a second on-site measurement, the actual effect of traffic load was quantified using strain gauges, and the stress-sensitivity of the micromagnetic method was increased by tuning the device settings and analysis methods. Figure 11 shows the result. Assuming Young's modulus of E = 202 GPa, the stress change $\Delta\sigma$ was computed from the measured strain ε (red curve). The micromagnetic materials characterization was performed using a 3MA device (3MA = Micromagnetic Multiparameter Microstructure and Stress Analysis), and the most stress sensitive parameter, derived from the incremental permeability measurement, was plotted over the same time axis as the strain gauge values (gray curve). In order to improve the signal/noise ratio, the 3MA signal was smoothed using a moving average filter, resulting in the black curve. The results show that a strong correlation between strain gauge signal and micromagnetic signal exists. Each peak in the strain gauge results from heavy loaded vehicles like trucks. This was confirmed by camera observations of the traffic. The strain gauge was calibrated with tension tests in the laboratory. Theoretical calculations of the static load on the ropes, due to a truck passing the bridge, led to a value of 15 MPa. The measured values are in good accordance with this calculation. The result of the micromagnetic measurement, which was performed parallel to the strain gauge tests, show that all peaks in the strain gauge signal can also be resolved in the micromagnetic signal. This experiment indicates that the resolution limit of the micromagnetic measurement should be approximately in the same order of magnitude as the traffic load. Therefore, we can assume that it will be sufficient to detect probable wire breaks within the frame of these planned long term monitoring activities, since wire breaks would generate much greater stress changes than the observed traffic loads.

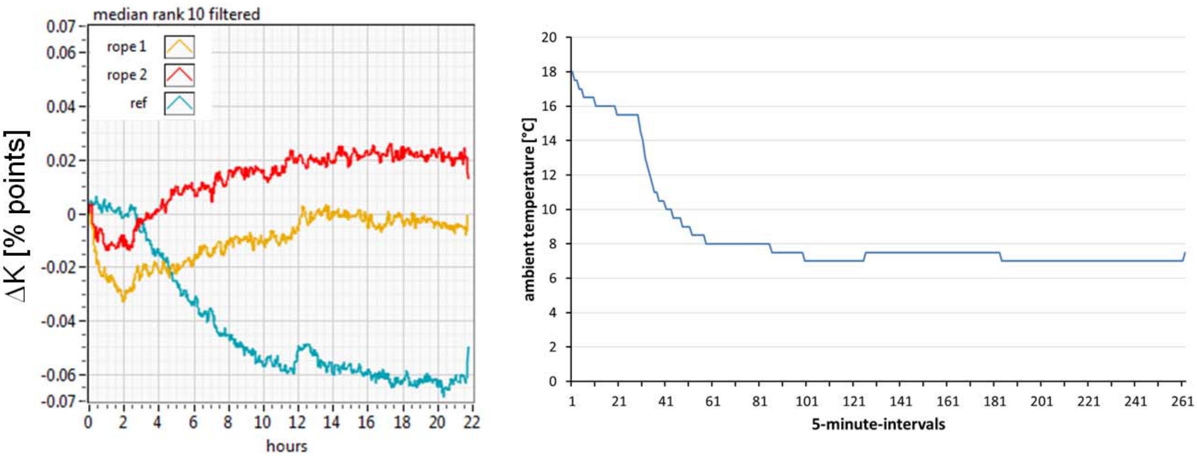


Figure 10. Change of harmonic distortion factor K (to the left, filtered by Median rank 10) and temperature (to the right) throughout the first experiment at the bridge

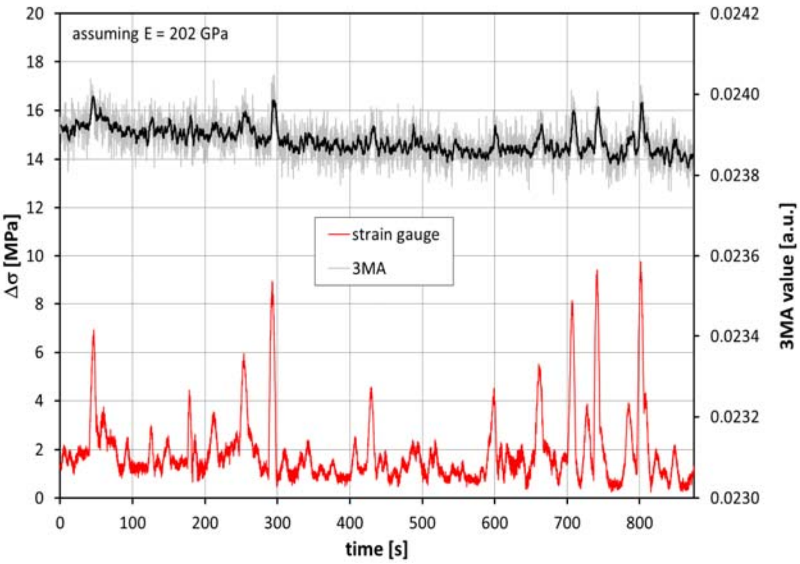


Figure 11. Strain gauge and micromagnetic signal of traffic load

With the experience from the two field tests which were carried out a long term micromagnetic monitoring of the bridge should be possible.

Right before the start of the renovation of the bridge an additional load test with a crane of 60 t weight was performed (Fig. 12). The crane stopped at three different positions resulting in different loading conditions. The reason for this load test was in the static assessment of the bridge before the start of the construction works. Furthermore, the load test was also used for a final calibration of the micromagnetic system which was installed first at only one anchorage zone for permanent monitoring. Three micromagnetic devices, similar to those from the first experiments as shown in Fig. 9, but smaller, with improved ruggedness and easier to apply, were attached to the cable using an elastic MS polymer glue. The reference cable was not used any further, since it was observed to react differently from the actual material at the bridge site. The three devices were applied to three of the eight bridge cables. The optimized system parameters according to the results shown in Fig. 11 were used. Fig. 12 shows shows the positioning of the 3 sensors at one achorage zone and the three loactions where the crane stopped for the different steps of the load test.

