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

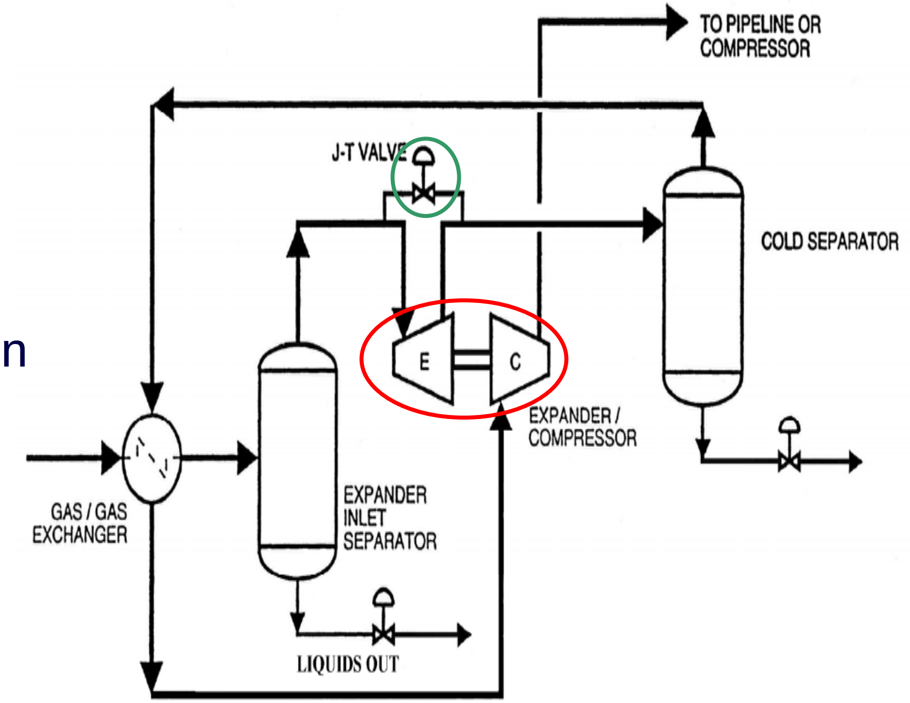
Turbo-Expander - Application

Why is it important

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

Downtime consequence

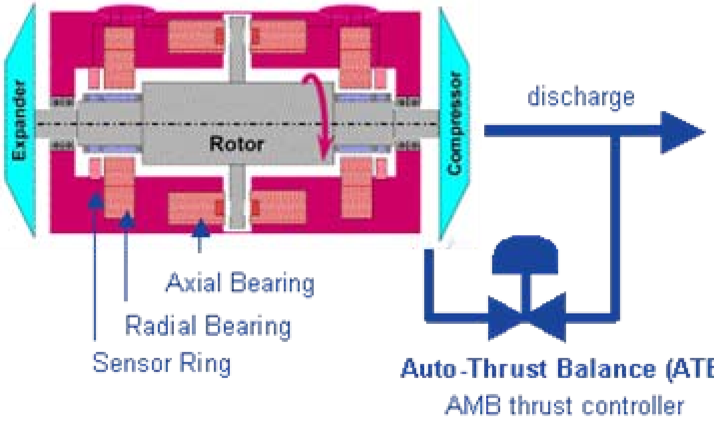
- If Turbo-Expander is down, plant can still operate in JT-Valve bypass or DPC modes
  - Reduced feed & off-spec LNG production, high loss (condensate)

