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

Chong Ong

Jim Cencula

Randy Wu

Marcin Bielecki

Matthias Lelanno

RasGas

GE O&G

GE O&G

GE O&G/ EDC

S2M

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

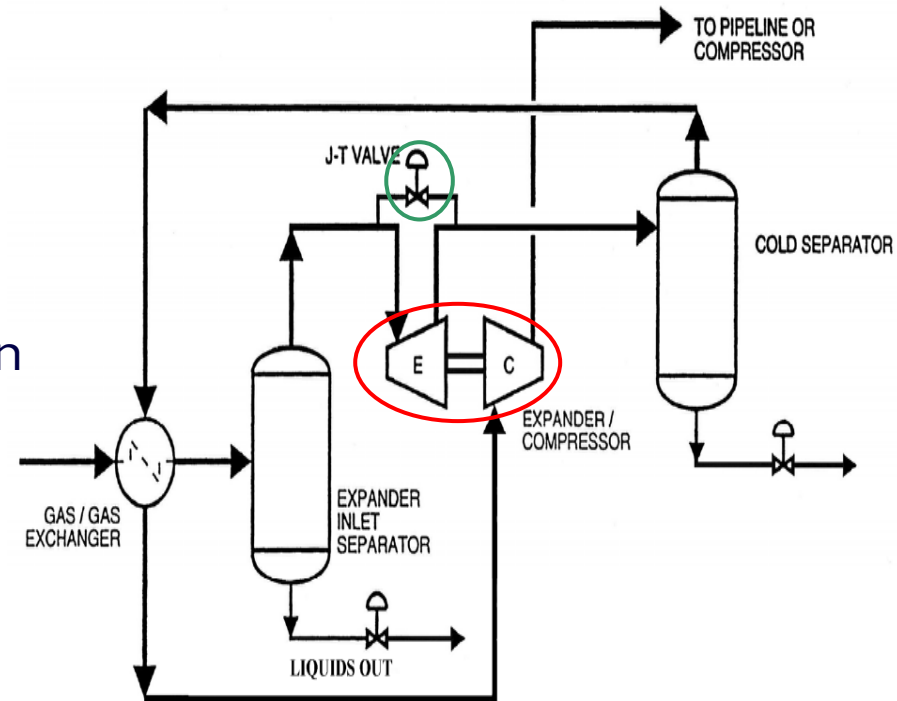
Turbo-Expander - Application

Why is it important

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

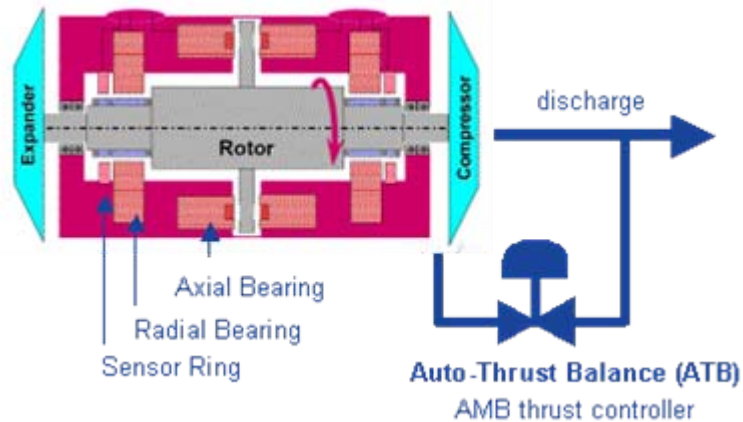
Downtime consequence

- 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

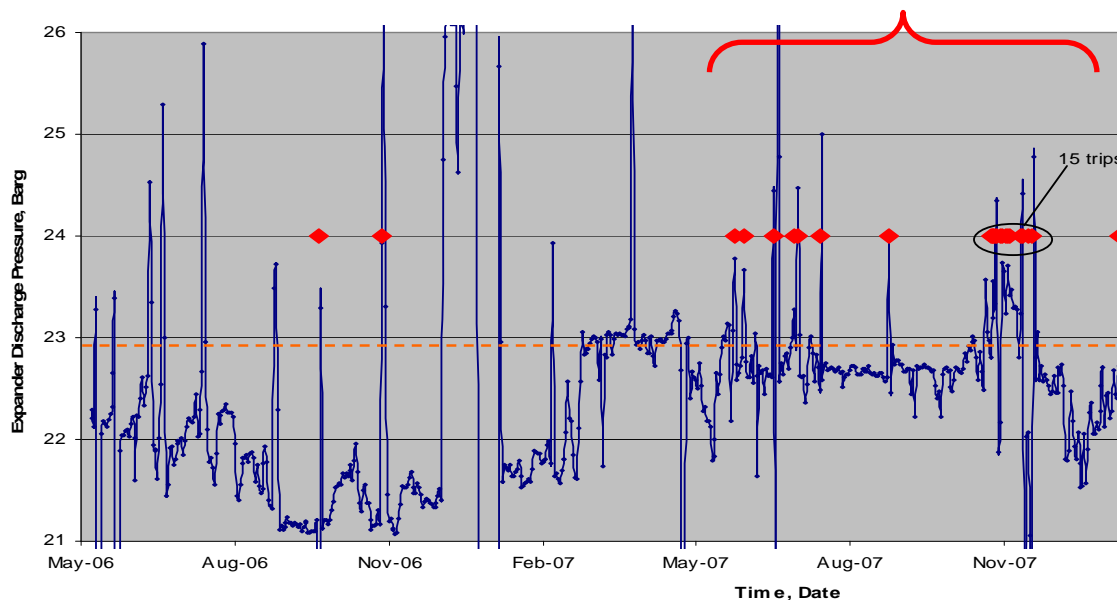
- OEM primary vendor of the TEC single shaft arrangement
- Sub-supplier for Active Magnetic Bearing
- Magnetic bearing is a relatively new technology in this application
- Operator relatively new in application that uses AMB technology



