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

- **D**efine – Clearly Define the Problem and Expectations
- **M**easure – Gather Data to enable Conclusions / Decisions to be made
- **A**nalyze – Analyze the Date to make Decisions
- **I**mprove – Implement a method to Improve the Situation
- **C**ontrol – 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.

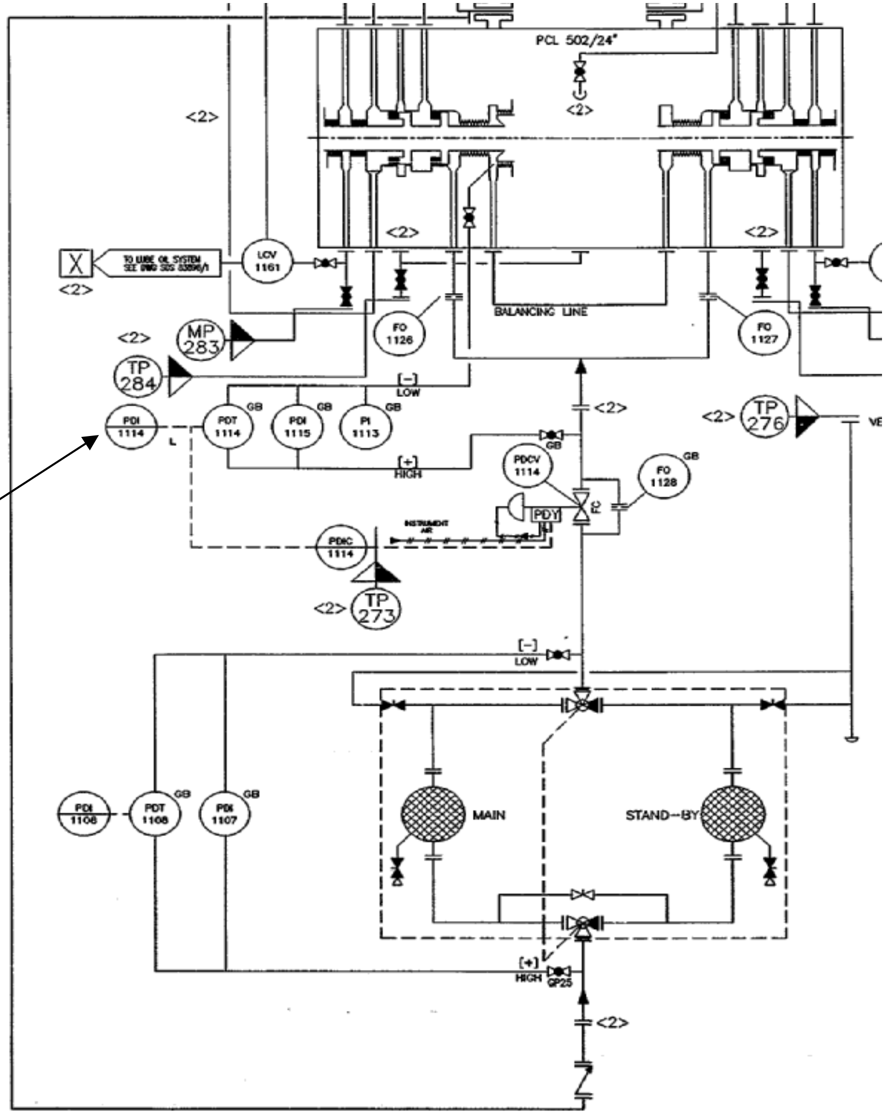
Second Case Study is Trouble Shooting Multiple Dry Gas Seal Cartridge Failures

