WORLD-CLASS OUTSTANDING INTERNATIONAL

PROGRAM | EXHIBITION | NETWORKING

ANALYSIS OF ROTOR RUB IN A LARGE CENTRIFUGAL REFRIGERATION COMPRESSOR

CASE STUDY

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1. Abstract

- The purpose of this case study is to present an investigation of substantial damage to the rotor of a large centrifugal propane refrigeration compressor that is installed in an 800 MTPA Ethylene plant.
- After ten years of normal operation since its commissioning, the compressor was shut down during the plant's scheduled turnaround to carry out peripheral inspection. As the speed of the compressor–steam turbine train was reduced; an abnormal sound was heard by the field operators.
- Instead of looking for the possible cause(s), the shutdown sequence was completed.

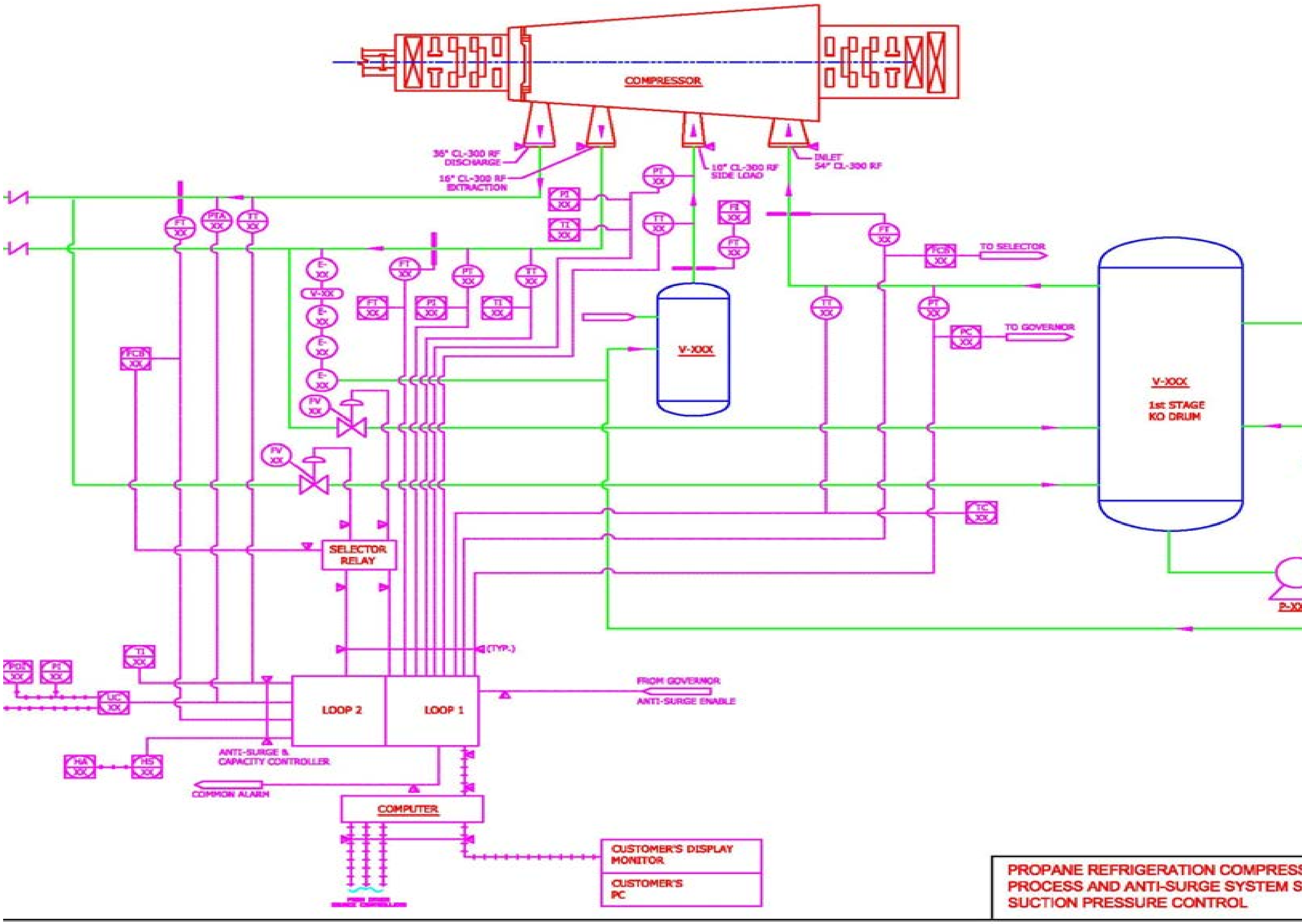
1. Abstract contd..