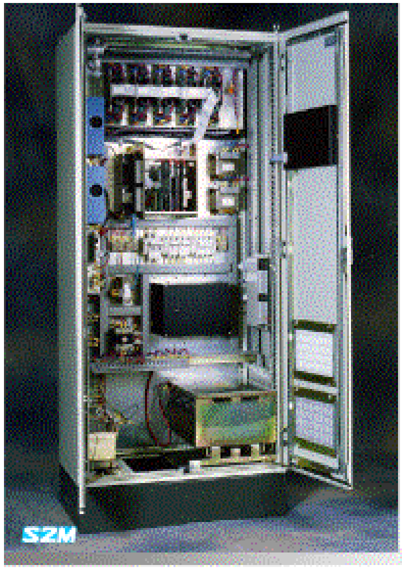


Turbo-Expander – Components

- 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

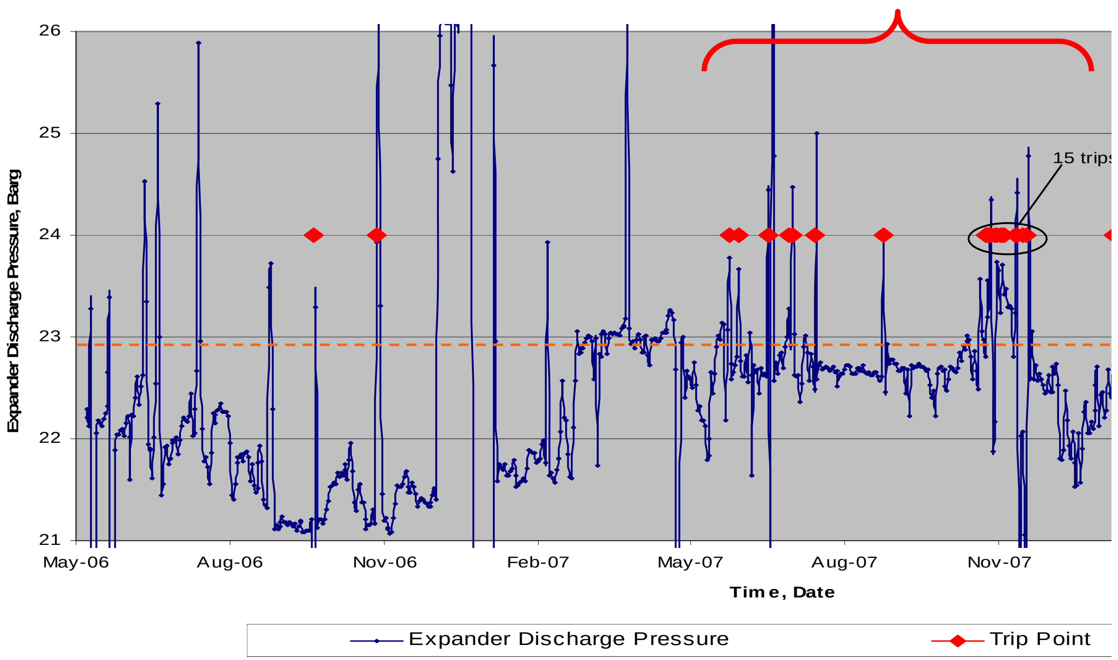




Active Magnetic Bearing
Control Cabinet

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 <u>axial</u> 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

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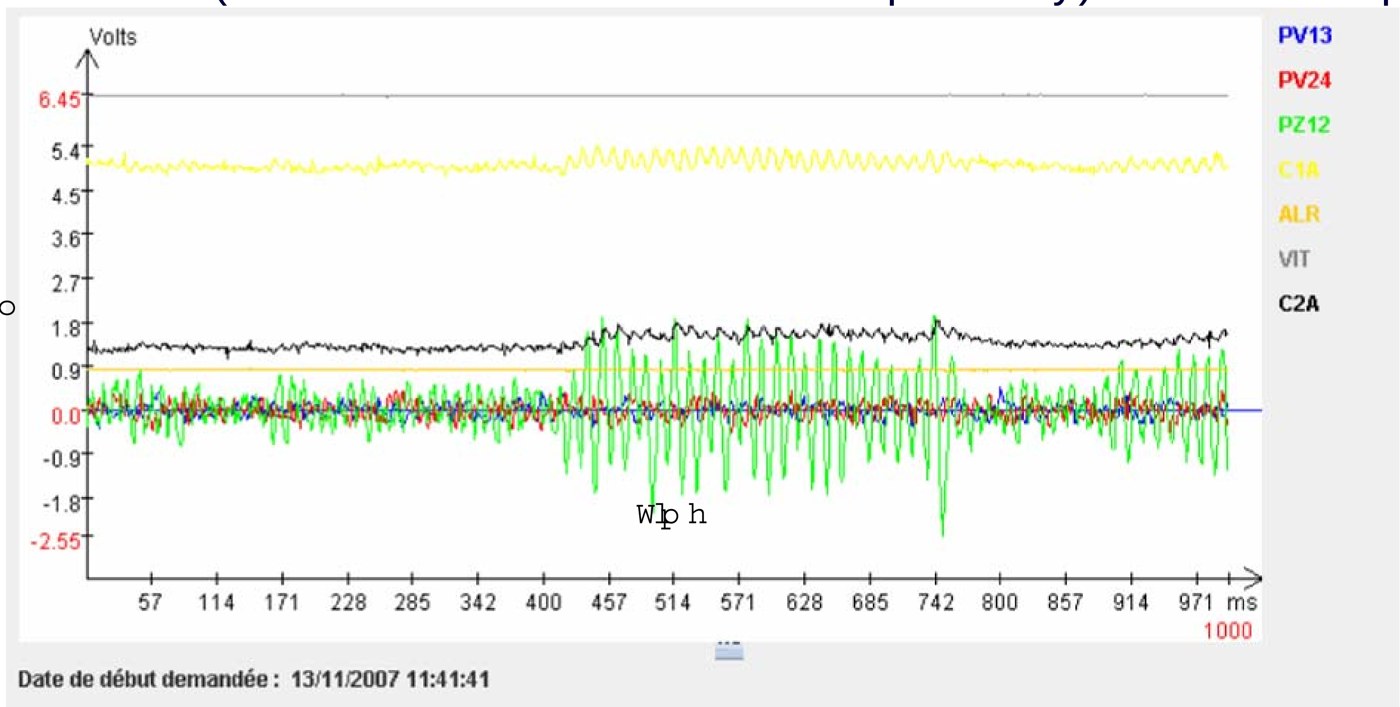
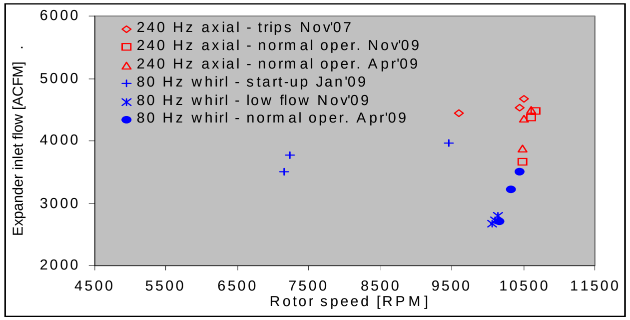
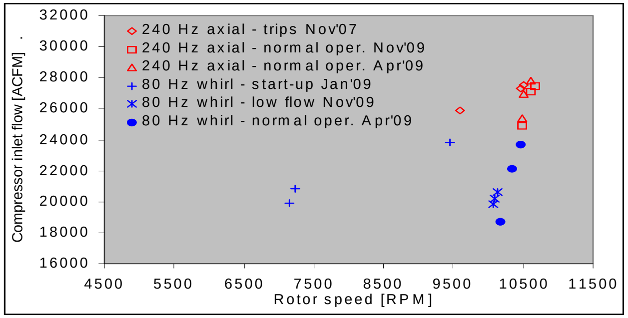
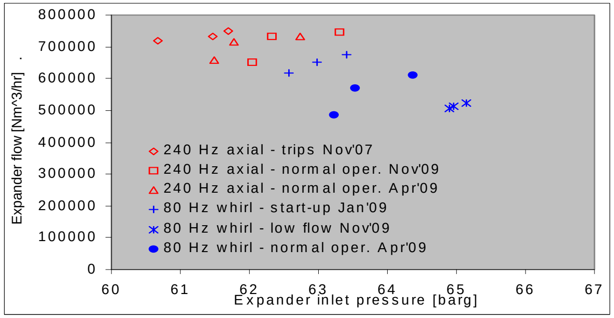