- 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

Case 1 - GAS SEAL PANEL IRREGULARITIES

Step 1- Define the Problem

FOLLOWING INSTALLATION OF NEW GAS SEAL ASSEMBLIES, UPON START-UP, ALARM SIGNALS LOW BUFFER GAS SUPPLY PRESSURE DELTA



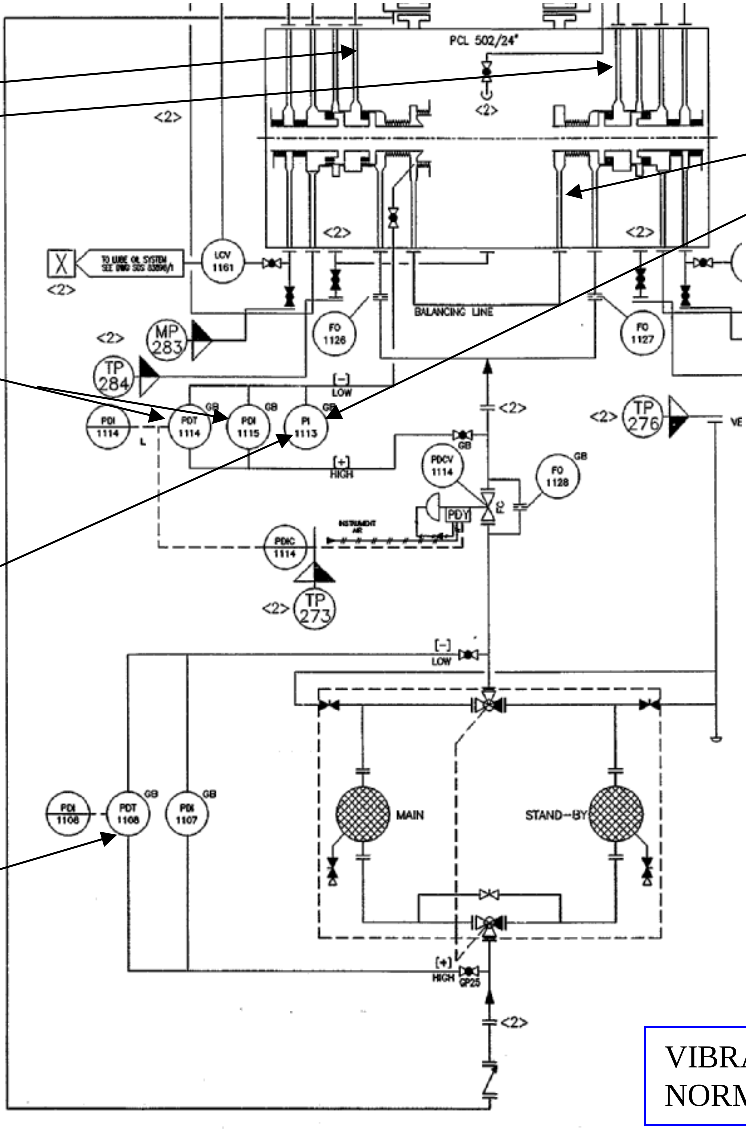
STEP 2, GATHER DATA - Measure:

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.



PDI 1113 INDICATES 50-180 PSID OVER INLET PRESSURE VERSUS 1-2 PSID NORMAL

PERFORMANCE, (P1, P2, T1, T2, FLOWRATE) APPEAR NORMAL

THRUST LOAD AND POSITION ARE NORMAL AND STABLE

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 ORAFICE PLATES FO1127 & FO1126 (ONE)
- BLOCKED ORAFICE PLATES FO1127 & FO1126 (BOTH)
- BLOCKED BALANCE LINE
- BALANCE PISTON SEAL DAMAGE
- HIGH PRESSURE SIDE DELTA TRANSMITTER VALVE BLOCKED
- FLOW BYPASSING PRESSURE DELTA INDICATOR PDI 1115 & PDT 1114
- LOW PRESSURE SIDE DELTA TANSMITTER 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.

