Utilization of Non-Destructive Methods for Monitoring Fatigue Crack Growth in Power Plant Material

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Introduction

- degradation of mechanical properties of a reactor pressure vessel (RPV) material is associated with microstructural changes induced by embrittlement and fatigue damage.
- In the conditions of cyclic temperature changes (start-ups and shut-downs) this may lead to material crack initiation (welded joints or pipeline installations).
- Assessment of the structural components’ lifetime requires the knowledge of fatigue properties of the power plant’s materials.

[ZHANG, 2012]

[BRUMOVSKY, 2010]
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Introduction

- operational effects acting on RPV:
  - fatigue damage
  - corrosion phenomena (environmentally assisted cracking – IASCC or PWSCC)
  - neutron radiation
  - material embrittlement

- early warning to possible fatigue failure and the prediction of the remaining lifetime is a task of practical relevance

methods of non-destructive testing (NDT)
Introduction

The most appropriate NDT method for studying material deformation under fatigue loading is the *acoustic emission (AE) technology*

- It's a useful tool for *detection of leakage* and after noise filtering also for *detection of crack initiation* and its growth under operation.
- AE analysis is *very sensitive* to *local transient instabilities*.

\[ d = \frac{1}{2} (D - \Delta T \cdot V) \]

- \( d \) = distance from first hit sensor
- \( D \) = distance between sensors
- \( V \) = wave velocity

Objectives and motivation

- to propose a methodology to predict a fatigue crack growth behaviour and to simulate the material behaviour during pressure test using non-destructive techniques
- to obtain a classification of the different stages of the crack propagation and by an AE advanced analysis to obtain AE identification of the different crack propagation mechanisms

using AE and electrical potential difference methods
Materials and mechanical testing

- **a nuclear Cr–Ni–Mo–V ferritic steel** (GOST 15Ch2NMFA)

<table>
<thead>
<tr>
<th>Material</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>15Ch2NMFA</td>
<td>0,15</td>
<td>0,50</td>
<td>0,23</td>
<td>max 0,02</td>
<td>max 0,02</td>
<td>2,1</td>
<td>1,1</td>
<td>0,60</td>
</tr>
</tbody>
</table>

- **heat treatment: two-stage quenching + tempering**
Materials and mechanical testing

- *fatigue tests* – MTS Systems Corporation servo-hydraulic machine under *room temperature*
- *frequency* = 10 (0.1) Hz, stress ratio R = 0.1, load range = 6-60 (5-50) kN
Acoustic emission measurements

- advanced modular XEDO system and IPL system with continuous AE signal recording capabilities (supplied by the DAKEL Company)
- two piezoelectric sensors (MDK13, magnetic disc, diameter 12 mm, DAKEL)
- AE data were collected and analysed using the DAKEL Daemon and DaeShow (XEDO) and DAKEL-UI (IPL) software
Crack propagation rate measurements

- **potential drop (PD) technique** is based on injection of currents into the examined object and measurement of the resulting voltage difference between two points on its surface.
- PD technique has been used for monitoring fatigue crack growth rate using the TECHLAB SRT-KK.2 device.

![schematic illustration of the PD testing](image1)

![experimental setup of the PD measurement](image2)
Acoustic emission response during fatigue loading

- AE measurement was carried out on several specimens under the same conditions.
- At the beginning, the crack formation and plastic deformation sources at the tip of the notch generate intense AE events, which contributed to rapid growth of AE counts.
- The fatigue crack propagation is characterized by highly fluctuating AE activity throughout the test.

*The first phase of the measurement (crack length = 11.7 mm)*
Acoustic emission response during fatigue loading

- **in the crack initiation stage**, the AE hits are generated in the entire range
- **in the second stage**, the clusters are created at maximum load and also at lower load levels

  the emissions in stage II are mainly generated by dislocation activities in the plastic zone

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The first phase of the measurement (crack length = 11.7 mm)
Acoustic emission response during fatigue loading

- to investigate correlation between the crack propagation and AE hits
  - *falling and rising phase* of the loading force
- most of the AE signals are generated in the *falling phase* of the loading force with amplitude of about 69 and 71 dB$_{AE}$ and duration of about 600 $\mu$s

*the first phase of the measurement (crack length = 11.7 mm)*
Acoustic emission response during fatigue loading

- in the last two phases of the measurement, compared to the previous phase, **the rise time starts to exhibit increasing tendency**
- **increasing rise time** parameter and changes in the frequency of occurrence as another parameter in time indicates possible **shift of the cracking mode from tensile to shear** or **changes in crack propagation rates** from slow to fast (or stable to unstable)

![Graph showing rise time vs. time](image1.png)
- the second phase

![Graph showing rise time vs. time](image2.png)
- the third phase of the measurement (crack length = 14.1 mm)
Acoustic emission response during fatigue loading

- Changes may be caused: shift of the cracking mode or changes in crack propagation rates
  - Changes in the fracture mode

The second phase

The third phase of the measurement (crack length = 14.1 mm)
Acoustic emission response during pressure test simulations

- **aim**: to simulate the *AE response to static pressure loading* which is applied during the *pressure tests of nuclear power plant components*
- experiments were carried out on the same CT specimens *at the beginning and end of the second phase*
- in case of *long cracks* the *AE hits increase* during the pressure holds
- in case of *short cracks* the *occurrence of AE hits is low*

![Cumulative Hits](image1.png)

- **long crack**
- **cumulative AE hits**

![Counts](image2.png)

- **count rate**
Acoustic emission response during pressure test simulations

increasing force at maximum

holding force

decreasing force
Acoustic emission response during pressure test simulations
Conclusions

This study shows the effectiveness of the non-destructive testing method by acoustic emission to detect different stages of fatigue crack propagation.

Results indicate that:

- Relationship between the count rate and crack propagation rate is nonlinear.
- Most of the AE signals are generated in the falling phase of the loading force.
- AE hits have a shorter duration and rise time in the rising phase of the loading force in the first phase.
- In the second and third phase, the rise time starts to exhibit increasing tendency.
- Changes in the fracture mode or in the crack propagation rates from slow to fast (or stable to unstable).
- Count rate, amplitude, rise time, duration and average frequency are the important parameters for AE identification of different crack propagation mechanisms.
Conclusions

- **pressure test simulations** gave us an understanding of the mechanical behaviour in terms of damage and crack propagation and the joint use of fractography.
- AE confirms identification of acoustic signatures of various phenomena of damage.
- Results provide a database allowing **identification of fatigue damage** and show AE technique may be very useful to fatigue crack growth assessment in pressure vessel materials.

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Thank you for your attention

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