Mechanical Component Failure Rates - Static vs. Dynamic Operation

Web Seminar March 11, 2015
Loren L. Stewart
exida
Sellersville, PA USA
Mechanical Component Failure Rates - Static vs. Dynamic Operation

Audio is provided via internet. Please enable your speaker (in all places) and mute your microphone.

There is a Q&A tab at the side of your screen. Please use this mechanism to type any questions you may have at any time. Questions will be read and answered.

A recording of this session and a copy of the slides will be posted on the exida website and made available for you.
Mechanical Component Failure Rates - Static vs. Dynamic Operation

Web Seminar March 11, 2015
Loren L. Stewart
exida
Sellersville, PA USA

Audio is provided via internet. Please enable your speaker (in all places) and mute your microphone.
Loren Stewart graduated from Virginia Tech with a BSME.

She has over 5 years of professional experience originating in custom design and manufacturing where she managed and was responsible in supporting key clients. She currently works for exida Consulting as a safety engineer, focusing on the mechanical aspects of their customers. Along with assessing the safety of products and certifications, she continually researches and published reports on stiction and is creating a database for the 2H initiative according to IEC 61508.
Who We Are

Founded in 1999 with offices around the world, exida is a system consulting, product test and assessment agency rich with functional safety & security expertise and experience.
exida Industry Focus

Automation
Process Industry

Automotive
Nuclear

OEM
- Management support
- Development support
- Certification
- Tools

System Designer
- FSM setup
- SIL verification
- Tools

Engineering Contractor
- Tools
- Competence development
- CFSE

End User
- SIL + device selection
- SIL verification
- Tools
- Security Audits
Main Product / Service Categories

**Consulting**
- Process Safety (IEC 61511, IEC 62061, ISO 26262)
- Alarm Management
- Control System Security (ISA S99)

**Product Certification**
- Functional Safety (IEC 61508)
- Control System Security
- Cyber-Security
- Network Robustness (Achilles)

**Training**
- Process Safety
- Control System Security
- Onsite
- Offsite
- Web
- Security Development

**Engineering Tools**
- exSIentia (PHA Import, SIL Selection, LOPA, SRS, SIL Verification)
- Safety Case
- FMEDA
- SCA

**Reference Materials**
- Databases
- Tutorials
- Textbooks
- Reference Books
- Market Studies

**Professional Certification**
- CFSE
- CFSP
Products

PHAx
Process Hazards Analysis, Hazard & Operability Studies

exSILentia
SIL Verification, SIL Selection, SRS, Proof Test Generator

SERH Viewer
Safety Equipment Reliability Database

SILAlarm
Alarm Rationalization, Master Alarm Database

SILStat
Collection & Analysis of Oper & Maint Safety Data
Reference Materials

- *exida* authored most industry references for automation safety and reliability.
- *exida* authored industry data handbook on equipment failure data.
- *exida* authored the most comprehensive book on functional safety in the market.
Mechanical Component Failure Rates - Static vs. Dynamic Operation
Key Point

The failure rates of certain mechanical components used in solenoid valves, actuators, and valves vary substantially depending on operation. For example, seals such as O-rings have fundamentally different failure modes when used in applications with frequent movement (dynamic) versus applications with infrequent movement (static).
Key Point

exida has accumulated over one hundred billion unit operating hours of field failure data primarily from the process industries which was used in recent mechanical failure research. This webinar explains some results from this recent exida research where failure rates and failure modes of several mechanical components were established.
IEC/EN 61508 – E/E/PE

IEC 61508 states it was written for E/E/PE based systems.

E – electrical

E – electronic

PE – programmable electronic

Therefore not applicable for mechanical products??
Just Google It

Edition 2.0
A) Scope

A1) Is IEC 61508 relevant to me?
A2) What systems does IEC 61508 cover?
A3) Give me some practical examples
A4) How does IEC 61508 apply where E/E/PE technology makes up only a small part of the safety-related system?
Safety Critical Mechanical Devices Must be Included

A4) How does IEC 61058 apply where E/E/PE technology makes up only a small part of the safety-related system?