CAUSES / INFLUENCE EFFECT: 9 = LARGE 3 = SOME 1 = NO INFLUNENCE	PI 1113 READING (BALANCE CAVITY PRESSURE REF)	THRUST BEARING DIRECTION AND BEARING TEMP.	PRIMARY VENT FLOWRATE	PDT 1114, & PDI 1115 READING (BUFFER SUPPLY DELTA)	PDT 1108, PDI 1107 READING (FILTER DP)	COMPRESSOR EFICIENCY	COMPRESSOR DISCHARGE PRESSURE
DAMAGED SEAL DISCHARGE END (EITHER ELASTOMER OR FACE DAMAGE, SINGLE OR DUAL FACE FAILURE)	1	1	9	9	3	1	1
DAMAGED SEAL INTAKE END (EITHER ELASTOMER OR FACE DAMAGE, SINGLE OR DUAL FACE FAILURE)	1	1	9	9	3	1	1
DAMAGED SEALS, BOTH END (EITHER ELASTOMER OR FACE DAMAGE, SINGLE OR DUAL FACE FAILURE)	1	1	9	9	3	1	1
PI 1113 FAULTY	9	1	1	1	1	1	1
PDI 1115 FAULTY	1	1	1	3	1	1	1
PDT 1114 FAULTY	1	1	1	3	3	1	1
PDT 1114 & PDI 1115 FAULTY	1	1	1	9	3	1	1
PDCV 1114 BLOCKED	1	1	1	9	9	1	1
MISSING BUFFER LABYRINTH SEAL EITHER OR BOTH ENDS	1	3	1	3	3	1	1
FO 1126 BLOCKED	1	1	1	3	3	1	1
FO 1127 BLOCKED	1	1	1	3	3	1	1
FO 1127 & F0 1126 BLOCKED	1	1	1	9	9	1	1
BALANCE LINE PLUGGED	9	9	1	9	3	3	3
BALANCE PISTON SEAL DAMAGE	3	1	1	3	3	9	9
GLOBE VALVE BETWEEN PDCV 1114 & PDI 1115 BLOCKED	1	1	1	9	1	1	1
LEAKAGE BYPASSING PDT 1114 & PDI 1115	9	1	1	9	3	1	1
NEEDLE VALVE BETWEEN PI1113 & BALANCE CAVITY BLOCKED	9	1	1	9	1	1	1