Fig. 13 shows the harmonic distortion factor K as one of the micromagnetic values acquired with the systems. Here, the signal of one sensors is shown revealing the different phases of the load test. When the bridge was buried for the load test at first no additional load due to traffic was on the bridge. This period represents the zero level of the signal. Then the crane moved on the bridge and stopped in the first position for about 15 minutes. This belongs to the first step-like increase of the signal. After that the crane moved on a bit towards the middle of the bridge. As expected this leads to a small increase of the signal since the increased bending in the middle of the bridge leads to a higher load at the anchorage zone. Entering the last position consisted of different steps which are all visible in the signal. At first the crane left the bridge. The signal returns to the initial level. The crane did a u-turn outside the bridge to stop again in the middle of the bridge, but now just on the lane which is closer to the anchorage zone where the sensors are situated. In the first two positions the crane stayed in the center area of the two driving lanes. As expected the signal in position 3 increases again compared to position 2 since the load was applied on the side of the sensors. Finally, the crane left the bridge and it was reopened for the traffic. This led to a small traffic jam on the bridge resulting in a small buckle in the signal between 45 and 50 minutes.

Additional AE monitoring was also performed during the load test. However, no signals were detected so far. Both monitoring systems are running now since autumn 2012 as a permanent monitoring system. The data is collected and passed to an internet drop box. The system sends screenshot by email that a status check is possible.

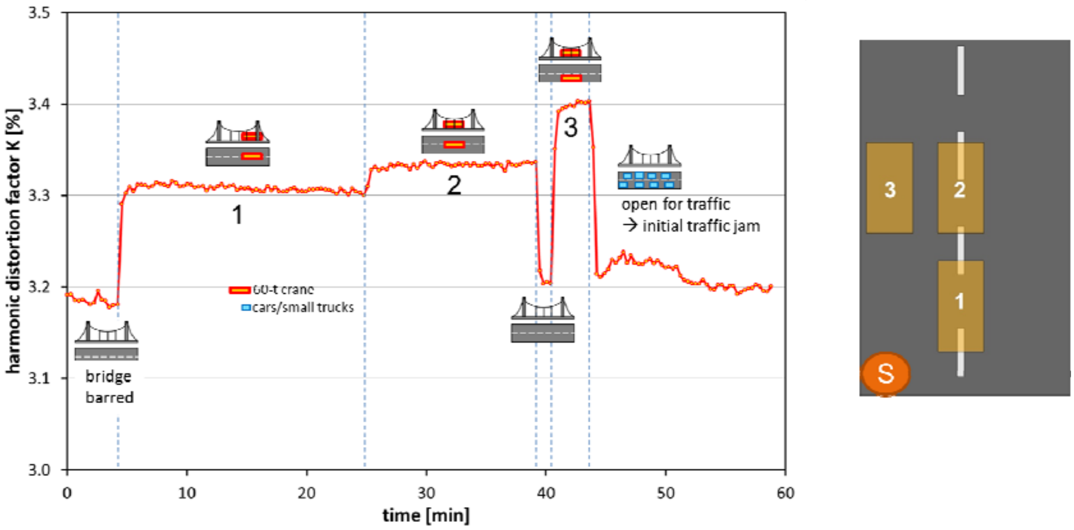


Figure 12. Result of micromagnetic stress monitoring experiment (evaluated quantity: harmonic distortion factor K) during a load test with a heavy crane. The crane positions are denoted 1,2,3, and the sensor position in relation to the crane truck is denoted “S”.

4. Conclusions

Steel wires of external tendon ducts and prestressing strands, prestressing rods, and stay cables are investigated with adapted and further developed non-destructive testing methods within the frame of the Franco-German project FilameNDT. Ropes and wires of infrastructure constructions represent load carrying elements and are often of great relevance for the safety of the construction. Inspection and monitoring of the hot-spots of these parts of a construction is often not possible or limited with conventional approaches. The developments described here show improved applications for the crucial parts of these elements.

For ultrasound inspections the geometrical boundary conditions of those structures require an optimized sensor design. Therefore, the sensor design was adapted for the given geometrical configurations based on simulation results. The EMAT technology offers the possibility to excite defined modes of ultrasound waves with a certain polarization. Furthermore, no couplant is required which is also an advantage for some applications. Sensors were built up for the inspection of 7-wired strands and fully closed spiral ropes. The results show that it is possible to detect critical defects in ropes and wires with selected guided ultrasonic wave modes over a certain distance but the basic conditions (constructive constraints, coating etc.) have a major influence on the inspection results. Therefore it is crucially important to have access to additional information on the inspected object.

Non-destructive inspection methods are one part of the maintenance concepts. In certain cases the monitoring of pre-stressed elements might be additionally required. A new approach based on micromagnetic measurements is presented. The applicability was demonstrated with measurements at a real bridge. The results show that the sensitivity of the micromagnetic approach is sufficient for detecting load changes such as trucks passing

the bridge. Signals from strain gauges were used as reference. Wire breaks would generate much higher signals and would be detectable. The tests also revealed that the influence of the temperature on the load carrying ropes can be resolved.
New concepts and adapted solutions, inspection and structural health monitoring of infrastructure constructions, were discussed. The applicability was demonstrated at realistic specimens and at a real bridge. The results are the base of a planned long term monitoring of the already investigated bridge.

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