Getting High Equipment Reliability

By

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High Reliability is a choice you make

1 – Reliability is highly profitable

2 – Control equipment behaviour down to its parts level

3 – Remove the chance of parts failure

4 – Eliminate variability that start the defects which lead to failures

5 – Meet quality control standards selected to eliminate failure causes
Value of reliability on operating time

“Time is Money” – Benjamin Franklin

MTBF - average time between failures

MTBF = \frac{A + B + C}{3}

Time

A

B

C

Time

A

B

C

Time
Value of reliability on Unit Cost of Production

Unit Cost of Production ($/T) = Operating Costs in the Period ($) / Total Saleable Throughput (Tonne)
Your machines are components in series

Electric motor drive end bearing
Series arrangements are at high risk

Motor parts shown as a series

“Any one part fails; all fails”

Here is why clean lubricant is so important: It gets between the parts in your machines!
Calculating series reliability

Reliability is the **chance** that an item will last long enough to do its duty

\[ R_{\text{series}} = R_1 \times R_2 \times R_3 \times \ldots R_n \]

\[ R_{\text{series}} = 0.99 \times 0.99 \times 0.99 \times 0.99 \times 0.99 \times 0.99 \times 0.99 = (0.99)^9 = 0.91 \text{ (or 91\%)} \]

\[ R_{\text{series}} = 0.99 \times 0.99 \times 0.99 \times 0.99 \times 0.5 \times 0.99 \times 0.5 \times 0.99 \times 0.99 = 0.23 \quad \text{“Any poor, all poor”} \]

\[ R_{\text{series}} = 0.99 \times 0.99 \times 0.99 \times 0.99 \times 0 \times 0.99 \times 0 \times 0.99 \times 0.99 = 0 \quad \text{“Any fails, all fails”} \]
But where do your failures start?

Your problems start with chance variation...

### Accuracy vs. Relative Cost

<table>
<thead>
<tr>
<th>Accuracy</th>
<th>Relative Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>± 35%</td>
<td>1</td>
</tr>
<tr>
<td>± 25%</td>
<td>1.5</td>
</tr>
<tr>
<td>± 15%</td>
<td>3</td>
</tr>
<tr>
<td>± 10%</td>
<td>3.5</td>
</tr>
<tr>
<td>± 3 - 5%</td>
<td>15</td>
</tr>
<tr>
<td>± 1%</td>
<td>20</td>
</tr>
</tbody>
</table>

**Standard deviation for ‘Feel’ is ± 12%, and you need maximum of ± 10% for sure fastening.**

- **Feel – Operator judgement**
- **Torque Wrench**
- **Turn-of-the- Nut**
- **Load Indicating Washer**
- **Fastener Elongation**
- **Strain Gauges**

100% Required Torque

- 35%
- 15%
+ 15%
+ 35%
What chance variation does to machines

High Vibration:

Deformation:

Misalignment:

Fastener Torque Error:

Unclean Lubricant:

Unbalance:

Extract from 'Shaft Alignment Handbook', Piotrowski
Cause and effect of your equipment failures

**Infant Mortality**
- Component Failure Rate
- Usage

**Random**
- Component Failure Rate
- Usage

**Wear-out**
- Component Failure Rate
- Usage

**System Rate of Failing**
- Time or Usage Age of System

**Component Rates of Failing**
- Time or Usage Age of Parts

The ‘failure curve’ for a machine has a special name – **ROCOF** – Rate of Occurrence of Failure.

**Mean of Many Systems**
- (machines)
- With more parts, ROCOF becomes approximately constant

**A Single System**
- (machine)

**Component Failure Rate**
- Usage

**Infant Mortality**
- Cause: Incorrect Processes
  - (controlled by management)
  - Defective parts
  - Poor assembly
  - Manufacture error
  - Poor start-up

**Random**
- Cause: Induced Stress
  - (controlled by people)
  - Operating overload
  - Stress aging of some parts
  - Local environment degradation
  - Operator error
  - Poor operating practices
  - Poor maintenance practices
  - Poor design choice

**Wear-out**
- Cause: Accumulated Fatigue
  - (controlled by people)
  - Many aging/used parts
  - Many parts degraded

**Mean of Many Systems**
- (machines)
- With more parts, ROCOF becomes approximately constant

**A Single System**
- (machine)
- Mean of Many Systems
- With more parts, ROCOF becomes approximately constant
The secret is to control variability to within the limits that bring benefits.