- Even twenty four hours after shutdown, the compressor’s casing remained unusually hot. This was a cause of concern. After deliberations, the train was isolated and released for external inspection.
- On decoupling the compressor, it was noticed that its rotor could not be moved axially and many attempts to turn the shaft to verify if there was binding proved to be unsuccessful.
- This case study outlines the sequence of events, the details of inspection, and the root cause analysis of the failure. It concludes with an understanding of thermal rub phenomenon and the primary causes which resulted in rotor-to-stator scuffing.

2. Compressor’s Constructional Details

- The Propane compressor’s casing is horizontally split and made of fabricated steel. Its nominal capacity is 140,000 CFM (3,964.4 m^3/min) and the pressure rating is 325 psig (~2,241 kpag). The rated power at the compressor’s shaft end is 51,000 HP (38,030 kW).
- The compressor has four main process nozzles.
- The interstage seals are the straight labyrinth type, made of aluminum. The balance piston diameter is 32” and its seal is made of non-interlocking lead which has a temperature limit of 350 ºF (~177 ºC).
- The Propane compressor has one anti-surge loop as shown in the schematic.

2A. Compressor Process Schematic



3. Root Cause Failure Analysis

Problem Statement:

- Using opportunity of the plant's scheduled turnaround, the compressor was shut down to carry out peripheral inspection and conduct overspeed trip test of its driver steam turbine.
- As the speed of the compressor was being lowered, an abnormal noise was heard from the machine by the field operators.
- In a rush to stop the compressor, shutdown sequence was continued without investigating and checking for the source of abnormal noise. Compressor load reduction and shutdown activities were completed during night shift by the plant's operations group.

3. Root Cause Failure Analysis contd..

- The compressor's casing remained hot even after several hours following the shutdown. Therefore it was decided to uncouple the machine and turn its rotor. After many attempts to turn the compressor shaft failed, it was surmised that the rotor was seized inside the casing presumably due to rotor-to-stator activity.

Inspection:

- Except for instrumented radial bearings, the other spare parts were available. The spare rotor was removed from its storage container, cleaned and examined.
- Upon disassembly of the compressor, the following observations were made.

3. Root Cause Failure Analysis contd..

a. Severe heat indications (heat marks) were noticed on the balance piston and the balance piston seal was found to be destroyed. This was the only region of the rotor affected by friction induced thermal distress.

b. The rotor was seized in the casing at the balance piston location.

c. Shaft runout was found to be 2.5 mil (63.5 μm), much more than the manufacturer's allowable limit of 1.0 mil (25.4 μm). The shaft had bent at the drive end.

3. Root Cause Failure Analysis contd..

Compressor rotor being removed from the lower half casing.

3. Root Cause Failure Analysis contd..

Investigation of the Failure Mode:

- Controlled shut down of this compressor involves many steps. The following precautions are critical for its safety.

a. Reduce load to 50%.

b. Disable remote speed control.

c. Reduce load further by reducing speed until the load has dropped to 5% of its full load.

d. Open anti-surge (recycle valve) as speed is lowered. This is supposed to be an automatic anti-surge controller action.

- Subsequent stop sequence results in closure of the turbine's governor valves and its Trip&Throttle (T&T) valve.

3. Root Cause Failure Analysis contd..

- The incident investigation team led by the author initiated a structured approach which primarily focussed on –

a. The timing (decision to stop a critical equipment in night shift instead of in day shift),

b. Trend record of the process data during normal and steady-state conditions as well as when the stop sequence was initiated, and

c. Transient data from online machine monitoring and diagnosis system.