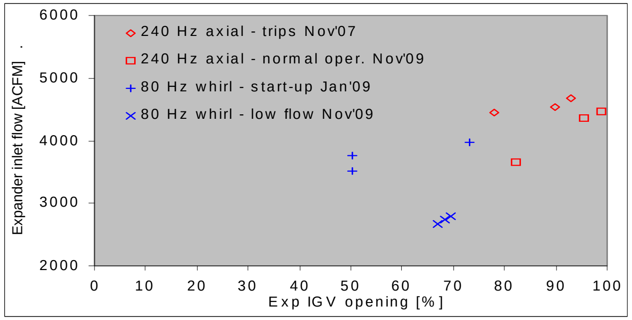
Failure Mode 1 – Axial Shuttling (Surge Failure Z12)

- 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







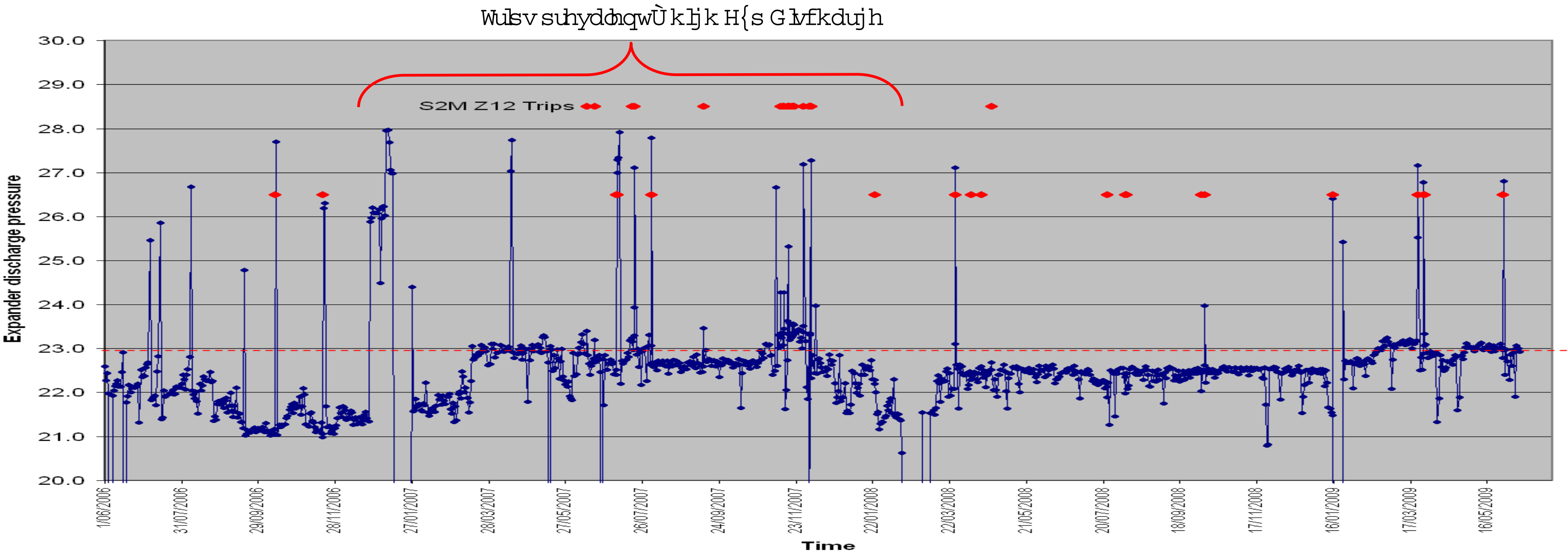


RCA Work/ CA Completed

- 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

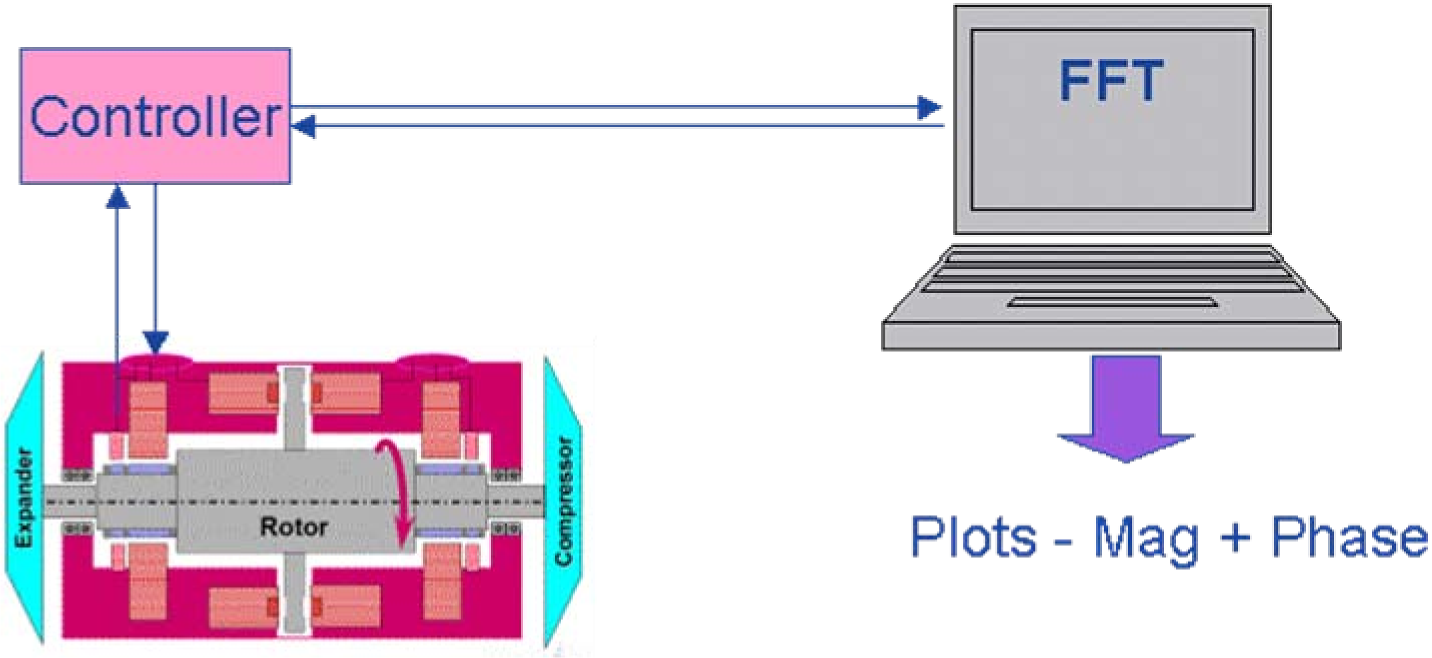
- **<u>No AMB/ Z12 Trips since April 2008</u>**



- 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