IEC 61508 is applicable to any safety-related system that contains an E/E/PE device.

This applicability is appropriate because many requirements, particularly in IEC 61508-1, are not technology specific. Indeed, early development phases (such as initial concept, overall scope definition, hazard and risk analysis and specifying the overall safety requirements) may take place before the implementation technology has been decided.

Even during later phases such as realisation, specific functional safety requirements apply directly to non-E/E/PE devices, such as mechanical components, as well as E/E/PE devices. For example, the requirements for hardware reliability and fault tolerance in IEC 61508-2 directly relate to the properties of all components in the E/E/PE safety-related system, whether or not they include E/E/PE technology.

For low complexity E/E/PE safety-related systems, it is possible to comply with IEC 61508 while not meeting every requirement of the standard.
Static vs. Dynamic Applications

- **Static Application** – “stationary or fixed”
  - Low demand mode operations
- **Dynamic Application** – “energetic, capable of action and/or change, or forceful”
  - High or Continuous mode operations
Mechanical Failure Data Sources

• FMEDA
  – PLUS: Can provide detailed / complete information
  – Predictive – does not require a multi-year lag time to gather statistics
  – MINUS: Depends on component failure mode/failure rate data

• End User Field Failure Studies
  – PLUS: Real Data
  – MINUS: Variations of amount of data collected
  – Different definitions of “FAILURE”
  – Categorizing and Merging Technologies

• Manufacturer Field Return Data Studies
  – PLUS: Real Data
  – MINUS: Calculation methods vary widely
  – Cannot know what percentage of actual failures are returned
  – Different definitions of “FAILURE”

• Cycle Test Data
  – Based on cycle testing for mechanical / electro-mechanical products
  – Assumes application has constant dynamic operation
Failure Modes, Effects, & Diagnostics Analysis (FMEDA)

- Gathering enough failure statistics at the product level has not happened – failure causes, failure modes, etc. are mixed together in failure reports.
- Therefore - Break problem to smaller pieces
- Perform a detailed study of each component and how the component failure will affect the instrument
Using a component database, failure rates and failure modes for a product (transmitter, I/O module, solenoid, actuator, valve) can be determined far more accurately than with only manufacturer’s field failure data.
FMEDA = Validated Results

Field Return Study
- Performed for all assessments

FMEDA = 88 FITS
PIU = 57 FITS

<table>
<thead>
<tr>
<th>Classified Failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
</tr>
<tr>
<td>Comment</td>
</tr>
<tr>
<td>Number of Failures</td>
</tr>
<tr>
<td>Total Operating Hours</td>
</tr>
<tr>
<td>% Reported Failures</td>
</tr>
<tr>
<td>Estimate Actual Failures</td>
</tr>
<tr>
<td>Point Estimate - Failure Rate</td>
</tr>
<tr>
<td>Complexity Factor</td>
</tr>
<tr>
<td>Estimate New Actual Failures</td>
</tr>
<tr>
<td>New Point Estimate - Failure Rate</td>
</tr>
<tr>
<td>Confidence Interval</td>
</tr>
<tr>
<td>Upper Confidence Limit failure rate</td>
</tr>
<tr>
<td>Lower Confidence Limit MTTF</td>
</tr>
</tbody>
</table>

March 16, 2015
Copyright © exida.com LLC 2000-2014
Mechanical Failure Data Sources

- **FMEDA**
  - PLUS: Can provide detailed / complete information
  - **Predictive** – does not require a multi-year lag time to gather statistics
  - MINUS: Depends on component failure mode/failure rate data

- **End User Field Failure Studies**
  - PLUS: Real Data
  - MINUS: Variations of amount of data collected
  - Different definitions of “FAILURE”
  - Categorizing and Merging Technologies

- **Manufacturer Field Return Data Studies**
  - PLUS: Real Data
  - MINUS: **Calculation methods vary widely**
  - Cannot know what percentage of actual failures are returned
  - Different definitions of “FAILURE”

- **Cycle Test Data**
  - Based on cycle testing for mechanical / electro-mechanical products
  - **Assumes application has constant dynamic operation**
Cycle Test Scaling

• Cycle testing is used to estimate failure rates in dynamic (high demand) applications.

