USE OF SIX SIGMA® TECHNIQUES IN GAS SEAL PANEL TROUBLESHOOTING AND SEAL FAILURE ANALYSIS

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Six Sigma® Overview

Six Sigma® is a process for applying critical thinking to; solve problems, improve processes, and improve products.

Six Sigma® uses a collection of tools that have been used by other Quality Initiatives, but focuses on a process driven implementation of those tools.

DMAIC is the Key Acronym

> **Define** — Clearly Define the Problem and Expectations

> **Measure** — Gather Data to enable Conclusions / Decisions to be made

> **Analyze** — Analyze the Date to make Decisions

> **Improve** — Implement a method to Improve the Situation

> **Control** — Establish Controls to keep from repeating the past
Two Case Studies

First Case Study is Trouble Shooting a DGS Panel that Experience Operational Irregularities

> Buffer Gas Supply Pressure Regulator was being driven to full open due to low Delta P between buffer gas supply and buffer chamber pressures.

> Customer afraid had lost the process labyrinth seal in the compressor and facing an outage to correct.

Second Case Study is Trouble Shooting Multiple Dry Gas Seal Cartridge Failures

> Customer experienced three outages at very short intervals to replace DGS

> Failures did not appear consistent in symptoms of the failure beyond high primary vent leakage

> After third failure, Conmec becomes involved to trouble shoot
Step 1- Define the Problem

FOLLOWING INSTALLATION OF NEW GAS SEAL ASSEMBLIES, UPON START-UP, ALARM SIGNALS LOW BUFFER GAS SUPPLY PRESSURE DELTA
STEP 2, GATHER DATA - Measure:

- **PDI 1113** indicates 50-180 PSID over inlet pressure versus 1-2 PSID normal.
- Thrust load and position are normal and stable.
- Primary vent flowrates appear normal.
- PDT 1114 & PDI 1115 show <1 PSID or requirement of >27 PSID.
- PDI 1113 tracks significantly with changing buffer gas flowrate.
- Filter DP tracks with changing buffer gas flowrate, 1-5 PSID.
- Performance, (P1, P2, T1, T2, flowrate) appear normal.
- Vibration levels are normal and stable.
SHOULD WE SHUTDOWN??

LOOK AT THE KNOWN FACTS…

• VIBRATION LEVELS APPEAR NORMAL AND STEADY
• PERFORMANCE APPEARS NORMAL
• GAS SEAL LEAKAGE APPEARS NORMAL
• BEARING TEMPERATURES ARE NORMAL AND STEADY.
• BUFFER GAS FLOW APPEARS NORMAL THROUGH THE FILTERS

• IF A SEAL HAS NO BUFFER… PROLONGED EXPOSURE TO PROCESS GAS WOULD ALLOW DEPOSITS IN THE SEAL FACES TO BUILD UP LEADING TO SEAL FAILURE.

• WITH THE CONTROL VALVE FULL OPEN, THE GAS SEAL SUPPLY, (COMPRESSOR DISCHARGE) COULD NOT GENERATE ENOUGH PRESSURE DELTA IN THE SUPPLY TO CAUSE SEAL DAMAGE.

ANSWER….UNLESS A SIGNIFICANT INCREASE IN PRIMARY SEAL LEAKAGE RATE IS SEEN, NO!!*

*SHORTLY AFTER THIS DECISION, AN INCIDENT WITH THE DRIVER FORCED A SHUTDOWN.
STEP 2 Cont, BRAINSTORM:

- Damaged primary seal both ends.
- Damaged primary seal discharge end only.
- Damaged primary seal intake end only.
- Faulty balance cavity pressure indicator PI 1113.
- Faulty buffer supply delta indicator PDI 1115.
- Faulty buffer supply delta transmitter PDT 1115.
- Blocked control valve PDV 1114.
- Missing inboard buffer cavity labyrinth seal.
- Missing inboard buffer cavity labyrinth seal.
- Blocked orifice plates FO1127 & FO1126 (one).
- Blocked orifice plates FO1127 & FO1126 (both).
- Blocked balance line.
- Blocked balance line.
- Balance piston seal damage.
- Block high pressure side delta transmitter valve blocked.
- Flow bypassing pressure delta indicator PDI 1115 & PDT 1114.
- Low pressure side delta transmitter valve blocked.
STEP 3 Analyze, CAUSE AND EFFECT:

IN THIS CASE WE WANT TO RANK THE EFFECTS BY THEIR LEVEL OF INFLUENCE ON THE OBSERVATIONS.

1 = NO INFLUENCE
3 = SOME INFLUENCE
9 = LARGE INFLUENCE

IN THE NEXT STEP WE WILL CONCENTRATE ON THE LARGE INFLUENCES.

