Experimental durability evaluation of coil springs - Influence of the test frequency under corrosion

S. Hoffmann, S. Rödling, M. Hück, M. Decker

9th International Congress of Spring Industry
Taormina (Sicily - Italy)
September 28th - October 1st 2017
Content

- Motivation
- Test procedure
- Test evaluation
  - Dry fatigue test - basic series
  - Dry fatigue test and corrosion fatigue tests
  - Dry fatigue test, corrosion fatigue tests and corrosion fatigue tests after pre-damage
  - Influence of the test frequency
  - Influence of Corrosion after pre-damage
- Summery and outlook
Motivation

Due to various designs of spring testing machine used all over the world, the testing frequency varies considerably e.g. from 1,0 Hz to 8,0 Hz.

The test duration caused by the different machines leads to different duration of corrosion impact during the corrosion fatigue test.

Question is: What is the effect on fatigue life?

Based on a lot of tests IABG has proposed a frequency correction of:

\[
\frac{N_1}{N_2} = \left(\frac{f_1}{f_2}\right)^3 \quad \text{(Hück, 1995)}
\]

Thesis 1 – Is this is still valid?

Thesis 2 - Has corrosion during fatigue tests a impact at all?
Motivation

Load cycles $N$ vs. amplitude $\sigma_A$ / MPa

- 42CrMo4, $R_m = 1050$ MPa
- $R = -1$
- $f = 21000$ Hz
- $f = 10$ - 60 Hz

$\alpha_K = 1.0$

- $\sigma_{AD} = 505$ MPa
- $\sigma_{AD} = 103$ MPa

$\alpha_K \to \infty$ (Riss)

$k = 3.6$

$k = 11.6$

$3 \times 10^5$

$1.7 \times 10^6$

$1 \times 10^2$ to $1 \times 10^9$
Motivation

Load cycles $N$

amplitude $\pm \sigma_{v,a}$

- $k = 7.8$
- $k = 2.3$
- $k = 3.4$

Federn tauchlackiert

d = 10.0 mm
$D_m = 99.5$ mm
Mittelspannung $\sigma_{v,m} = 613$ N/mm²

- Normale Laboratmosphäre, $f = 20$ Hz
- Kontinuierlicher Salzsprühnebel, $f = 20$ Hz
- Intermittierender Salzsprühnebel, $f \approx 0.6$ Hz
  (5 min Salzsprühnebel, 30 min Luft)

ca. 500 h (0.6 Hz)
Test Procedure – Test Equipment

**CSTM**
Corrosion Spring Testing Machine (high frequency)

**VTRC**
Variable Test Rig for resilient Components (low frequency)

**GISM**
Grit Impact Simulation Machine

Corrosion Chamber
Test Procedure

- **Spring design**
  - Simple design with a wide range of stress variations
  - Use of original spring pads in order to avoid any influence of the load input

- **Test procedure**

  - **Pre-damage**
    - Pre-damage grit impact
    - 4 weeks – alternating climate test unloaded
    - Corrosion fatigue test, const. mean load, different frequ.

  - **Dry fatigue test, const. mean load**

  - **Corrosion fatigue test, const. mean load, different frequ.**

  - **Dry fatigue test, const. mean load**

- Dimensions:
  - $d = 14.25 \text{ mm}$
  - $D_m = 85.0 \text{ mm}$
  - $L_0 = 350 \text{ mm}$
Test Procedure – Test-setup

1,5 Hz
Electro hydraulic

4,1 Hz
Resonance testing machine

7,4 Hz

Grit Impact
- Gravel 5-6 mm
- 70 km/h
- Rotating spring
- Spring body
Content

- Motivation
- Test procedure
  - Test evaluation
    - Dry fatigue test - basic series
    - Dry fatigue test and corrosion fatigue tests
    - Dry fatigue test, corrosion fatigue tests and corrosion fatigue tests after pre-damage
    - Influence of the test frequency
    - Influence of Corrosion after pre-damage
- Summery and outlook
Life without corrosive environment - Basic Series

\[ T_N = 1,63 \]

\[ T_H = 1,12 \]

\[ k = 4,3 \]

\[ L_m = 240,0 \text{ mm} \]
Influence of corrosion of undamaged springs

- Dry cycling: $k = 4.3$
- Corrosion cycling: $k = 2.3$

Load cycles $N$ vs. Stroke $H$ / mm

$L_m = 240.0$ mm
Influence of corrosion of undamaged springs

\[ L_m = 240,0 \text{ mm} \]