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



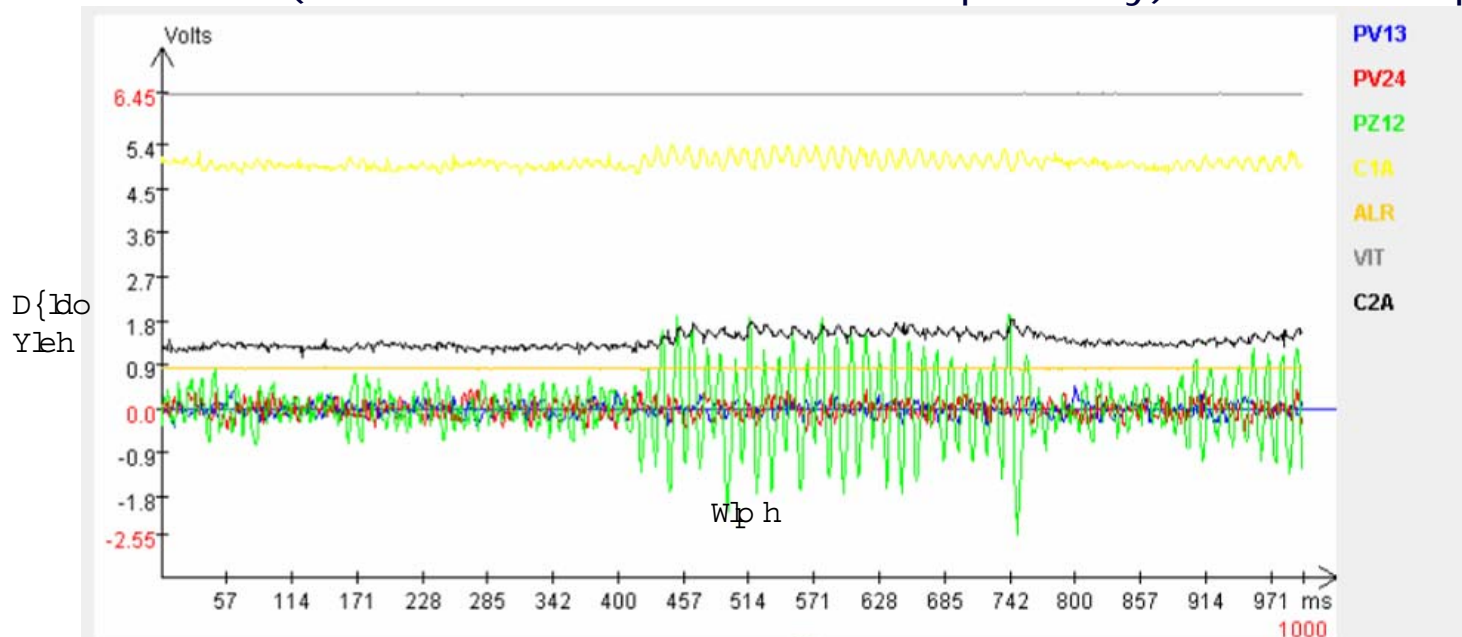
— Expander Discharge Pressure — Trip Point

