Non-destructive stress determination of steel elements in pre-stressed constructions using micromagnetic and ultrasound methods

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Abstract
Pre-stressed construction elements have been extensively used since the 1950s for infrastructure and large span constructions. During maintenance renovation and after events causing damages it is often important to know the current stress on the pre-stressed steel elements of the structure, such as tendon ducts or cables. Access can often be provided. Then a non-destructive assessment of the current stress is possible. However, several points have to be taken into account before micromagnetic (MM) or ultrasound (UT) methods can be used for determining the current stress values. For both methods the determination of quantitative values requires a prior calibration. MM measurements were performed with the 3MA approach developed by Fraunhofer IZFP. 3MA is the acronym for Micromagnetic Multi-parameter Microstructure and stress Analysis. It has different sensitivities for microstructure and stress state, but disturbing influences related to microstructure, geometrical effects, temperature etc. also have to be taken into account. UT for stress determination are based on very accurate time-of-flight (TOF) measurements. The consideration of the influence of texture of the steel has also to be considered. The paper explains how quantitative stress values can be determined based on MM and UT TOF data recorded in the field and laboratory. Furthermore, a MM monitoring example is described.

Keywords: Steel, stress, ultrasound, micromagnetic methods, monitoring

1. Introduction
Civil Engineering structures are mainly made of reinforced or pre-stressed concrete. A further large group of constructions is made of steel. The reinforcement is carrying the tensional forces. Besides tendon ducts, wires, bridge cables and strands are also of relevance [1]. If a construction is renovated, renewed or if an assessment after damage is required the knowledge of the true actual stress in these elements is very often one of the most relevant parameters.

All methods which are or were used for stress determination in constructions require access to the parts under stress. So far no stress determination method is existing which allows in the field of civil engineering remote stress determination through different layers of a construction in the range of centimetres or even meters. However, in the case of direct access different approaches were developed for applications in civil engineering. The so called Arbalète system [2] is an in situ tension test designed especially for tendon ducts. Therefore, the construction has to be opened and a tension test is performed using a minimized adapted device for a single wire.

Non-destructive testing (NDT) methods can also be applied for determining current stress values of materials. Especially for the assessment of residual stresses X-Ray methods are used [3]. However, these approaches can only be used on laboratory scale and are not suitable for onsite applications. There ultrasound and micromagnetic methods which will be described within this paper are more employable. These approaches can be directly applied to constructions if access to the load carrying parts is given. It has also to be stated that NDT methods generally require calibration procedures if quantitative values are requested.

Besides non-destructive inspection measurements a continuous monitoring of changing stresses is also of relevance for some constructions. Acoustic emission analysis shows stress relief and stress redistributions due to fracture processes [4] [5]. This can be also used for monitoring. Monitoring stress changes in anchorage zones of bridges with an electromagnetic
approach described in [6] in another monitoring approach. Fibre bragg gratings are also used for monitoring of strain [7]. This information is then used to calculate stress values.

2. Methods and Applications

Stress changes which occur under presence of varying loads are often requested to be detected or even monitored as a function of time. Investigations concentrated on the applications of micromagnetic methods for monitoring purposes and ultrasonic methods for the stress assessment of pre-stressed elements.

2.1 Stress detection and monitoring with micromagnetic methods

The behaviour of ferromagnetic materials when exposed to a magnetic field is known to react on mechanical stress. A common challenge of indirect stress determination with micromagnetics is the calibration required for a quantitative stress measurement. This process can be additionally complicated due to a sometimes observed non-biunique behaviour of the magnetic parameters as a function of stress [8].

The micromagnetic detection and monitoring of stress changes in pre-stressed constructions is based on the assumption that any loss e.g. of wire cross-section, due to cracked fibres, should lead to a redistribution of the tensile load over different measuring locations on a wire rope or 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. An on-site test of the micromagnetic monitoring approach was performed at the bridge over the Saar river in Mettlach, Germany [1].

Fig. 1 shows the harmonic distortion factor $K$ of the magnetic tangential field strength as a function of applied tensile stress during calibration on a single strand (diagram to the left) and during long-term measurement in Mettlach (to the right), also showing that ambient temperature affects the load in the wire significantly (thermo-cyclic effects).

2.2 Stress detection with ultrasonic methods

The elastic behaviour of materials can be described by Hook’s Law. Directly influenced by the elastic behaviour is also the propagation of ultrasonic waves and thereby the velocity of ultrasonic waves as well. This allows the measurement of the time of flight of ultrasonic waves as a function of applied stresses. The influence of stresses in the elastic region on the
time of flight is a second order effect. The relative change of the velocity lies in a per mill range [9]. A similar behaviour as shown in Fig. 1 (left) can also be observed for ultrasound time of flight measurements. The time of flight increases with increasing tensional stresses. The determination of quantitative stress values requires also a calibration approach. Since the stress dependent change of the ultrasound velocity is a relatively small effect environmental and material conditions have to be carefully considered. Furthermore, accurate and stable travel time measurements of high resolution are required. The potential of the ultrasonic based stress determination for different industrial areas is shown e.g. in [10, 11].

3. Conclusion

Pre-stressed structures are state of the art for civil engineering structures. Many constructions are of advanced age. Lifetime extension including significant renovations is often of relevance for their further use since e.g. traffic loads increased in the last decades. Therefore, the determination of current stress values with micromagnetic and ultrasonic methods can be a useful tool for the maintenance and lifecycle management of structures.

Both methods addressed here are sensitive to stress and stress changes. The micromagnetic approach inspects a small volume very close to the surface at the measurement point. Using the ultrasound approach the integral travel time information of the volume scanned by the ultrasound is analysed. If quantitative values are required a calibration is needed. Furthermore, micromagnetic methods can also be used for long term monitoring of stress changes. First results are shown in Fig. 1 which are also strongly affected stress changes due to varying temperatures.

References

