Assessment of a steel bridge using magnetic methods

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Ageing Bridges and Related Issues

• Railway steel bridges in Europe are > 80 years old in average; oldest German bridge 175 years
• Operational conditions changed
• Environmental conditions changed
• Standards changed
• No adequate material data available
• Damage degree only observed visually with respect to corrosion
• Enhanced inspection effort required

Photos: www.dieolsenban.de
         www.fotocommunity.de
Key Elements in Structural Design

- **Load (assumed)**
  - Static Load: Ultimate Load
  - Fatigue Load:
    - Constant Amplitude Load
    - Random Load (Service Load)
- **Geometry (given)**
  - Notches
  - Stress States/Multiaxial Loading
- **Material (to be selected)**
  - Strength
  - Ductility

![Diagram diagram showing the flow of load, applied stress, and allowable stress with a decision point: Allowable Stress > Applied Stress ?]
MicroMach Monitoring Device

Electronics
Solenoid
Sensor
USB
Power
Yoke
Specimen

Solenoid
Alternating current
Sensor (i.e. Hall element or GMR)
Amplifier & Filter
Signal Processing
Magnetic field

Figures left & bottom: Fraunhofer IZFP
Electromagnetic Techniques and their Potential for Data Fusion (3MA Approach)

- Barkhausen Noise
- Incremental Permeability
- Distortion of Tangential Magnetic Field Strength
- Eddy Current Impedance

Magnetic Hysteresis Curve
Magnetisation in Ferromagnetic Materials

- **Ferromagnetic material**
- **Magnetic domains**
- **Bloch walls**
- **External magnetic field, $H$**
- **Bloch wall motion**
- **Rotation**
- **Saturation**
- **Irreversible motion**
- **Reversible motion**
- **Pinning point**

**Ferromagnetic material**

- **Blochwalls**
- **Pinning point**

**External magnetic field, $H$**

- **Bloch wall motion**
- **Rotation**

**Magnetisation in Ferromagnetic Materials**
Steel Railway Bridge to be Inspected
Stress Distributions along Lower Girder Beam

simulated

measured
Figure 5: Trolley positions during measurements. On the left: coordinate system.

Figure 6: Screenshot from measurement... with the system time being displayed is recorded continuously in order to synchronize the video with the measurement.

Measured and Simulated Stress Data for Different Loading Conditions
Monitoring of Train Crossing over Bridge
Fatigue Life Calculation Method “PHYBAL”

\[
\sigma_a = K' \cdot (\varepsilon_{a,p})^{n'}
\]

\[
\sigma_a = K'_M \cdot (M)^{n'_M}
\]

\[
b_M = \frac{-n'_M}{5n'_M + 1}
\]

\[
\sigma_a = \sigma'_{f,M} \cdot (2N_f)^{b_M}
\]

\[
N_f = 0.5 \cdot \left( \frac{\sigma_a}{\sigma'_{f,M}} \right)^{\frac{1}{b_M}}
\]
Cyclic Deformation Behavior

changes in micro- and macrostructure

SAE 4140
$\sigma_a = 620$ MPa

e.g. dislocation reaction

formation and propagation of microcracks

propagation of macrocracks

plastic strain amplitude in $10^{-3}$

number of cycles

impedance of giant magneto resistor

NDT measurand

conventional measurand
Conclusions

- Life cycle management of ageing steel infrastructure can be made more efficient with NDT and associated structural technologies.

- The NDT and associated technologies are:
  - Magnetics or other technologies to measure actual stress, strain and loading conditions.
  - Damage tolerance ‘redesign‘.
  - Material residual fatigue life assessment with PhyBaL.
  - Magnetics for the assessment of the damage and stress condition in the pre-cracked phase.
  - Prognostics for the assessment of residual fatigue life.
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