• Assumption is that premature wearout is the dominant failure mechanism and that **no other failure mechanisms are significant**.
## 3. Summary of the technical safety characteristics

<table>
<thead>
<tr>
<th>Probability of dangerous failure on demand</th>
<th>PFD$_{spec}$</th>
<th>Failure/demand</th>
<th>7.48E-06</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testinterval</td>
<td>Ti</td>
<td>y</td>
<td>1</td>
</tr>
<tr>
<td>Confidence niveau</td>
<td>1-α</td>
<td>%</td>
<td>90</td>
</tr>
<tr>
<td>Safe failure fraction</td>
<td>SFF</td>
<td>%</td>
<td>90</td>
</tr>
<tr>
<td>Hardware fault tolerance</td>
<td>HFT</td>
<td>[-]</td>
<td>0</td>
</tr>
<tr>
<td>Diagnostic coverage</td>
<td>DC</td>
<td>%</td>
<td>0</td>
</tr>
<tr>
<td>Type of sub system</td>
<td>IEC 61508-2, 7.4.4.1.2</td>
<td>Type A</td>
<td></td>
</tr>
<tr>
<td>Mode of Operation</td>
<td>IEC 61508-4, 3.5.16</td>
<td>Low Demand Mode</td>
<td></td>
</tr>
<tr>
<td>Assumed demands per year</td>
<td>$f_{np}$</td>
<td>demand/y</td>
<td>10</td>
</tr>
<tr>
<td>Interval for closing test</td>
<td>y</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Derived Values</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demand/hour</td>
<td>$f_{np}$</td>
<td>demand/h</td>
<td>1,14E-03</td>
</tr>
<tr>
<td>Meantime between demands</td>
<td>h</td>
<td></td>
<td>8.76E+02</td>
</tr>
<tr>
<td>Dangerous failure rate</td>
<td>$\lambda_D$</td>
<td>1/h</td>
<td>8.54E-09</td>
</tr>
<tr>
<td>MTBF dangerous failures</td>
<td>MTBF$_D$</td>
<td>h</td>
<td>1,17E+08</td>
</tr>
<tr>
<td>Safe failure rate</td>
<td>$\lambda_S$</td>
<td>1/h</td>
<td>7.68E-08</td>
</tr>
<tr>
<td>Total failure rate</td>
<td>$\lambda_S + \lambda_D$</td>
<td>FIT</td>
<td>76,85</td>
</tr>
<tr>
<td>MTBF total</td>
<td></td>
<td></td>
<td>85,39</td>
</tr>
</tbody>
</table>

Copyright © exida.com LLC, 2000-2015
# Comparison of Solenoid Valve Data

<table>
<thead>
<tr>
<th>Source</th>
<th>Product Type</th>
<th>D Failure Rate per hour</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMEDA #1 (exid1)</td>
<td>Solenoid Valve</td>
<td>1.59E-07</td>
<td></td>
</tr>
<tr>
<td>FMEDA #2 (exid2)</td>
<td>Spool Solenoid Valve</td>
<td>5.66E-07</td>
<td></td>
</tr>
<tr>
<td>DOW Plant Study [Skwe08]</td>
<td>Solenoid Valve</td>
<td>3.51E-07</td>
<td>Actual field data - chemical industry</td>
</tr>
<tr>
<td>OREDA / PDS-BIP</td>
<td>Solenoid Valve</td>
<td>9.00E-07</td>
<td>Highest Number</td>
</tr>
<tr>
<td>Cycle Test Results #1 (TUVR)</td>
<td>Solenoid Valve</td>
<td>8.59E-09</td>
<td>Very Low Number</td>
</tr>
<tr>
<td>Cycle Test Results #2 (TUVR)</td>
<td>Solenoid Valve</td>
<td>4.53E-10</td>
<td>Lowest Number</td>
</tr>
<tr>
<td>Manufacturer Study [AEAT05]</td>
<td>Solenoid Valve</td>
<td>1.70E-08</td>
<td>Warranty Data</td>
</tr>
</tbody>
</table>

