Turbo-Expander Compressor
Active Magnetic Bearing
Trips Reduction - A Case Study

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Objectives

- To share lessons learned from the operations of Cryogenic Turbo-Expander Compressors (TEC)

- Scope of discussions will be limited to the 3 earlier units in Qatar Operator supplied by Turboexpander OEM with Active Magnetic Bearings (AMBs)
  - Unit #1 – operational in Mar-06
  - Unit #2 – operational in Apr-06
  - Unit #3 – operational in Feb-07
Contents

• Brief Introduction to Turbo-Expander Compressor (TEC)
• Brief Issues History At Qatar Operator
• Discussion of Failure Mode 1 (Axial Shuttling)
• Discussion of Failure Mode 2 (Machine-AMB Control Loop Transfer Function Change)
• Summary
Turbo-Expander - Application

Why is it important
- Key for liquid natural gas recovery processes to enhance C3 recovery
- On spec lean LNG production

Downtime consequence
- If Turbo-Expander is down, plant can still operate in JT-Valve bypass or DPC modes
  - Reduced feed & off-spec LNG production, high loss (condensate)
Turbo-Expander – Components

- OEM primary vendor of the TEC single shaft arrangement
- Sub-supplier for Active Magnetic Bearing

- Magnetic bearing is a relatively new technology in this application
- Operator relatively new in application that uses AMB technology
The Beginning of Problems

- Failures were initially one-off’s & electronic components related
  - sensor rings, detector boards, battery, etc
- High rate operations of Unit #1 caused 32 trips in several months in mid-late 2007
  - Extensive Root Cause Failure Analysis (RCFA) efforts including engagement of TEC OEM, AMB supplier & Operator team
Failure Modes Experienced

• Primary Failure Modes Seen in Qatar site TEC included
  1. Axial Shuttling
  2. Machine-AMB Control Loop Transfer Function Change

• Other Failure Modes & Lessons Learned:
  • Sensor Failures
  • Batteries & Single Feed Power Supply
  • Electronic Board (Digital Signal Processor & Detection)
  • Poor Soldering (components in Field Junction Box)
  • Rotor Whirl
  • Compressor Wheel Erosion
  • Hold Down Bolt Loosening (Loctite not meeting low temperature specification)
  • Seal Gas Supply Low
Failure Mode 1 – Axial Shuttling (Surge Failure Z12)

- Axial Shuttling (Surge Failure Z12) – Spurious Trips
  - Some radial vibration at 1st natural frequency (~80Hz) and but thru certain conditions axial 240 Hz. Picks up exceeded the trip limit – affected only Unit #1
  - Trip generated by AMB control system when it detects at least 5 peaks of vibration amplitude higher than alarm and trip threshold values (default 87 um and 105 um respectively) in a 7s time period
Failure Mode 1 – Axial Shuttling (Surge Failure Z12)

- RCFA Found Combination of Factors
  - ATB was initially not functioning correctly (logic, stroke & setting)
  - Off-design condition due to high rate operations creating low back wheel pressure (high axial thrust load)
  - Unknown high frequency (240Hz) vibration used up dynamic capability of AMB – only seen at specific low pressure/ high flow/ speed settings

![Graphs showing various parameters such as rotor speed, compressor inlet flow, expander inlet flow, expander inlet pressure, and expander IGV opening against different operating conditions.

- 240 Hz axial - trips Nov’07
- 240 Hz axial - normal oper. Nov’09
- 240 Hz axial - normal oper. Apr’09
- 80 Hz whirl - start-up Jan’09
- 80 Hz whirl - low flow Nov’09
- 80 Hz whirl - normal oper. Apr’09

- Expander inlet flow (ACFM)
- Rotor speed (RPM)
- Expander inlet pressure [bar]
- Expander flow [Nm^3/hr]
- Exp IGV opening [%]
RCA Work/ CA Completed

- Automatic Thrust Balance logic, stroke & setting corrected
- Increased Thrust Bias Current (12A –> 15A) to improve Dynamic Capability of AMB (by 60%)
- Better thrust balance after change of TEC Machine Center Section in Jan. 2009
- Stability check performed unloaded/ 50% neg. stiffness
- Extensive review confirmed ATB design (valve and piping), but measured pressure drop higher than expected
- Rotor dynamic analysis confirmed 80Hz natural frequency ... but could not detect any 240Hz cross-coupling
Failure Mode 1 - Current Status
Unit #1 TEC

- **No AMB/ Z12 Trips since April 2008**

- **Outstanding Works**
  - Source of high frequency (240Hz) vibration is still to be determined, though
  - ATB valve and piping to be inspected and if necessary upgraded to reduce pressure drop
Failure Mode 2 – Transfer Function Changed

- Control Loop Transfer Function (TF) Changed
  - TF is the ratio of output of a control system to its input; once set up, it represents the system signature (i.e., natural frequencies)
  - Change of TF during active operation is rare, but RasGas experienced twice in 2009
• Closed Loop TF on Translation and Tilting mode controllers (measured at standstill) appear to be very flat in the 70-120 Hz frequency range. This is a good indicator of system stability.

• Closed Loop TF should be measured with machine in operation to have confirmation on stability margins.

The standard S2M Amplification factor criteria on a close loop transfer function is <2.5
Failure Mode 2 – Transfer Function Changed

- High frequency TF change in Unit #1 unit (*Figures A1-A3*)
  - Mitigated by software modification
  - Machine operational, but fault unknown

- Low frequency change in Units #2 & #3 unit (*Figure B1*)
  - Cannot restart, reinstall old unit
  - Severe rubs of stator and rotor (photos)
  - Root cause identified
A1 - Typical Transfer Function Plots

- Natural frequencies as per design
- Compared with previous reading – good to go
High frequency TF change measured before the replacement of the MCS (this is the expected curve).
A3 – Unit #1 Controller Modified to Counter TF Change

- Controller modified to reduce mismatch response to within acceptable limit

- TEC Operational with no trips, but true fault unknown
B1 – Unit #2 TEC Unstable Vibration following TF Change

- Unstable vibration when ramp up the machine
- Cannot restart, reinstall old unit
- Severe rubs of stator and rotor (photos)

Rubs on shaft and varnish
B2 – Unit #2 TF Changed at Low Frequency

- Low frequency response changed
- Indicating instability
B3 – Unit #2 Machine Center Section Root Cause

Root Cause

- Axis identification on compressor side was wrong (signals cables)
  - Wiring was also crossed inside MCS
  - Wiring was crossed at JB during replacement

- Static levitation can be performed even if lower radial coils crossed and appeared to be stable, but in dynamic mode unit is unstable

- Field error replicated in the vendor facility

Long term options

- Spare AMB cabinet to test all MCS before installation
Summary

- Overviewed 2 unique Failure Modes and provided insight and steps to take to overcome the problems – technical interaction between Operator and OEMs are key
  - ... timely and complete information vital

- These and other Lessons Learned have been fed back to OEM and incorporated into Design Specification for incorporation into future projects
Thank You