<table>
<thead>
<tr>
<th>CAUSES</th>
<th>INFLUENCE EFFECT</th>
<th>PI 1113 READING (BALANCE CAVITY PRESSURE REED)</th>
<th>THRUST BEARING DIRECTION AND BEARING LAMP</th>
<th>PRIMARY VENT FLOWRATE</th>
<th>PDT 1114 &amp; PDT 1115 READING (BUFFER SUPPLY DELTA)</th>
<th>PDT 1118, PDI 11107 READING</th>
<th>COMPRESSOR EFFICIENCY</th>
<th>COMPRESSOR DISCHARGE PRESSURE</th>
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</thead>
<tbody>
<tr>
<td>DAMAGED SEAL DISCHARGE END (EITHER ELASTOMER OR FACE DAMAGE, SINGLE OR DUAL FACE FAILURE)</td>
<td>1 9 9 3 1 1 1 1 1</td>
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<tr>
<td>DAMAGED SEALS, BOTH END (EITHER ELASTOMER OR FACE DAMAGE, SINGLE OR DUAL FACE FAILURE)</td>
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<td>PI 1113 FAULTY</td>
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<td>PDI 1115 FAULTY</td>
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<tr>
<td>PDT 1114 &amp; PDI 1115 FAULTY</td>
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<td>PDCV 1114 BLOCKED</td>
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<tr>
<td>MISSING BUFFER Labyrinth SEAL EITHER OR BOTH ENDS</td>
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<tr>
<td>FO 1126 BLOCKED</td>
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<tr>
<td>FO 1127 BLOCKED</td>
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<tr>
<td>FO 1127 &amp; F0 1126 BLOCKED</td>
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<td>BALANCE LINE PLUGGED</td>
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<tr>
<td>BALANCE PISTON SEAL DAMAGE</td>
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<tr>
<td>GLOBE VALVE BETWEEN PDCV 1114 &amp; PDI 1115 BLOCKED</td>
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<tr>
<td>LEAKAGE BYPASSING PDT 1114 &amp; PDI 1115</td>
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<tr>
<td>NEEDLE VALVE BETWEEN PI1113 &amp; BALANCE CAVITY BLOCKED</td>
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</tbody>
</table>
CONCENTRATING ON THE HIGH EFFECTS WE ENDED UP WITH ONLY 2 LIKELY CAUSES FOR OUR OBSERVATIONS.

<table>
<thead>
<tr>
<th>CAUSES</th>
<th>INFLUENCE EFFECT:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LARGE 9 =</td>
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<td></td>
<td>SOME 3 =</td>
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<td></td>
<td>NO INFLUENCE 1 =</td>
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<tr>
<td>FLOW BYPASSING PDT 1114 &amp; PDI 1115</td>
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<tr>
<td>NEEDLE VALVE BETWEEN PI1113 &amp; BALANCE CAVITY BLOCKED</td>
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</tbody>
</table>
Case 1 - SUMMARY, PANEL IRREGULARITIES

Inspection of the components showed debris buildup in the needle valve assembly.

Flow bypassing gauges contributed to the irregularities.

The needle valve was cleaned and the bypass valve pressure tested. Upon resart, system response was normal.
Case 2 – Multiple Dry Gas Seal Failures

Background

> Natural Gas Pipeline Compressor
> New Bundle installed with new DGS
  – Compressor ran ~ 1500 hours
  – Other Issues caused train to come down – Driver Auxiliary System Failure. No work done to Compressor.
  – On Start-up, High Primary Vent Leakage at Shutdown Level on both ends of compressor
  – Replace both DGS
> Run ~ 450 and again experience High Primary Vent Leakage Shutdown
  – Both DGS replaced
> Run ~ 450 hours and experience third High Primary Vent Leakage Shutdown
  – Both DGS replace, High Leakage alarm on opposite end of Compressor from last failure.
Case 2 - Define

Three failure events that occur at 1500, 450 and 450 approximate hours intervals

First Failure

> Inspection of DGS shows possible explosive decompression of primary O-ring in DGS on both ends
> Barrier Seal shows damage to carbon rings and face springs
> Oil contamination from Driver Auxiliary failure
  – Aux oil pump continued to run while compressor shut down over night, no barrier seal nitrogen buffer present.
Case 2 – Define Cont

Second Failure

> Discharge End DGS O-ring shows signs of heavy nibbling and a white substance in the compressor ports, some small amount of residual oil in ports found

> Barrier seal shows signs of damage to carbon ring and face springs

Third Failure

> Suction End DGS O-ring shows signs of heavy nibbling, a white substance and small amount of oil in the compressor ports is found.