Compare failure rate data from process industry calibrated FMEDA results and Field Failure data results from the process industries to cycle test results.
Low Demand Application Hazards

- While cycle testing is an acceptable failure rate prediction technique for high or continuous demand applications, using it for low demand is **DANGEROUS**
- Low demand applications can generate failures that high demand applications cannot develop
- While in an inactive state for long periods of time, issues such as stiction can transpire.
What is Stiction?

- Stiction – Static + Friction
  - The resistance to the start of motion usually measured as the difference between the external force being applied in order to overcome the static friction and the force to maintain movement between the two contacting or working surfaces.
  - Can result from: corrosion, cold welding, break down of lubrication, build-up of deposits, chemical reactions, breakdown of the sealing components...
Who cares about Stiction?

• exida has studied stiction to determine the maximum time period before stiction impacts failure rates.

• This is the maximum time period for scaling cycle test results.
Impact of Stiction

• We discovered that stiction becomes significant after one week therefore never scale cycle test results beyond 200 hours.

• We also discovered that improvements in safety and reliability can be obtained with stroke testing.
Solenoid Valves
Evidence of Stiction Analyzed

• **Expert Knowledge**
  - Technicians and engineers routinely work on valves
  - Stiction occurring after a week or more

• **O-ring Manufacturer's Guides**
  - Stationary between 1 week and 1 month
  - “Delay between cycles” plateaus at approximately 300 hours

• **Experimental Study**
  - Studies conducted on lubrication thickness in magnetic thin-filmed disks.
  - As equilibrium rest time increases, stiction increases to a plateau around 275 hours, depending on lubrication type

• **ISO 13849**
  - “Valve must be operated at least once per week or once per shift to insure the intended function”
Stiction Impact

• Failures result when forces are insufficient to move mechanical parts as designed.

• Environmental variables impact rate of friction buildup. Therefore stiction is treated as a stochastic variable for failure rate analysis.

• Once stiction is broken via a movement the friction build starts over.
Impact of dynamic versus static failure rates

Values of FMEDA failure rates from the solenoid valve (manufacturer X, model Y)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>failures/10^9 hrs operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda_{DISTCTION}$</td>
<td>103.7</td>
</tr>
<tr>
<td>$\lambda_{NON-DISTCTION Detectable}$</td>
<td>84.3</td>
</tr>
<tr>
<td>$\lambda_{NON-DISTCTION Undetectable}$</td>
<td>1.9</td>
</tr>
</tbody>
</table>
Static vs. Dynamic

• Static Operation
  • \( \lambda_D = \lambda_{DStiction} + \lambda_{Dnon-StictionDetectable} + \lambda_{Dnon-StictionUndetectable} \)
  • \( \lambda_D = 103.7 + 84.3 + 1.9 = 189.9 \text{ fits} \)

• Frequent Dynamic Movement
  • \( \lambda_D = \lambda_{Dnon-StictionDetectable} + \lambda_{Dnon-StictionUndetectable} \)
  • \( \lambda_D = 84.3 + 1.9 = 86.2 \text{ fits} \)
Recommended Best Practices

1. **Never** use cycle test results unless the application moves the mechanical device at least once every 200 hours.

2. In low demand applications where the mechanical device does not move at least every 200 hours, use FMEDA failure data or expert analyzed plant failure data.
Questions? Comments?

More Information:
1. Free Web Seminars – see www.exida.com/webinars
2. White Papers

Email me at: Lstewart@exida.com