Accelerated Life Test of Mechanical Components Under Corrosive Condition

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Outline

❖ Objective
❖ Modeling
  – Model assumptions
  – Formulas and model parameters identification
❖ Experimental Investigation
  – Experimental Setup
  – Optimal Test Condition (Experimental Parameters)
  – Experimental Data
❖ ALT Package
  – Results of Modeling and Prediction
❖ Outcomes
Objective

❖ Develop a scientific, systematic, and reliable methodology to evaluate the life probability of mechanical components based on accelerated testing theory.

❖ Offer the attractive benefit of requiring relatively less investment in both time and resources for accelerated life testing of the mechanical component.
Model Assumptions

- Weibull distribution of Time-to-failure is applied.

- Life of bearing under salt water condition is an inverse power function of a non-thermal accelerating stress.

- The failure modes at accelerated stress are as same as those observed under use stress conditions.

- Each sample tested at a specified stress level is homogenous.

- Only the stress of acceleration is applied, all other stresses remain unchanged.
The Inverse Power Law Model

**Characteristic life:**
\[ \eta(V) = \frac{1}{K V^n} \]

**Reliability Function:**
\[ R(T;V) = e^{-\left[ \frac{T}{\eta(V)} \right]^\beta} \]

**Life Distribution:**
\[ f(T;V) = \frac{\beta}{\eta(V)} \left[ \frac{T}{\eta(V)} \right]^{\beta-1} e^{-\left[ \frac{T}{\eta(V)} \right]^\beta} \]

**Accelerated Factor (AF):**
\[ AF = \frac{\eta_U}{\eta_A} = \frac{T_{U-Q*100\%}}{T_{A-Q*100\%}} = \left[ \frac{V_A}{V_U} \right]^n \]

Where, \( \beta, K, n \) - shape parameters
\( T \) - failure lifetime
\( V \) - stress
Model Parameter Identification

- Arrange the failure lifetime $T_{ij}$ from low to high (i) for each stress step (j)
- Calculate the failure probability $Q_{ij}$ for all replications and all stress steps
- Calculate the shape parameter $\beta_j$ for all stress steps by using Least Square Regressive Analysis
- Calculate the total average shape parameter $\beta$
- Calculate the Characteristic Life $\eta_j$ for each stress step
- Estimate the shape parameters $K, n$ by using Least Square Regressive Analysis
- Obtain the accelerating factor, reliability function, failure rate, life distribution, characteristic life of bearing corrosion failure under salt-water environment
- Model Verification and Calculation of Estimation and Prediction Error
Experimental System

Monitoring Diagnostic Prognostic System

Environmental Stress Generating, Measurement and Control System

ACC & AE sensors

Radial Loading System

Tooling

DC Control Motor

O-ring

Shaft Connector

Tested Bearing: Timken LM501310 Cup, Timken LM501349 Cone

Thrust Load & Seal

Bearing Housing

Sensors of Environmental Parameter
Photo 1 - Overall Setup

- hydraulic loading mechanism
- tapered roller bearing tooling
- drive system
- ball and plain roller bearing tooling
- Test Housing
Photo 2 - Testing Housing
Photo 3 - Testing Components

Tested Bearing
Experimental Parameters of ALT

- **Main Stress Parameter** is the *Salt Content* in water.

- **Controlled Stress Steps**
  - Five stress steps for testing and modeling analysis
    - 1% salt water
    - 8% salt water
    - 16% salt water
    - 26% salt water
    - 36.1% salt water
  - Two stress steps for model verification
    - 12% salt water
    - 21% salt water

* (100*Salt Weight / Water Weight)

- **Replication Number for each stress step** is 2.
Parameters of the Operating Condition

1. Rotational Speed:  600 rpm

2. Relative Humidity: The bearings were immersed in the salt water completely

3. Radial Load: 0 lb_f

4. Thrust load:  288 lb_f

5. Temperature: Controlled with a variation range of 10°C

6. Lubrication: No (Except the salt water)
### Experimental ALT Data

<table>
<thead>
<tr>
<th>SAMPLES</th>
<th>MODEL IDENTIFICATION SAMPLES</th>
<th>MODEL VERIFICATION SAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress Levels (Salt/Water %)</td>
<td>36.1 26 16 8 1 12 21</td>
<td>12 21</td>
</tr>
<tr>
<td>Failure Time 1 (Hour)</td>
<td>27.88 35.55 42.07 47.89 55.12</td>
<td>44.5 35.67</td>
</tr>
<tr>
<td>Failure Time 2 (Hour)</td>
<td>66.5 67.2 73.3 94.7 100.9 75.2 69.4</td>
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</tr>
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ALT Package

GT ALT Data

User’s Data

Welcome to Accelerated Life Testing Analysis

Modeling

Prediction
Figure 1. Relationship between Failure Time and Percent Failure
Figure 2. Percent Failure versus Failure Time Based On $\eta(V)$ Obtained from the Estimated Inverse Power Law
Failure Time Versus Stress Level Under Certain Failure Rate
Model Verification

Failure Time (Hour) vs. Percent Failure %

- 21%
- 12%

Log-log scale with 10^1 and 10^2 increments.
## Prediction Errors

<table>
<thead>
<tr>
<th>Sample</th>
<th>ALT Data for Model Verification</th>
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<tbody>
<tr>
<td></td>
<td>Tested</td>
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<tr>
<td>Stress Level (Salt / Water %)</td>
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<td>Predicted</td>
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<tr>
<td>Errors</td>
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Outcomes

- Develop a systematic and scientific methodology to assess the life probability of mechanical component.
- Optimize the accelerated life testing to achieve the maximum time/cost saving and the highest life prediction accuracy.
- Extend the methodology to any mechanical components with the same failure mode in nominal and in accelerated testing conditions.
- Pilot the case study of rolling element bearing testing to illustrate the fundamental basis and the implementation principles.