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

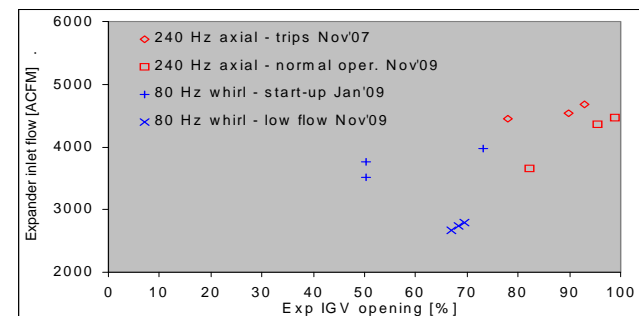
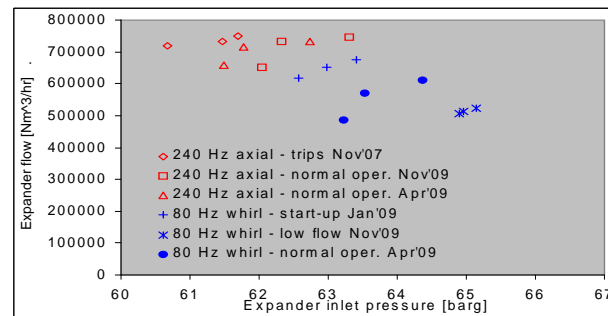
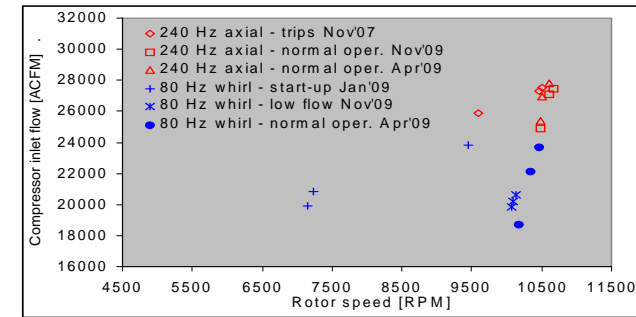
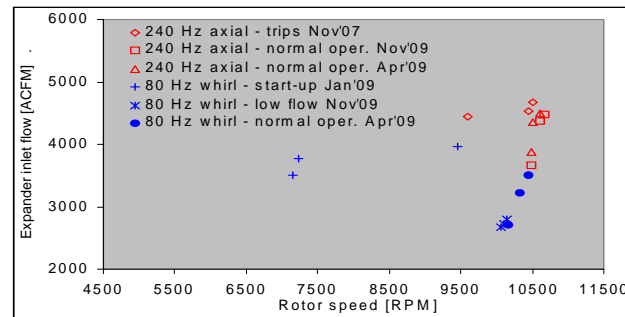
Failure Mode 1 – Axial Shuttling (Surge Failure Z12)