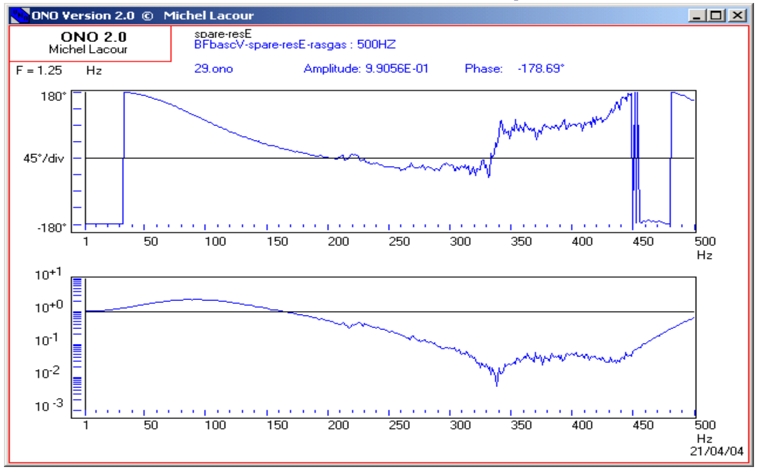
Failure Mode 2 – Transfer Function Changed

- 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 (ie, natural frequencies)
  - Change of TF during active operation is rare, but RasGas experienced twice in 2009

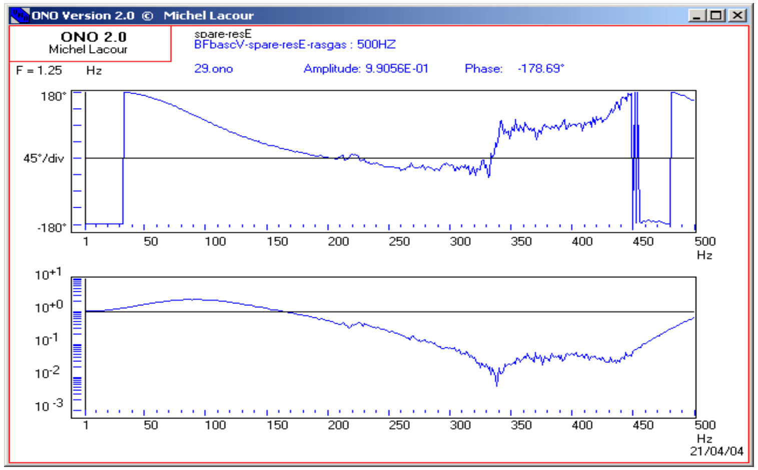


AMB / Rotor Dyn TF Measuement In Field

Translation Closed Loop TF



Tilting Closed Loop TF



- 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.