- It was revealed that after reducing the compressor’s load to 50% of the full load, the operators had shifted its anti-surge controller from automatic to manual mode.

3. Root Cause Failure Analysis contd..

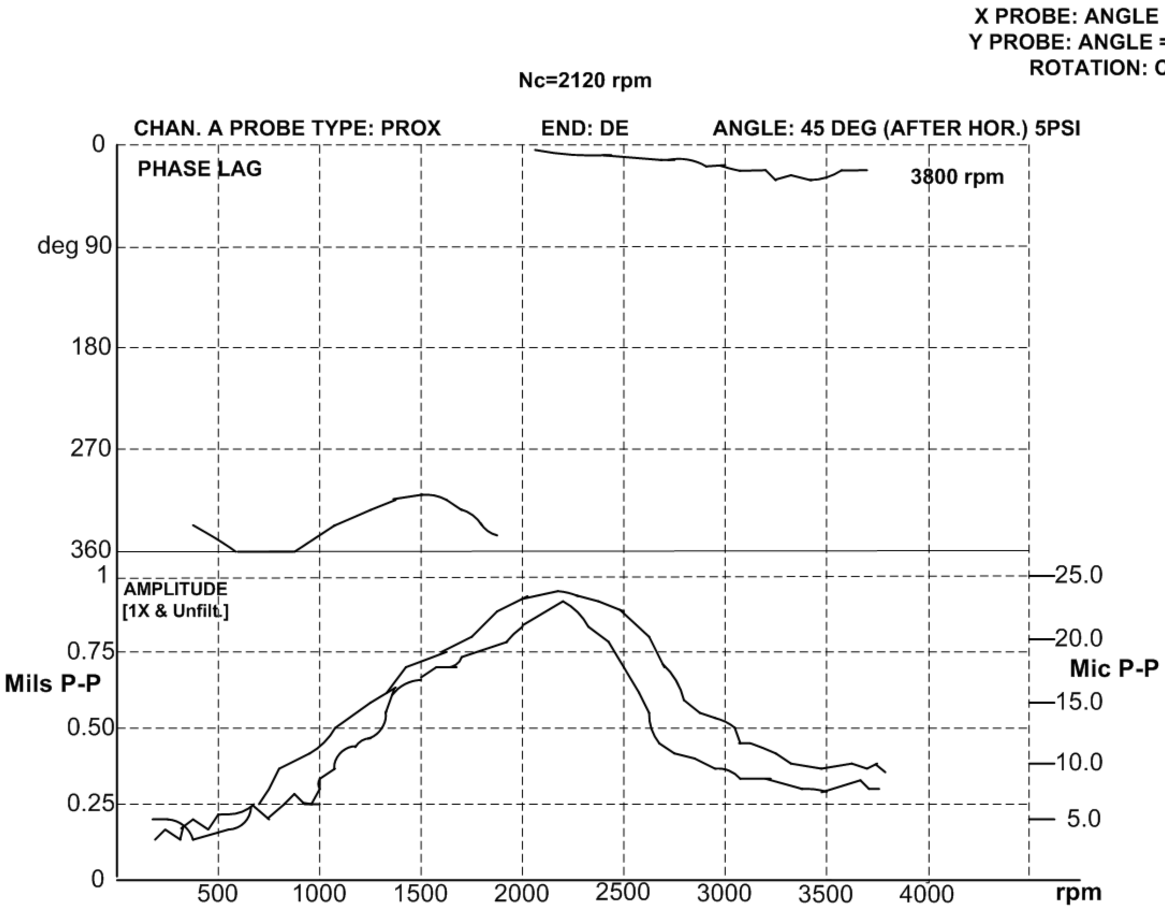
- In their intent to manually control the anti-surge valve to minimize recycle flow, the operators had compromised the safety of the machine.
- As the speed was reduced to correspond with further load reduction, the surge limit line was crossed, with resultant flow reversals within a span of 20 - 40 milliseconds.
- The energy level associated with the flow reversals imposed shock loading on the compressor's rotor with consequent change in the shaft centerline position and increase in its vibrations.