- 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



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

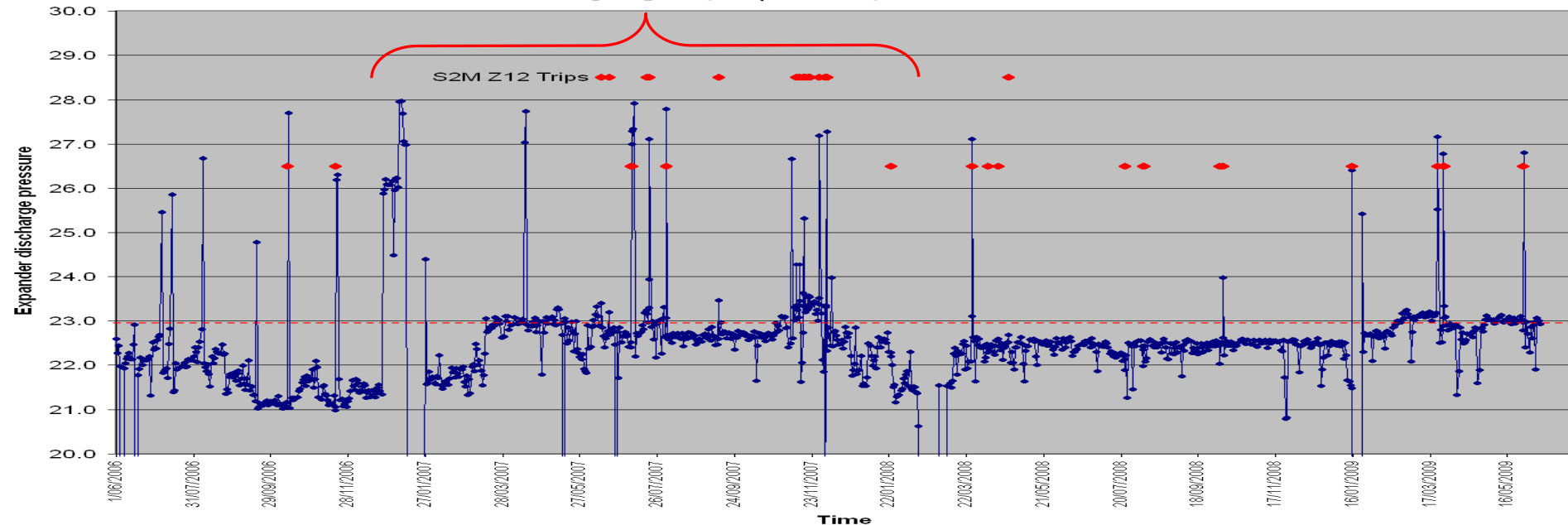
Failure Mode 1 - Current Status

Unit #1 TEC

- No AMB/ Z12 Trips since April 2008

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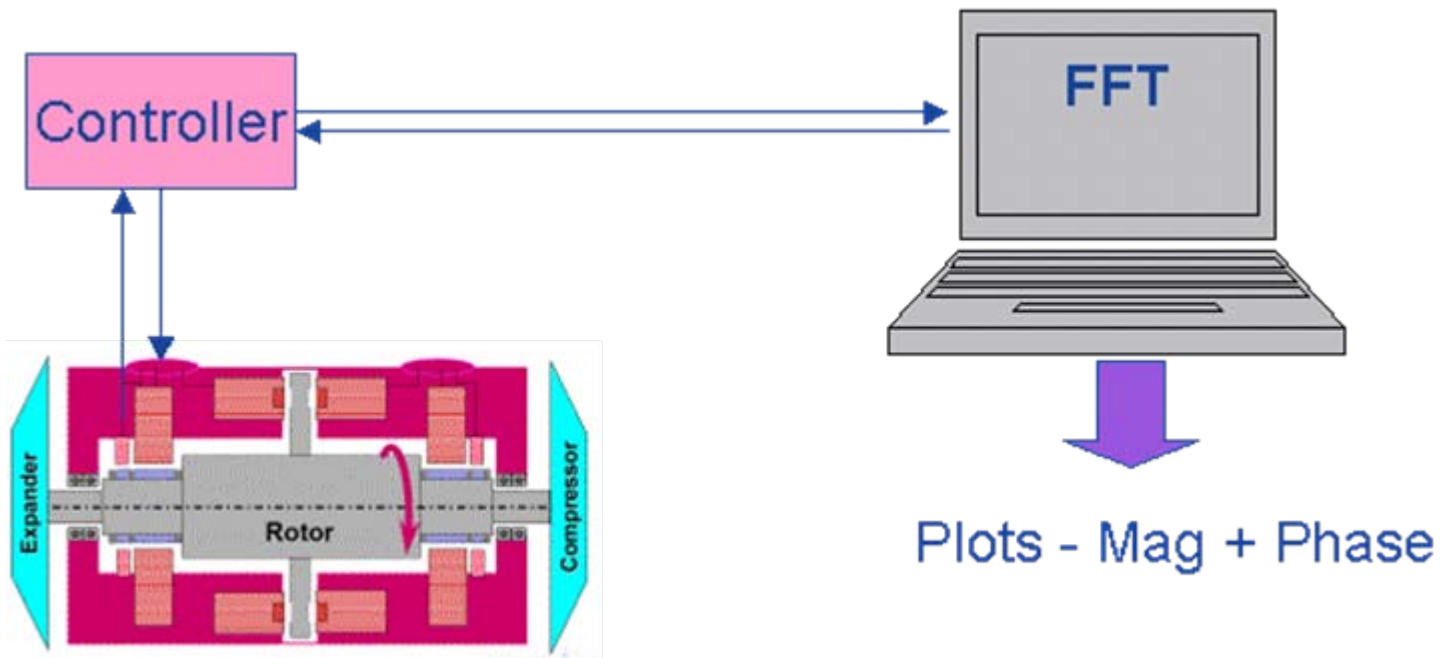
S2M Z12 Trips



- 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

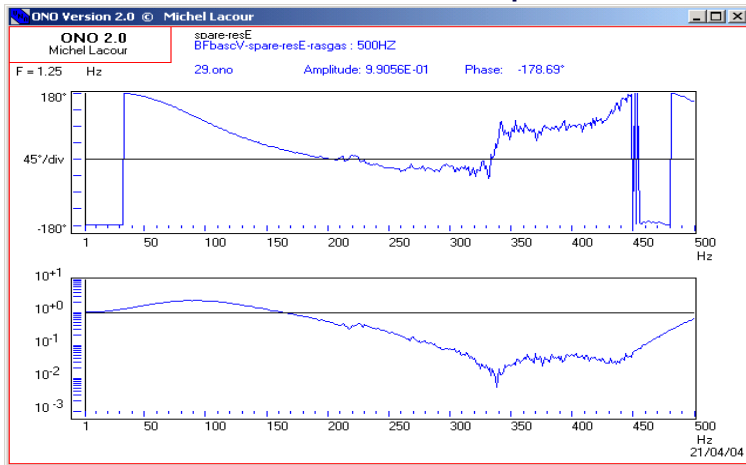
Failure Mode 2 – Transfer Function Changed

- 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



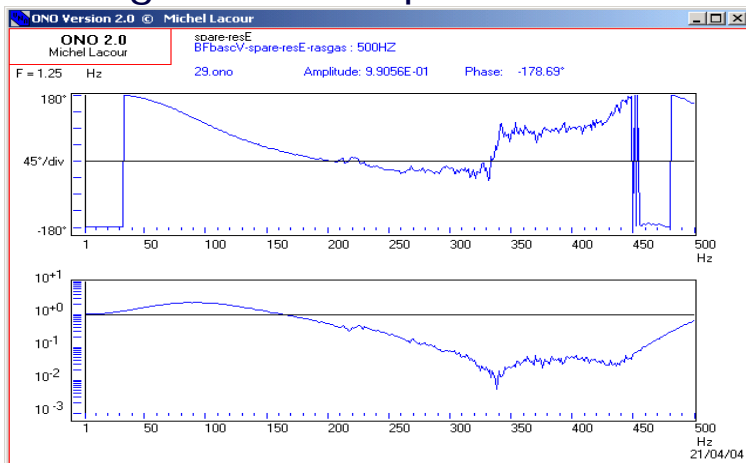
AMB/Rotor Dyn TF Measurement In Field

Translation 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.