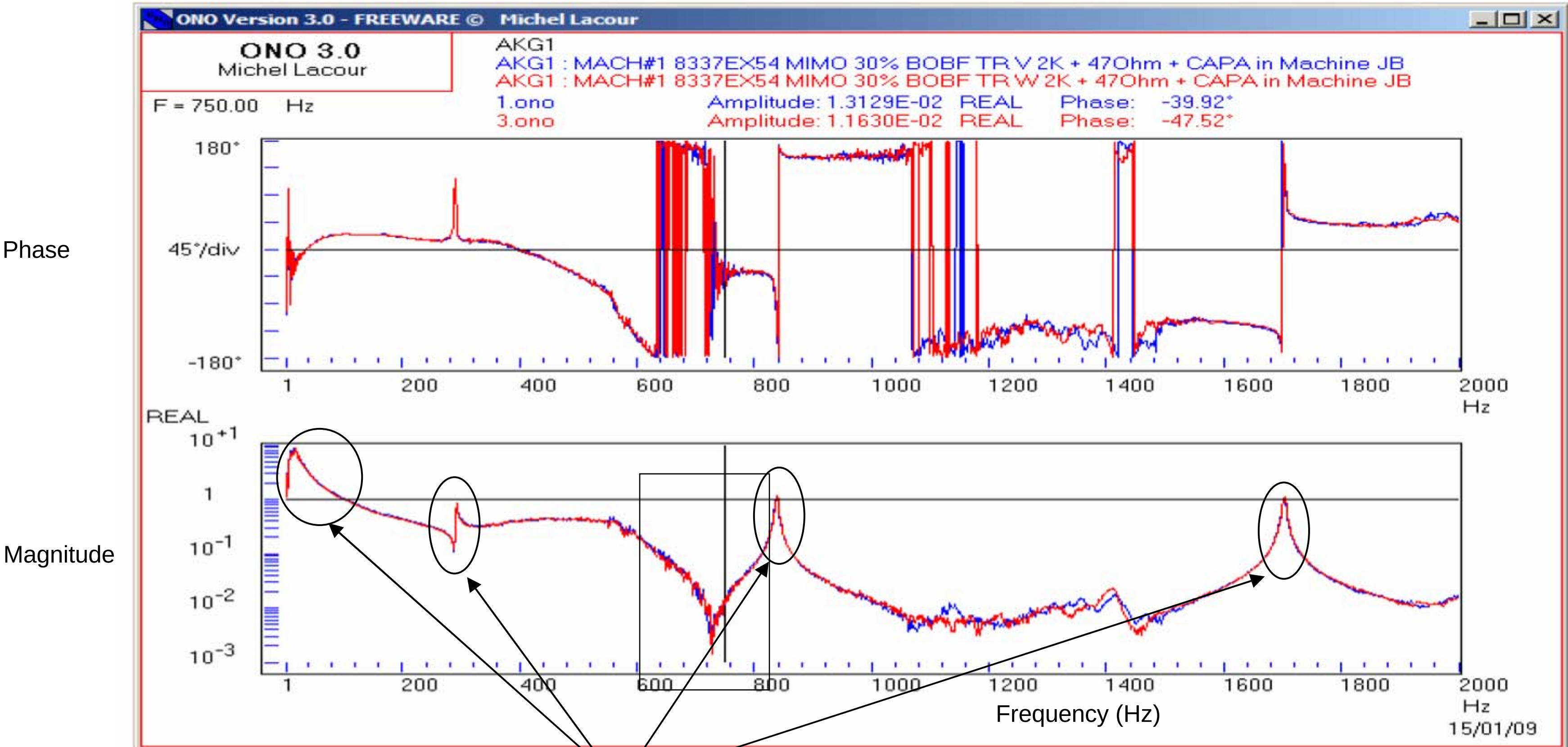
The standard S2M Amplification factor criteria on a close loop transfer function is <2.5