> Barrier seal shows signs of damage to carbon ring and face springs.
## Use of Time Line in Sorting Out the Facts

Use of Time Line assists in sorting out the facts.

### Are the Failures Same Root Cause or are Multiple Root Causes Occurring?

Use of Fishbone Diagram helps identify possible root causes – Input from all Stakeholders.

### Case 2 - Define Cont

#### Use of Time Line

<table>
<thead>
<tr>
<th>Date</th>
<th>GT Failure</th>
<th>DGS Changed Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-Jun-03</td>
<td>Surge Testing Comp Station</td>
<td>Visual Inspection by Vendor</td>
</tr>
<tr>
<td>18-Jul-03</td>
<td>High Primary Vent Leaks reported both suction and discharge ends</td>
<td>Customer Faulty designs with methanol and coolant separators</td>
</tr>
<tr>
<td>31-Jul-03</td>
<td>Start Unit back up - GT issues</td>
<td>Worked for 5 days FBD TA to site to change DGS</td>
</tr>
<tr>
<td>30-Jul-03</td>
<td>High Primary Vent Leaks reported at discharge seal</td>
<td>Start up yields no buffer gas. CH4 Pressure at PDCV 1114</td>
</tr>
<tr>
<td>5-Sep-03</td>
<td></td>
<td>Castor SuperClean and Methanol injected to flush seals separately</td>
</tr>
</tbody>
</table>

- **All events post OT repair work, both suction and discharge ends with high leakage:**
  - DGS sent to vendor for RCA (Report received 01/10)
  - DGS didn't fit. Return to vendor to replace or return to manufacture, seal OD too big, shaft sleeve ID too small
  - RCA yields blocked test cell in resonant frequency signature testing line to low side of PDCV 1114
  - Leakage rate did not decline

- **Suspect and discharge seals changed/ crane report dated 02/03:**
  - Methanol then Castor SuperClean injected to wash seals in NP unit
  - Oil in seal drain cell and seal vents, dry white residue on buffer side of seals, on suction side there was sludge from process and strong process odor.
  - Seal opened on site 01/04, primary and secondary dynamic seals cut. DGS of primary seal carbon ring embedded in seal (90 deg from where ring cut)

- **Approx 1500 hrs since rebundle:**
  - Seal leakage returned to low range
  - Several springs in tertiary seal extruded out
  - Approx 450 hrs since DGS failure #1

- **After unit experienced high DGS leakage and was washed at same time, tripped off line when NP unit surged:**
  - Pressure test of 70 psi

- **Process flow point traverse:**
  - Liquid building at NP unit

- **Per customer, both units tripped off line due to high phosphorus at a later date. Found to be faulty high alarm switch:**
  - Unit held pressurized during marine stops

- **1 spring left out of new tertiary seal on reinstallation (low demarsh):**
  - Extruded out of valve, applied force to carbon ring, crime 01/04 per FBD TA

- **Low demarsh odors, carbon ring/damaged, primary seal face looks clean:**
  - Seals currently at vendor

- **Approx 490 hrs from failure #1**
Case 2 – Measure & Analyze

Fishbone Diagram

Plant Process
- Low Differential Pressure
- Pressureization Rate
- Liquid Slug during start-up

Contamination
- Air Buffer Source
- Solids
- Liquid Knockout

DGS Design
- Liquids
- Run Out of Rotating Components
- O-Ring Compatibility, Hardness

- DGS replaced due to high primary vent pressure alarms, indicating a failure of the DGS
- Wrong spec to seal vendor
- Rotor dimensional differences after re-bundle
- DGS Shaft Sleeve Lock Nut Faces Not Parallel

Installation
- Axial Rotor Position
- Piping Not Cleared from Prior Failure
- DGS not installed correctly

Buffer Seal System
- Buffer Air/Gas Supply Problem
- Alignment of Machine Train

Machine Design
- Final Filtration
- Port Sizing

If you are unhappy with the fishbone diagram, click on the appropriate buttons below to adjust data:

- Back to Specific Causes
- Back to Cause Categories
- Back to Problem
- Back to Main Menu
- Print Color Diagram

- Cause not ruled out for DGS Failure #1, 2 or 3
- Cause not ruled out for DGS Failure #1 or 2
- Cause has been ruled out for DGS Failures 1, 2 and 3
### Process/Product
Failure Modes and Effects Analysis (FMEA)