Tilting Closed Loop TF



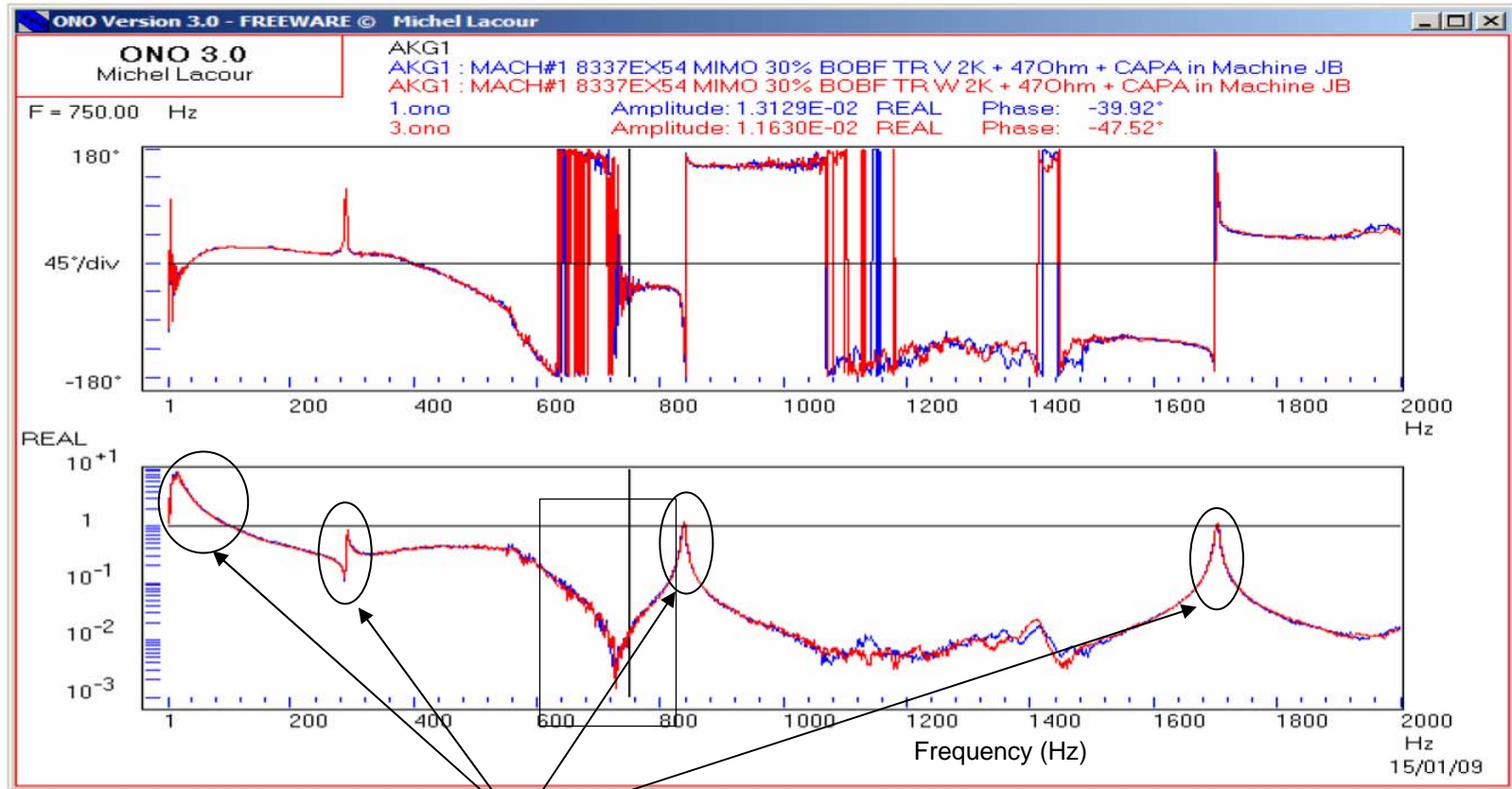
- Closed Loop TF should be measured with machine in operation to have confirmation on stability margins.