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

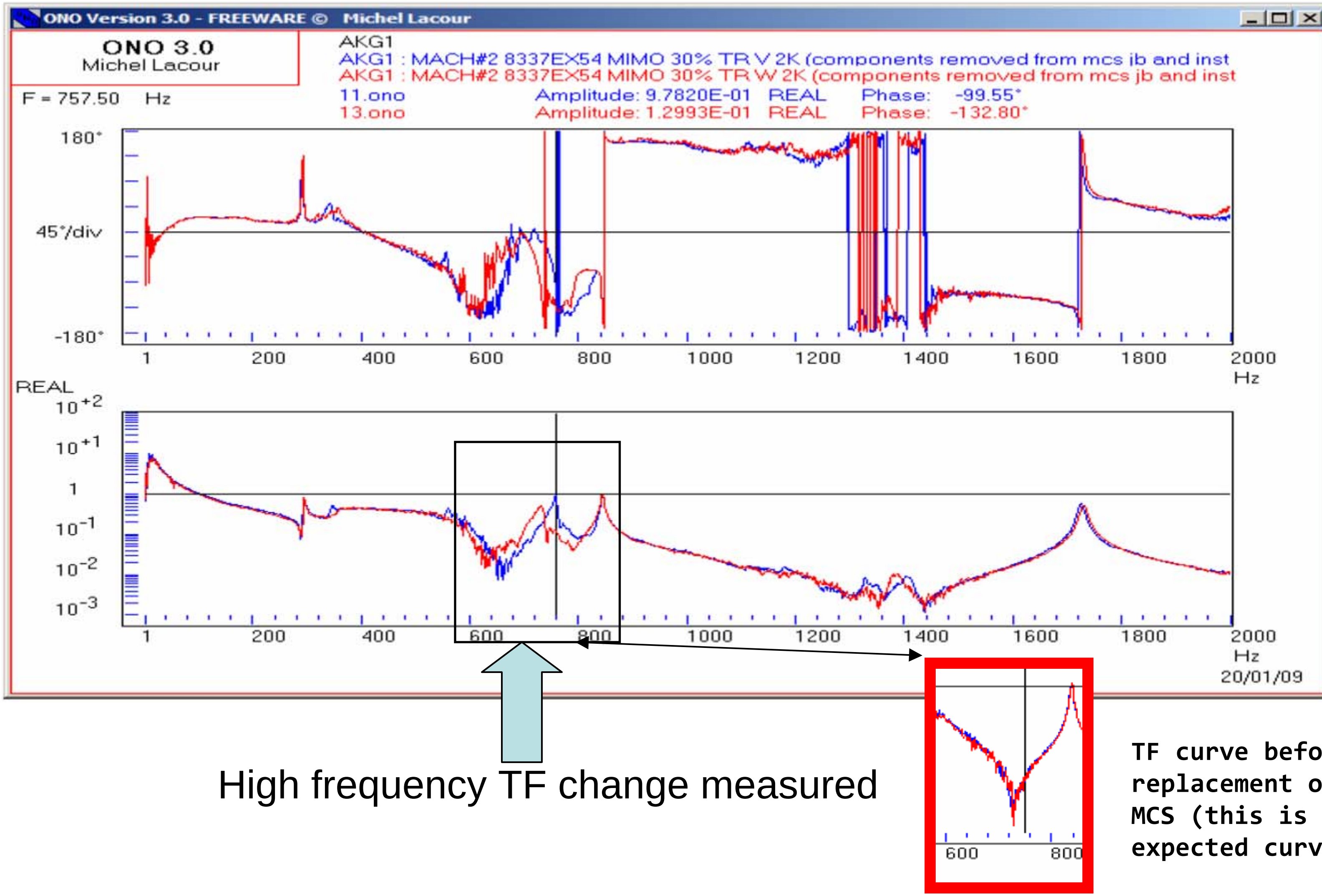
- Low frequency change in Units #2 & #3 unit (*Figure B1*)
  - Cannot restart, reinstall old unit
  - Severe rubs of stator and rotor (photos)
  - Root cause identified

A1 - Typical Transfer Function Plots



- Natural frequencies as per design
- Compared with previous reading – good to go

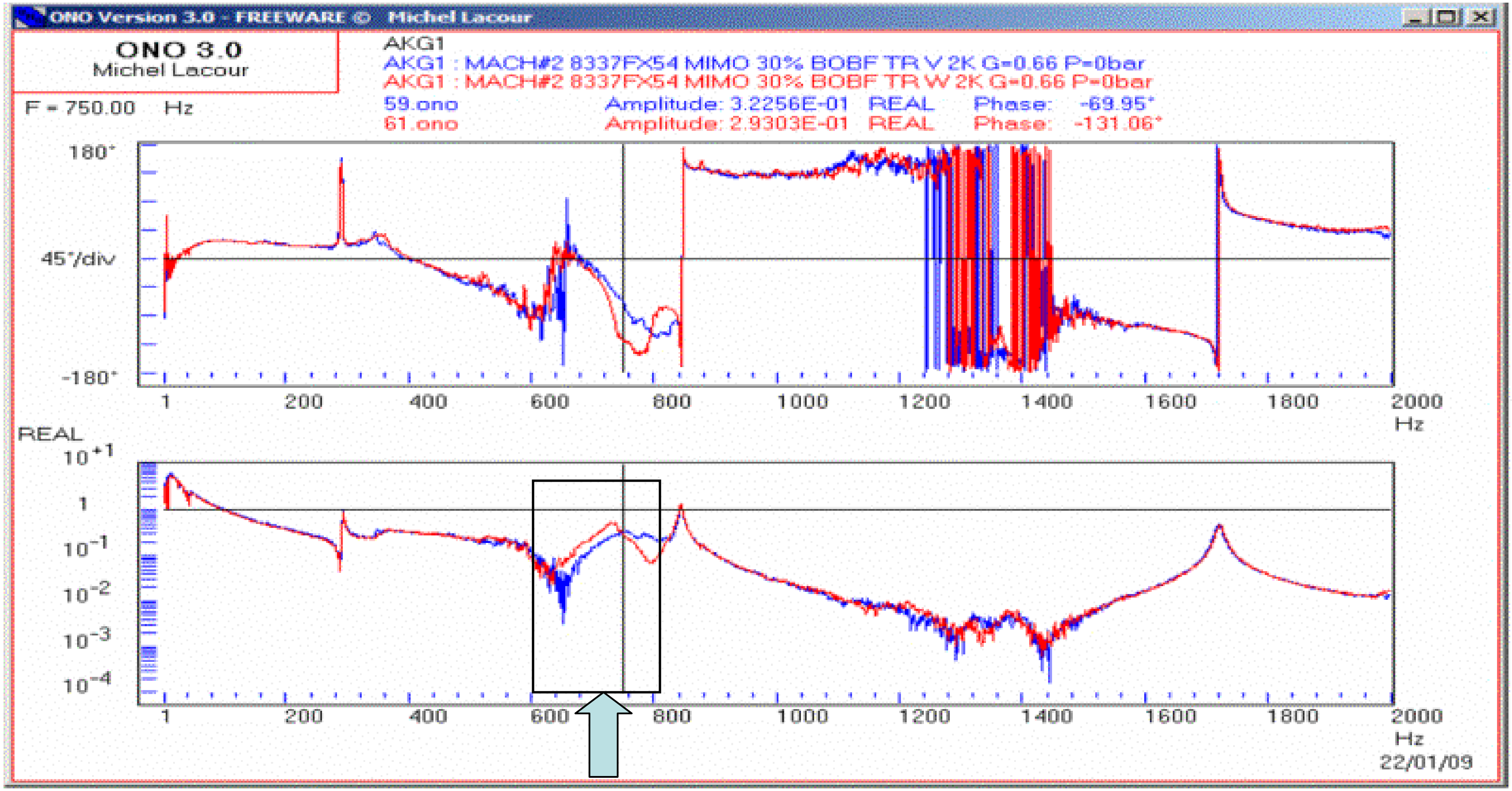
A2 – Unit #1 TF Change at High Frequency