<table>
<thead>
<tr>
<th>Process Step/Part Number</th>
<th>Potential Failure Mode</th>
<th>Potential Failure Effects</th>
<th>S</th>
<th>E</th>
<th>V</th>
<th>Potential Causes</th>
<th>O</th>
<th>C</th>
<th>C</th>
<th>Current Controls</th>
<th>D</th>
<th>E</th>
<th>T</th>
<th>R</th>
<th>P</th>
<th>N</th>
<th>Actions Recommended</th>
<th>Resp.</th>
<th>Actions Taken</th>
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</thead>
<tbody>
<tr>
<td>Primary O-ring</td>
<td>Explosive Decompression</td>
<td>High gas leakage rate</td>
<td>8</td>
<td></td>
<td></td>
<td>explosive decompression</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>Office in blow down line</td>
<td>3</td>
<td>97</td>
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<td></td>
<td></td>
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<td>Increase blow down duration via smaller orifice</td>
<td>Decreas...</td>
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<tr>
<td>Primary O-ring</td>
<td>Extrusion</td>
<td>High gas leakage rate</td>
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<td>soft o-ring</td>
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<td>4</td>
<td>64</td>
<td>Review Spec with Vendor - Vendor OA Documents</td>
<td>6</td>
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<td>Reviewed vendors spec / history</td>
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<tr>
<td>Primary O-ring</td>
<td>Extrusion</td>
<td>High gas leakage rate</td>
<td>8</td>
<td></td>
<td></td>
<td>axial oscillation of rotor</td>
<td>4</td>
<td>120</td>
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<td>Check Part Specs - Inspect actual parts</td>
<td>164</td>
<td>8</td>
<td>3</td>
<td>2</td>
<td>48</td>
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<td>Inspected related parts of CCS - replaced Shim Rings</td>
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<td>Primary O-ring</td>
<td>Extrusion</td>
<td>High gas leakage rate, vibration</td>
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<td>misalignment</td>
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<td>4</td>
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<td>Check Vibration data - High 2x?</td>
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<td>16</td>
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<td>No 2x vibration found, machines out of alignment</td>
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<td>Primary Seal Face</td>
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<td>High gas leakage rate, vibration</td>
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<td>liquid contamination</td>
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<td>System inspected, change source of buffer gas supply</td>
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<tr>
<td>Barrier Seal</td>
<td>Oil Migration past Seal</td>
<td>Liquid into OSS</td>
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<td></td>
<td>buffer supply interrupted, damaged seal at installation</td>
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<td>96</td>
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<td>PCVs in place, installation procedures</td>
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<td>4</td>
<td>48</td>
<td></td>
<td></td>
<td>Installed STPCV dedicated to each barrier seal</td>
<td>48</td>
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</tbody>
</table>

This table outlines potential failure modes and their effects for a process involving a dry gas seal failure. Each failure mode is analyzed for severity (S), occurrence (O), and detection (D), with recommended actions and responsible parties listed.
Case 2 – Field Inspections

The Timeline, Fishbone Diagram and FMEA Tools helped to identify several possible root causes.

Planning of Shutdown to Inspect the machine for these root causes could then be accomplished – Down time, equipment and personnel.

Do not stop at first “smoking” gun – this method prepared all involved to avoid jumping to a conclusion at the first source of problem found – keep digging to rule out possible root causes or identify multiple root causes.
Multiple Root Causes were Found

> First DGS failure (1500 hours)
  > Slight nibbling and heavy “cracking” of the primary O-Ring
  > • DGS Shim Ring run out – axial oscillation of seal
  > • Explosive Decompression – blow down rate several times faster then recommended
  > • Oil Flooding of Seals caused initial shut down – fault of GT auxiliaries – symptom

> Second DGS failure (~450 hours)
  > Heavy nibbling of DGS primary O-Ring
  > • Sever misalignment of compressor to GT
    » Root cause of misalignment not discovered
    » Check of alignment records and piping strain made
Case 2 – Summary Cont.

> Third DGS failure (~450 run hours)
  - Heavy nibbling of DGS primary O-Ring
    • Sever misalignment of compressor to GT
      » Root cause of misalignment not discovered
      » Check of alignment records and piping strain made

> Other Factors found and addressed
  - Barrier Seal Failures – buffer gas supply regulation
    • Oil getting to secondary vent port but not found at primary seal face
      » Not a root cause but would lead to failure
  - Detergent cleaning of DGS
    • White residue found in DGS port cavities
    • Testing determined that detergent used to “wash” the seals was reacting with Methanol Alcohol that was also used to wash the seals
      » Not found on seal faces, could lead to a failure – practice stopped
Case 2 – Summary (Improve)

Seals have now logged ~2500 run hours with out signs of problem per End User

> Changed Shim Rings

> Changed blow down orifice size

> Aligned machinery – monitored alignment

Changes through first 500 hours of operation

> Changed buffer supply regulation system

> Stopped use of Detergent cleaning of DGS