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

Failure Mode 2 – Transfer Function Changed

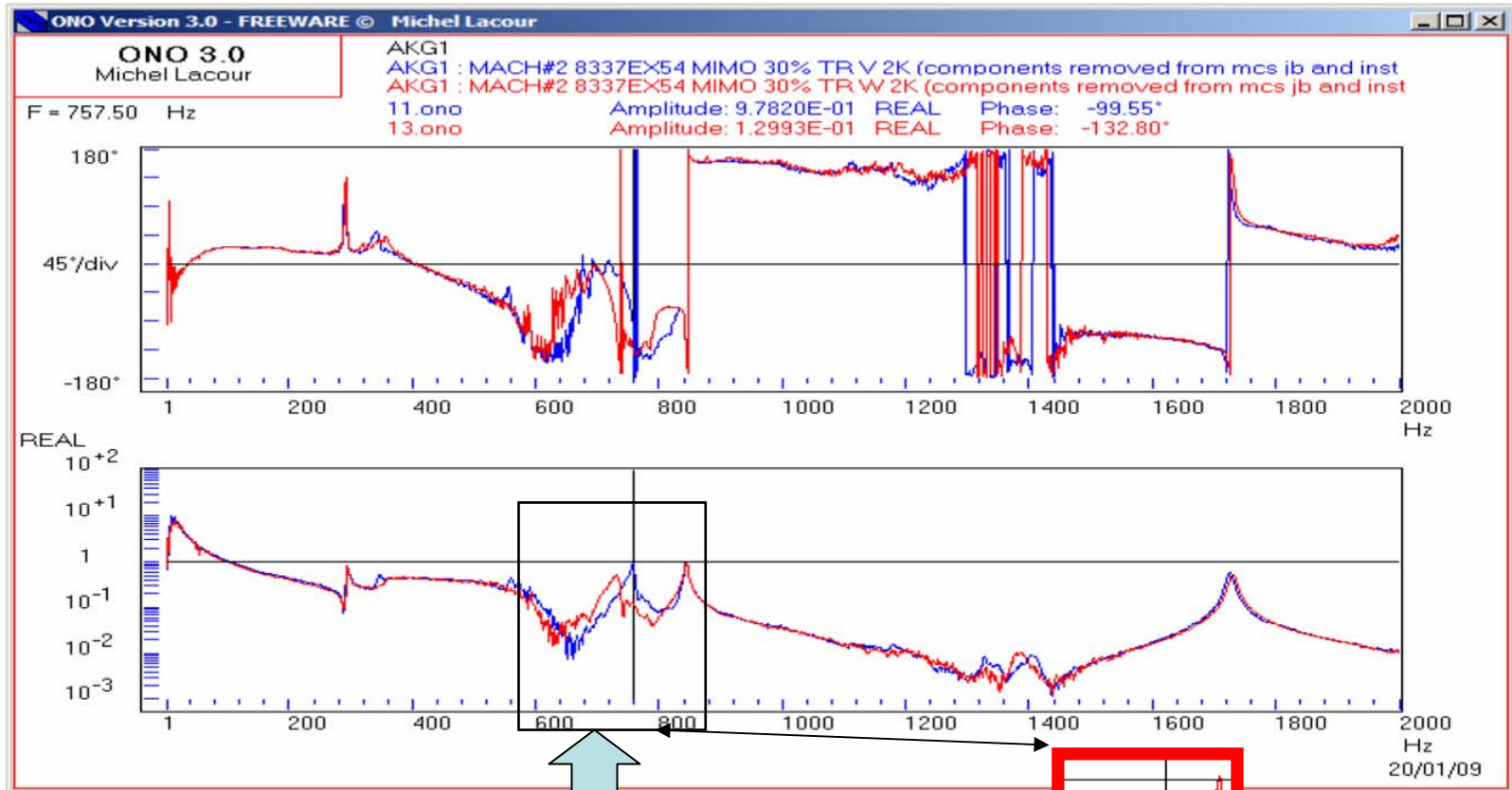
- High frequency TF change in Unit #1 unit (*Figures A1-A3*)
 - Mitigated by software modification
 - Machine operational, but fault unknown
- Low frequency change in Units #2 & #3 unit (*Figure B1*)
 - Cannot restart, reinstall old unit
 - Severe rubs of stator and rotor (photos)
 - Root cause identified

A1 - Typical Transfer Function Plots

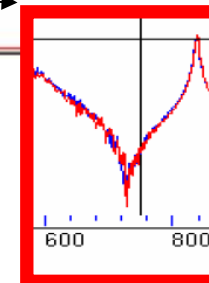


- Natural frequencies as per design
- Compared with previous reading – good to go