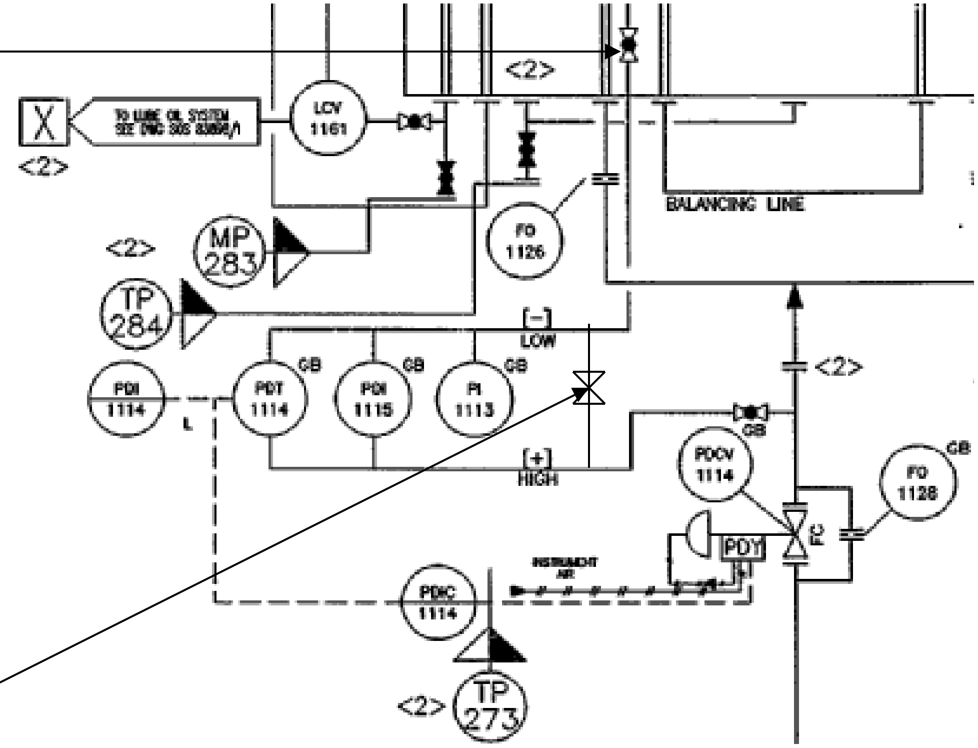
STEP 4, ANALYZE

CONCENTRATING ON THE HIGH EFFECTS WE ENDED UP WITH ONLY 2 LIKELY CAUSES FOR OUR OBSERVATIONS.

CAUSES / INFLUENCE EFFECT: 9 = LARGE 3 = SOME 1 = NO INFLUNENCE	PI 1113 READING (BALANCE CAVITY PRESSURE REF)	THRUST BEARING DIRECTION AND BEARING TEMP.	PRIMARY VENT FLOWRATE	PDT 1114, & PDI 1115 READING (BUFFER SUPPLY DELTA)	PDT 1108, PDI 1107 READING (FILTER DP)	COMPRESSOR EFFICIENCY	COMPRESSOR DISCHARGE PRESSURE
FLOW BYPASSING PDT 1114 & PDI 1115	**9**	**1**	**1**	**9**	**3**	**1**	**1**
NEEDLE VALVE BETWEEN PI1113 & BALANCE CAVITY BLOCKED	**9**	**1**	**1**	**9**	**1**	**1**	**1**

Case 1 - SUMMARY, PANEL IRREGULARITIES

INSPECTION OF THE COMPONENTS SHOWED DEBRIS BUILDUP IN THE NEEDLE VALVE ASSEMBLY.



FLOW BYPASSING GAUGES CONTRIBUTED TO THE IREGULARITIES.

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 show's 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

Primary Seal O-Ring and Tungsten Face – As removed from Compressor

Third Failure

- Suction End DGS O-ring show's 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.