High frequency TF change measured

TF curve before the replacement of the MCS (this is the expected curve).

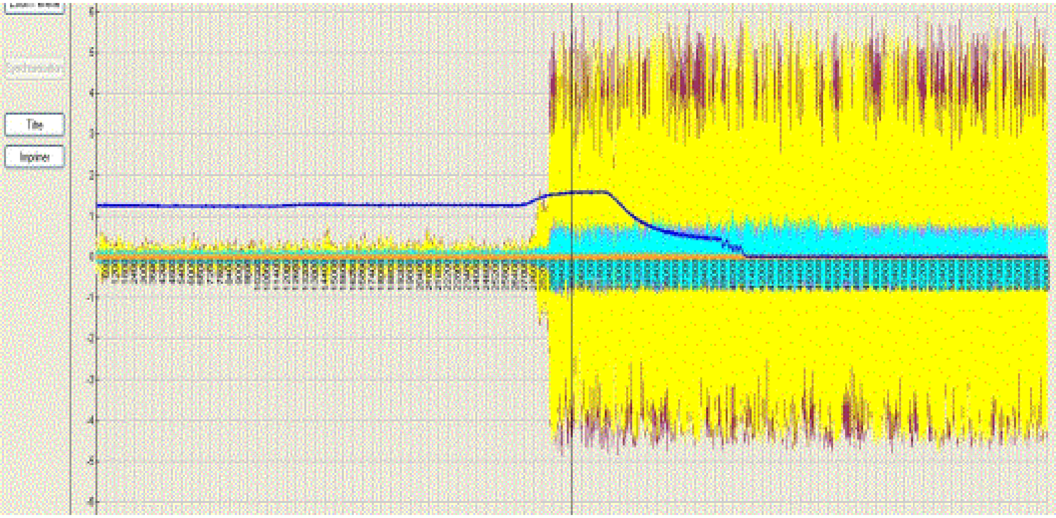
A3 – Unit #1 Controller Modified to Counter TF Change

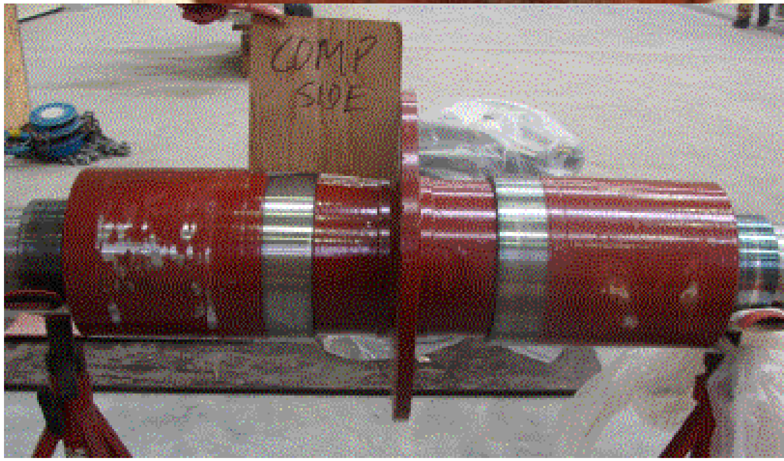


- <u>Controller modified</u> to reduce mismatch response to within acceptable limit