Only accept this range of outcomes because they give very low risk.
Understanding what it means to be ‘in control and capable’

Figure 83: Progression of a Process to Capability
Work is a series process of tasks

A Job

\[ R_{\text{job}} = R_1 \times R_2 \times R_3 \times R_4 \times R_5 \]

What is the chance that the whole job will done right?
Risks to work quality and machine reliability

Task Reliability is the chance that a task will be performed to its required quality. 

\[ R_{\text{job}} = R_1 \times R_2 \times R_3 \times R_4 \times R_5 \]

A five task job.

Complicated non-routine tasks

| 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.59 |
| 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.77 |
| 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.95 |

<table>
<thead>
<tr>
<th>10 tasks</th>
<th>20 tasks</th>
<th>50 tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.35</td>
<td>0.12</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Controlling human error is the greatest challenge to reliability
Carpenter’s creed: ‘measure twice, cut once’

- Get wood
- Measure 1
- Mark wood
- Cut wood

- **R = 0.995**

1 error every 200 opportunities
~ 1 / wk

1 error every 5000 opportunities
~ 1 / 20 wk
The power of parallel proof-tests

Original task reliability

Proof-test reliability

Equivalent series reliability

\[ R_{\text{system}} = 1 - [(1 - R_1)(1 - R_2)(1 - R_3) \ldots] \]

1 - [(1 - 0.9)(1 - 0.99)]

1 - [0.1 x 0.01]

1 - [0.001] = 0.999
Remove the variability from your business processes – unless you want to run your business by luck!

In the end... reliability is a quality control issue.
Set work task standards to deliver the quality that produces the reliability you want

<table>
<thead>
<tr>
<th>No.</th>
<th>Range of Outcomes</th>
<th>Task Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>‘Good’ reliability</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>‘Better’ reliability</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>‘Best’ reliability</td>
<td>X</td>
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</tbody>
</table>

- **Accuracy**
- **Precision**

Accuracy and Precision are metrics used to evaluate the performance of a task or process.

- **X** indicates a task specification that aligns with the desired reliability level.
Equipment reliability is malleable by choice of policy and quality of practice.

- Better quality control
- More training
- Precision assembly
- Precision installation
- Condition Monitoring
- Better operator training
- Total Productive Maintenance
- Precision Maintenance
- Better design/material choices
- Machine protection devices
- More parts on PM
- Better materials
- Considerate operation

When we remove parts’ failure by changing our policies and using better practices, the old ROCOF falls to the new ROCOF.
How do we apply it to our machines?

Electric motor drive end bearing
Control Your Processes by Converting your SOPs to 3T Accuracy Controlled Procedures

<table>
<thead>
<tr>
<th>Task Step No.</th>
<th>Task Step Owner</th>
<th>Task Step Name</th>
<th>Full Description of Task</th>
<th>Test for Correctness</th>
<th>Tolerance Range</th>
<th>Record Actual Result</th>
<th>Action if Out of Tolerance</th>
<th>Sign-off After Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Max 3 – 4 words)</td>
<td>(Include all tables, diagrams and pictures here)</td>
<td></td>
<td></td>
<td>Good</td>
<td>Better</td>
<td>Best</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Specify the 3Ts (Target, Tolerance, Test) for task precision and accuracy
- Describe in a measurable fashion what ‘good’, ‘better’ and ‘best’ are to challenge people to strive for excellence
- Advise what to do when out of tolerance – i.e. when not ‘it’s good enough’
- Get a signature when 3T done to tolerance so people are committed to precision
- Drive continual improvement by regularly introducing an even more precise ‘best’
Use condition monitoring as the proof test for task quality

- **Reliability Improvement Zone**
  - CM is an information tool for reliability improvement.

- **Plant Optimization Zone**
  - CM is used as a tool to optimize plant availability.

- **Practical limit of Availability**

- **CM is used only to extend equipment life to failure**

- **CM is also used to reduce chance of failure**

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**Operating Cost** vs. **Availability**

**Life Extension Zone**

**Failure Elimination Zone**
Getting high equipment reliability...

1 - Is Valuable... more time; more throughput; no losses
2 - Is Parts based... low stress, low fatigue, low contamination
3 - Is Malleable... by the risks you allow your parts to carry
4 - Depends on stopping Variability
5 - Requires meeting world-class quality standards
6 - Use Condition Monitor to provide proof of precision...