Secondary Seal – As removed from Compressor

Case 2- Define Cont

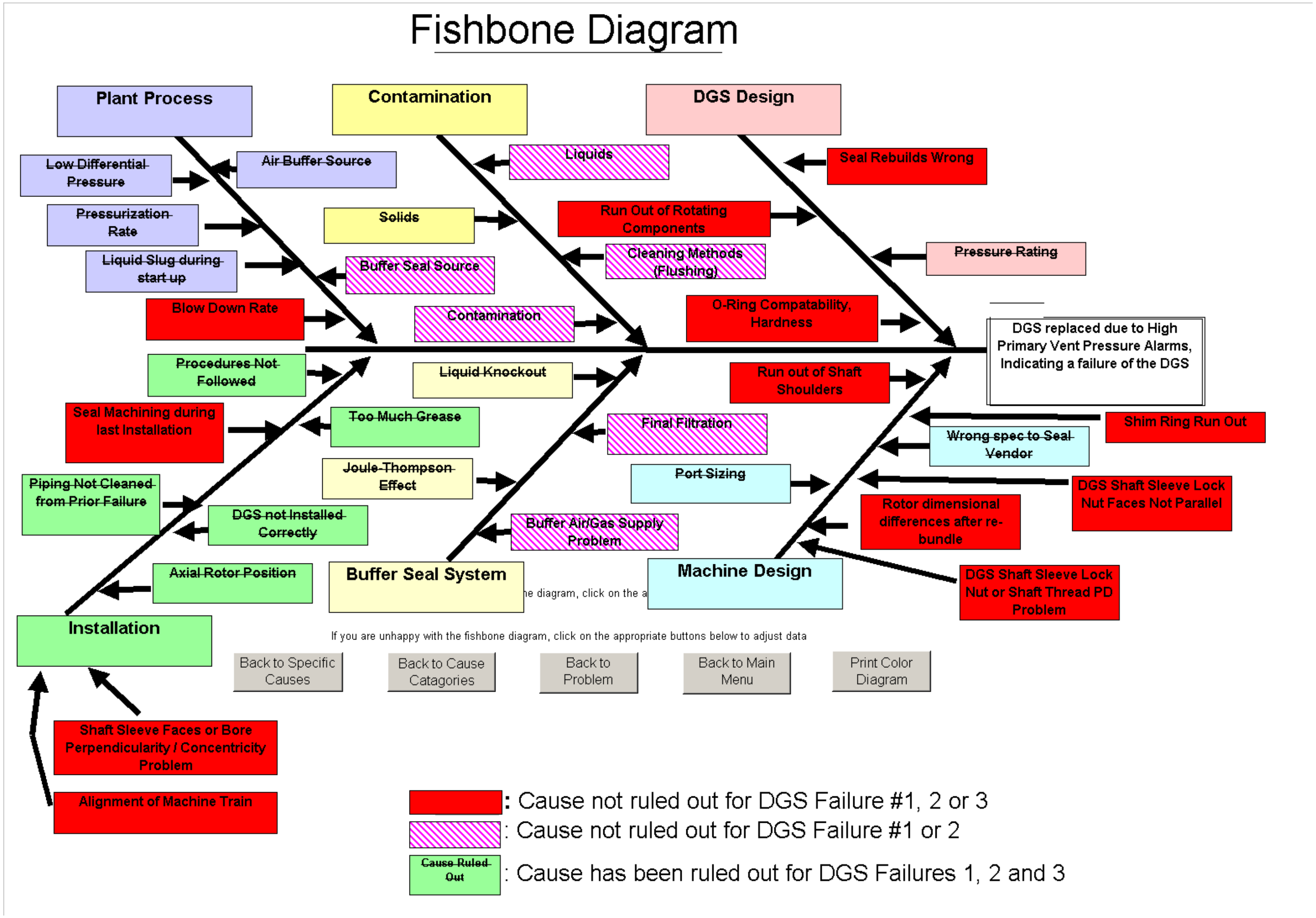
Use of Time Line assists in sorting out the facts.

Are the failures same root cause or are multiple root causes occurring?

Use of Fishbone Diagram help Identify possible root causes – Input from all Stake Holders

DGS Failure #1 30-Jun-03	18-Jul-03	DGS Failure #2 21-Jul-03	30-Jul-03	DGS Failure #3 9-Sep-03
GT Failure	Surge Testing Comp Station	High Primary Vent Leakage Reported both Suction and Discharge Ends	Start Unit Back Up - GT Issues	High Primary Vent Leakage Reported at Discharge Seal
DGS Changed Out	Visual Inspection by Conmec of DGS Changed post Fire: Tertiary Seal Springs extruded from damaged seal and carbon rings wiped	Customer flushed seals with methenol and castrol superclean Worked for 5 days FSO TA to Site to Change DGS	Start Up Yields No Buffer Gas Diff Pressure at PDCV 1114	Castrol SuperClean and Methanol injected to Flush Seals Separately
At start up post GT repair work, both Suction and Discharge End with High Leakage	DGS Sent to Seal Vendor for RCA (Report Received 9/11/03)	DGS didn't Fit, Returned to Crane to Machine, Seal OD too big, shaft sleeve ID too small	RCA Yields Blocked Sinterd Filter in Instrument Sensing Line to Low Side of PDCV 1114	Leakage rate did not decline
	During Surge Testing DGS Leakage went up after a surge event. Scrubbers tripped on High Level.	Seal Vendor Rep to Site after machining to witness installation		Seals removed from Discharge End, Inspection of Seals finds White sludge and powder contamination
Suction and Discharge Seals Changed. Crane Report Dated 8/28/03	Methanol then Castrol SuperClean injected to wash seals in NP Unit	Oil in Seal Drain Cavities and Seal Vents, dry white residue on buffer side of seals, on Suction Side there was sludge from process and strong process oder.		Seal opened on Site 9/18/03, Primary and Secondary Dynamic Orings cut, OD of Primary Seal carbon ring rubbed at top (180 deg from where oring 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 #2
	Solar unit experianced High DGS leakage and was washed at same time, tripped off line when NP Unit Surged	Pressurization Orfice Changed to 7/8"		
	Process Low Point Drains checked for Liquids, None Found	Blow Down Orifice Changed to 2", rate is now 7-10 psi / sec vs recommendation of 4		
	Per Customer, both units tripped off line due to High Scrubber at a later date. Found to be faulty High Alarm Switch	Unit held pressurized during routine stops		
		1 Spring left out of New Tetiary Seal on Re-Installation (Lowdermilk), was extruded out of DGS, applies force to carbon ring, crane OK'd per FSO TA		
		Lowdermilk advises o-ring cut/damaged, primary seal face looked clean		
		Seals currently at Vendor		
		Approx 450 hrs from Failure #1		