- TEC Operational with no trips, but true fault <u>unknown</u>

B1 – Unit #2 TEC Unstable Vibration following TF Change

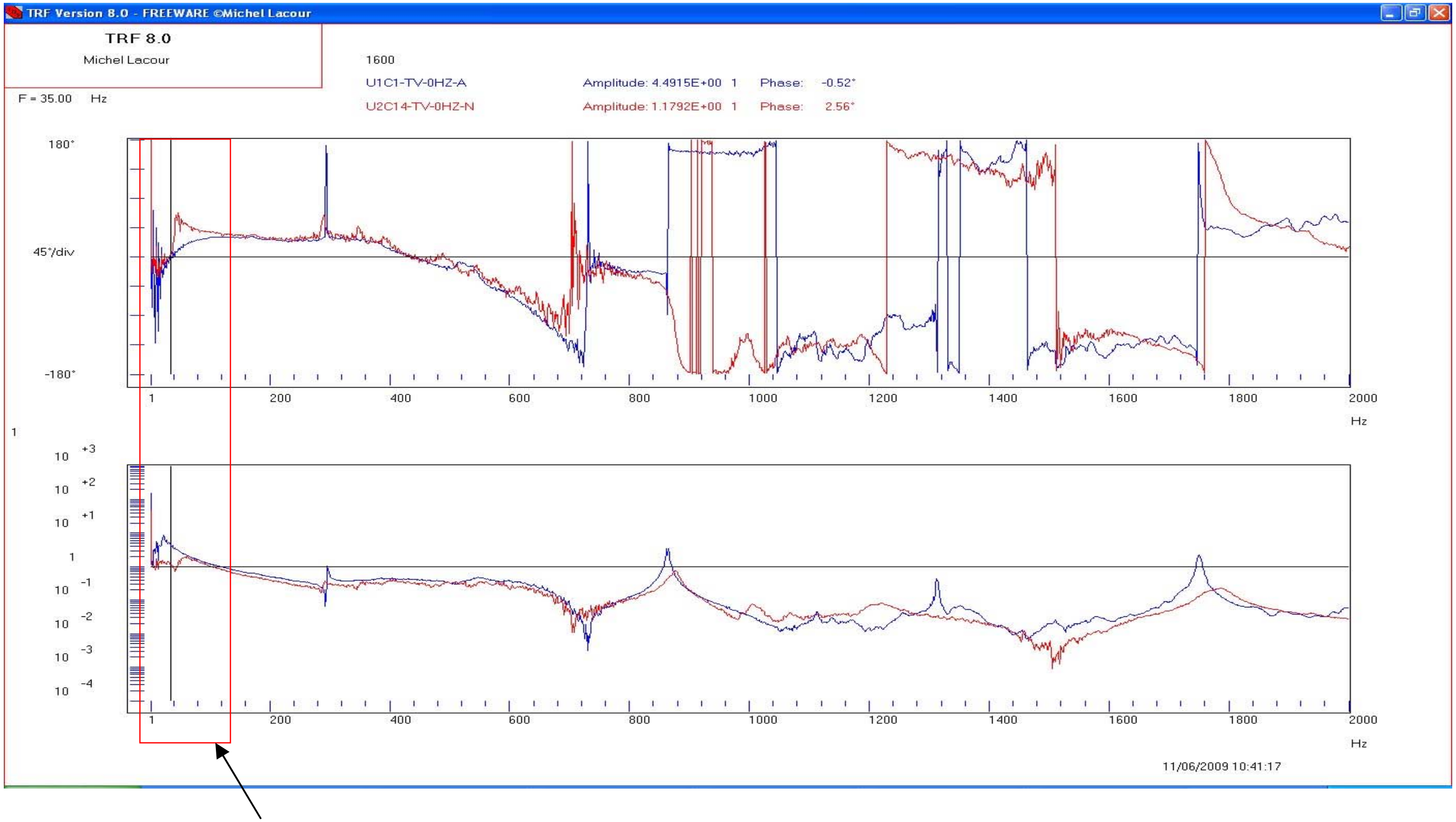




Rubs on shaft and varnish

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

B2 – Unit #2 TF Changed at Low Frequency



- Low frequency response changed
- Indicating instability

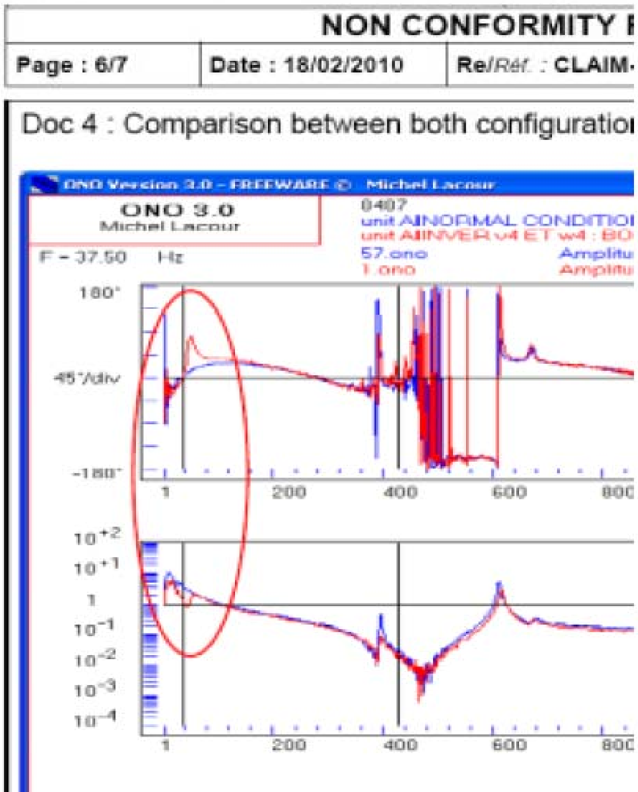
B3 – Unit #2 Machine Center Section Root Cause

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