- \( k = 2,3 \) corrosion cycling 4,1 Hz
- \( k = 4,3 \) dry cycling

Fatigue test - Basic Series and Corrosion fatigue test

Load cycles \( N \)

Stroke \( H / \text{mm} \)
Life under corrosion at 3 different test frequencies

\[
P_{Fi} = \frac{103 \cdot i - 37}{103 \cdot n + 29}
\]

- \(L_m = 240,0\ mm\)
- \(H = 100,0\ mm\)

- \(f = 1,5\ Hz, N_{PF50\%} = 465,667\)
- \(f = 4,1\ Hz, N_{PF50\%} = 569,248\)
- \(f = 7,4\ Hz, N_{PF50\%} = 560,072\)

- \(L_m = 240,0\ mm\)
- \(H = 65,0\ mm\)

- \(f = 7,4\ Hz, N_{PF50\%} = 2,6 \times 10^6\)
- \(f = 4,1\ Hz, N_{PF50\%} = 1,5 \times 10^6\)
Basic Series + Corrosion fatigue + Corrosion fatigue after pre-damage

- $k = 2.62$ after pre-damage corrosion cycling
- $k = 4.3$ dry cycling
- $k = 2.3$ corrosion cycling

$L_m = 240.0$ mm
Basic Series + Corrosion fatigue + Corrosion fatigue after pre-damage

$k = 2.62$

after pre-damage corrosion cycling

$k = 4.3$
dry cycling

$k = 2.3$
corrosion cycling

$4.1$ Hz

$L_m = 240.0$ mm
Life under corrosion after pre-damage at 3 different test frequencies

\[ P_{Fi} = \frac{(103 \cdot i - 37)}{(103 \cdot n + 29)} \]

\[ L_{m} = 240,0 \text{ mm} \]
\[ H = 100,0 \text{ mm} \]

- \[ f = 1.5 \text{ Hz}, N_{PF50\%} = 10.858 \]
- \[ f = 4.1 \text{ Hz}, N_{PF50\%} = 15.412 \]
- \[ f = 7.4 \text{ Hz}, N_{PF50\%} = 19.379 \]

Normal distribution

Probability of failure \( P_{F} \)/% vs. load cycles \( N \)
Influence of the test frequency

- Significant influence of frequency from 1.5 to 7.4 Hz
- No significant influence of frequency from 1.5 to 7.4 Hz
- Small influence of frequency from 4.3 to 7.4 Hz

$k = 2.62$
corrosion cycling after pre-damage
$k = 4.3$
dry cycling
$k = 2.3$
corrosion cycling

$L_m = 240.0 \text{ mm}$
Test Evaluation – Corrosion fatigue after pre-damage at 3 different speed with frequency correction

Application of frequency correction proposed

\[ \frac{N_1}{N_2} = \left( \frac{f_1}{f_2} \right)^{\frac{1}{3}} \]

\[ P_{Fi} = \frac{(10^3 \cdot i - 37)}{(10^3 \cdot n + 29)} \]

Influence of test frequency

Corrosion fatigue test after pre-damage

Result after frequency correction

Normal distribution

\[ L_m = 240,0 \text{ mm} \]
\[ H = 100,0 \text{ mm} \]
Basic Series + Corrosion fatigue + Fatigue test after pre-damage