Case 2 – Measure & Analyze



Case 2 - Analyze

Process/Product
Failure Modes and Effects Analysis
(FMEA)

Process or Product Name:	Dry Gas Seal Failure	Prepared by: RAH	Page __1__ of __1__
Responsible:		FMEA Date (Orig) __9-10-03___________ (Rev) ____2_______	

Process Step/Part Number	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken	SEV	OCC	DET	RPN
Primary O-ring	Explosive Decompression	High gas leakage rate	8	explosive decompression	4	orifice in blow down line	3	96	Increase blow down duration via smaller orifice		Decreased orifice size	8	1	1	8
Primary O-ring	nibbling / extrusion	High gas leakage rate	8	soft o-ring	2	specification of material	4	64	Review Spec with Vendor - Vendor QA Documents		Reviewed vendors spec / history	8	3	2	48
Primary O-ring	nibbling / extrusion	High gas leakage rate	8	axial oscillation of rotor	4	control run out of parts	4	128	Check Part Specs - Inspect actual parts		Inspected related parts to DGS - replaced Shim Rings	8	1	2	16
Primary O-ring	nibbling / cutting	High gas leakage rate, vibration	8	misalignment	3	align machine / control thermal growth / control pipe strain	2	48	Check Vibraion data - High 2x?		No 2x vibration found, machines out of alignment	8	4	2	64
Primary Seal Face	FOD	High gas leakage rate, vibration	8	solid - liquid contamination	6	filtration of buffer gas	4	192	Inspect Filtration System		System inspected, change source of buffer gas supply	8	4	2	64
Barrier Seal	Oil Migration past Seal	Liquid into DGS	8	buffer supply interupted, damaged seal at installation	6	PCV's in place, installation procedures	2	96	change to 2 stage press reducing system		installed 2-PCV dedicated to each barrier seal	8	3	2	48
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Case 2 – Field Inspections

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

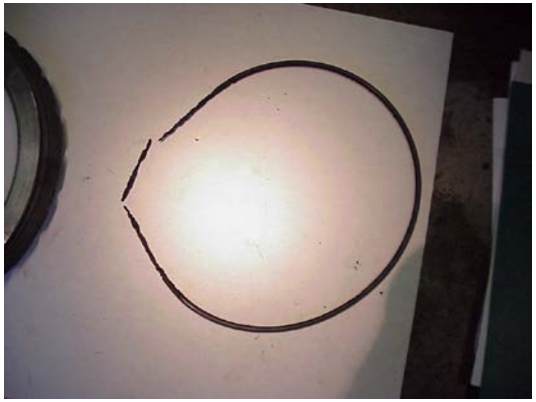
<u>Planning</u> of Shutdown to Inspect the machine for these root causes could then be accomplished – Down time, equipment and personnel

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.

Case 3 - Summary

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