A2 – Unit #1 TF Change at High Frequency

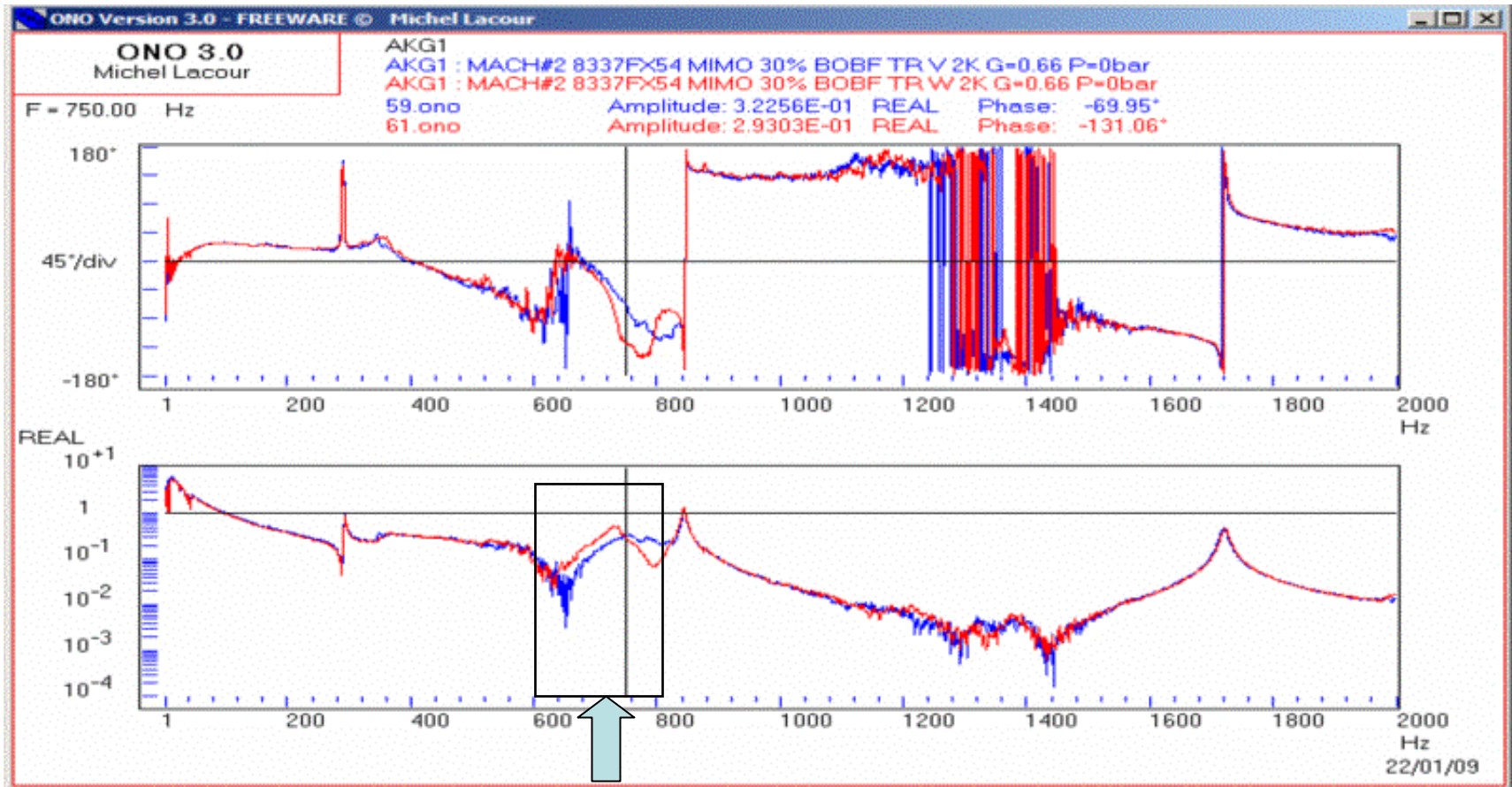


High frequency TF change measured



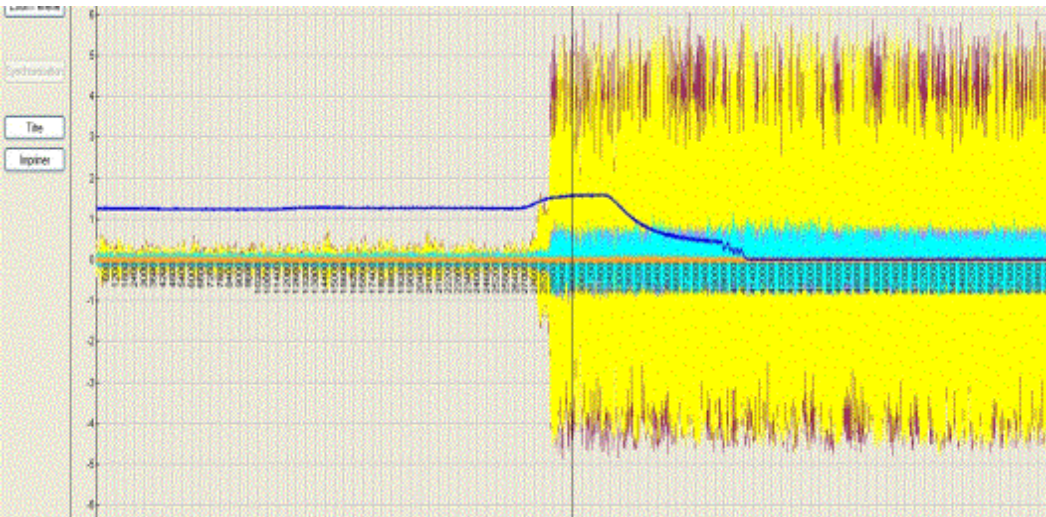
TF curve before the replacement of the MCS (this is the expected curve).

A3 – Unit #1 Controller Modified to Counter TF Change



- Controller modified to reduce mismatch response to within acceptable limit
- TEC Operational with no trips, but true fault unknown