S/N-Curve

Fatigue test - Basic Series

and Corrosion fatigue test

Load cycles N

Stroke H / mm

$k = 4.3$

Dry cycling

$k = 2.62$

corrosion cycling after pre-damage

4.1 Hz

$k = 2.3$

corrosion cycling

4.1 Hz

factor 20

corrosion cycling after pre-damage

Dry cycling after pre-damage

$L_m = 240.0 \text{ mm}$
Basic Series + Corrosion fatigue + Corrosion fatigue after pre-damage

Load cyles N vs Stroke H / mm

- **Dry cycling**: $k = 4.3$
- **Corrosion cycling after pre-damage**: $k = 2.62$
  - Corrosion cycling at 4.1 Hz
- **Corrosion cycling**: $k = 2.3$
- **Corrosion cycling after pre-damage**: $k = 2.3$

$L_m = 240.0 \text{ mm}$
Basic Series + Corrosion fatigue + Corrosion fatigue after pre-damage

Load cyles N

Stroke H / mm

$k = 4,3$
Dry cycling

$k = 2,3$
corrosion cycling 4,1 Hz

$L_m = 240,0 \text{ mm}$

corrosion cycling after pre-damage

dry cycling after pre-damage

same mechanism?
Fracture reason after pre-damage

Fracture pattern after pre-damage and **corrosion** during fatigue test
Fracture reason after pre-damage

Fracture pattern after pre-damage and fatigue test
Fracture reason after pre-damage

Fracture pattern after pre-damage and *corrosion* during fatigue test

Fracture pattern after pre-damage and fatigue test

Corrosion fatigue in both cases

- Subsidiary cracks in z-direction, cross pattern
- Cracks are widely open and rough crack flanks
- Mechanical and corrosive effect evolve to a corrosion fatigue
Basic Series + Corrosion fatigue + Corrosion fatigue after pre-damage

Load cyles N

Stroke H / mm

$k = 4,3$

Dry cycling

$k = 2,3$

corrosion cycling

$4,1 \text{ Hz}$

$L_m = 240,0 \text{ mm}$

Corrosion fatigue

Corrosion cycling after pre-damage

dry cycling after pre-damage

corrosion cycling after pre-damage

dry cycling after pre-damage

Dimensioning Situation

Load spectrum 300,000 km

\[ L_m = 240.0 \text{ mm}, \quad L_0 = 350 \text{ mm} \]

Tests in lab. air
\[ k = 4.3 \]

Tests under corrosion
no pre-damage
\[ k = 2.76 \]

Stroke H / mm

cycles N

Limitation in the car

most damaging stroke

27.0 mm

k = 4.3

wet after pre-damage

wet no paint

covered by tests

300,000 km

TAF4-PPT-038-17 © IABG 2017 | 26
Summary

- The influence of the test frequency is not significant at standard corrosion fatigue test.
- The influence of the test frequency is just visible at the corrosion fatigue test after pre-damage and the proposed frequency correction factor is a good approximation:

\[
\frac{N_1}{N_2} = \left(\frac{f_1}{f_2}\right)^{\frac{1}{3}}
\]

- Corrosion during fatigue test has an influence on the fatigue life.
- The influence of corrosion increases at lower test levels.
- At the test after pre-damage with and without corrosion the springs fail caused by corrosion fatigue.

Outlook

- The influence of the surface protection chosen?
- What is the fatigue life of springs after pre-damage with and without corrosion?
- What are the main influencing factors to the frequency influence?
Your Contact

IABG mbH
Tests und Analyses
Service Strength, Component Testing, Test Rigs (TAF4)

Sebastian Hoffmann | Thomas Bartnik | Claus Friese
Einsteinstrasse 20 |  |  
85521 Ottobrunn |  |  
Germany |  |  
Phone | +49 89 6088-3321 | +49 89 6088-3118 | +49 89 6088-2326 
Fax | +49 89 6088-3591 | +49 89 6088-3591 | +49 89 6088-3591 
Mobile | +49 170 6356745 | +49 151 15767488 | +49 170 2205572 
  | hoffmanns@iabg.de | bartnik@iabg.de | friese@iabg.de 
  | www.iabg.de |  |  