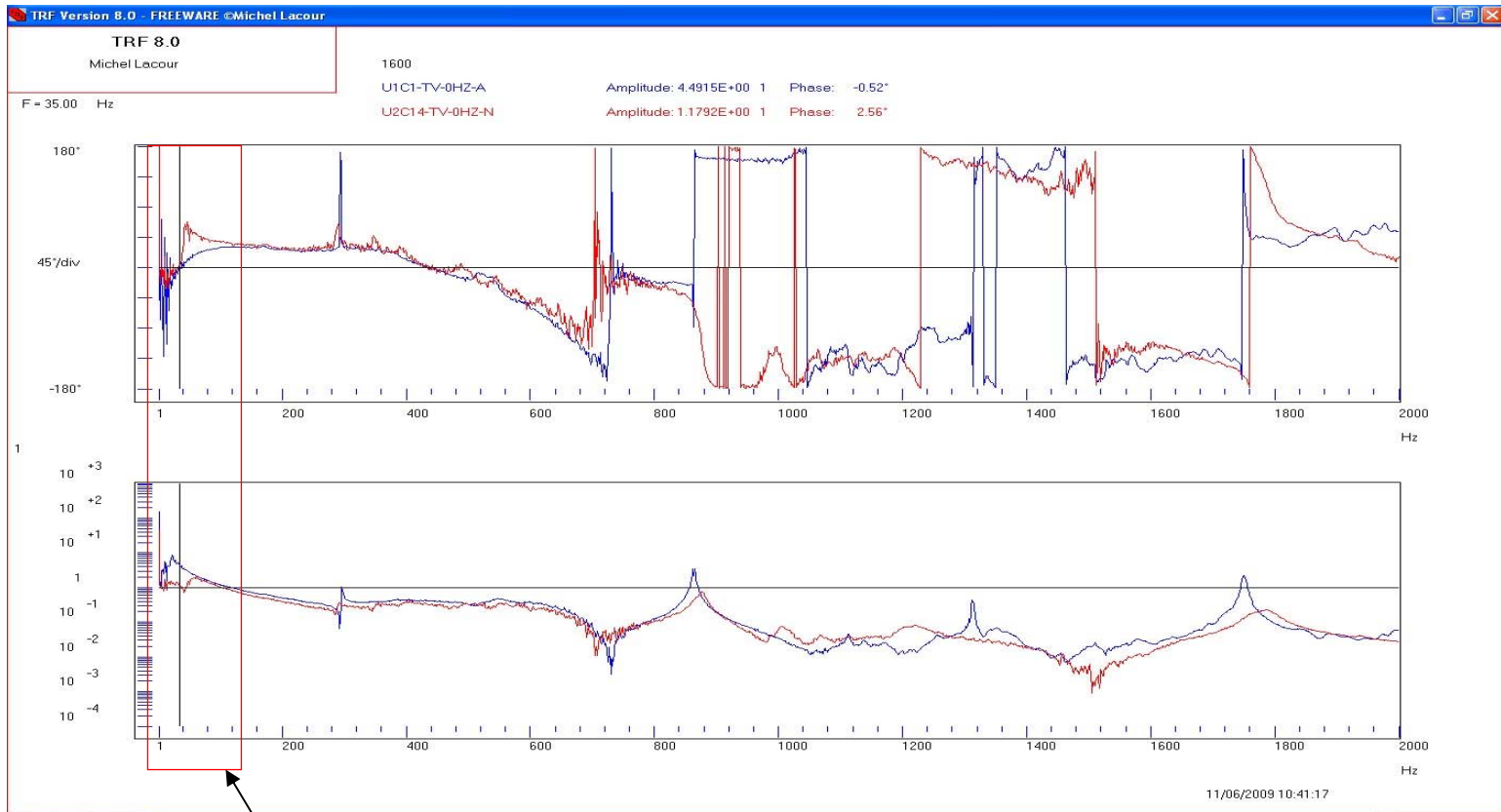
B1 – Unit #2 TEC Unstable Vibration following TF Change



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

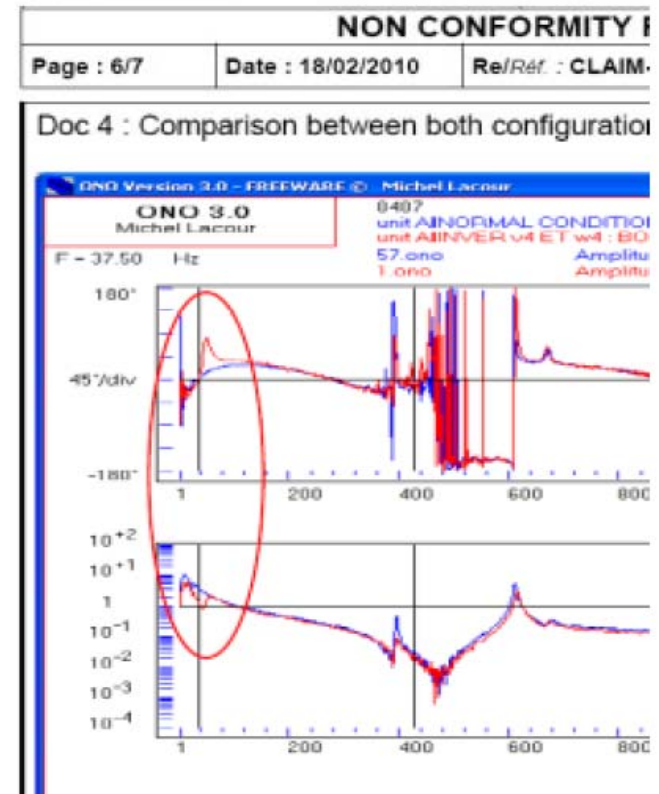
B3 – Unit #2 Machine Center Section Root Cause

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