3. Root Cause Failure Analysis contd..

- The compressor rotor’s calculated first critical speed is 2120 rpm. As the operating speed was reduced to below the critical speed, the radial vibrations became more prominent, both in p-p amplitude and phase.

3. Root Cause Failure Analysis contd..

Bode Plot during Compressor's deceleration



3. Root Cause Failure Analysis contd..

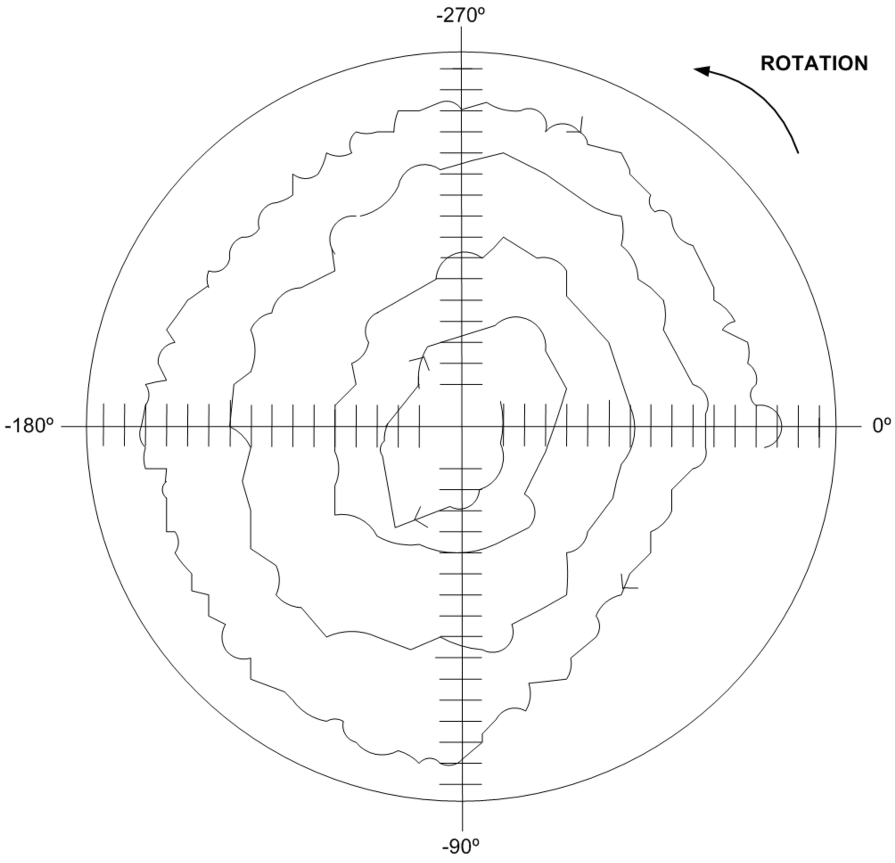
- The change in radial vibrations was 35%, from normal 0.67 mil (17 μm p-p) to 0.90 mil (23 μm p-p). High vibration alarm is set at 0.98 mil (25 μm p-p).
- The panel operators had ignored increasing vibration amplitude at both radial bearings and also the shift from normal thrust.
- With elevated vibration level, clearance at the balance piston seal was eventually exceeded and its rotating labyrinths rubbed with the stationery lead seal lining, causing friction that negatively impacted the rotor's stiffness.
- Rub at the balance piston seal caused localized heating and expansion.

3. Root Cause Failure Analysis contd..

- It is mentioned earlier in this case study that the temperature limit of the lead seal installed in this compressor is 350 ºF (~177 ºC). The investigators concluded that the rub induced heat was severe enough to destroy the lead seal and the localized expansion caused the shaft to bend, thus adding to unbalance.
- In addition to frequency-amplitude spectrum, the polar plot data generated by the online data acquisition software also showed 1X signal's orbital motion within the radial bearings in the 15-minutes time period prior to full stop. This is a distinctive characteristic of thermal rub phenomenon.

3. Root Cause Failure Analysis contd..

Polar Plot at Compressor Non-Drive End Radial Bearing

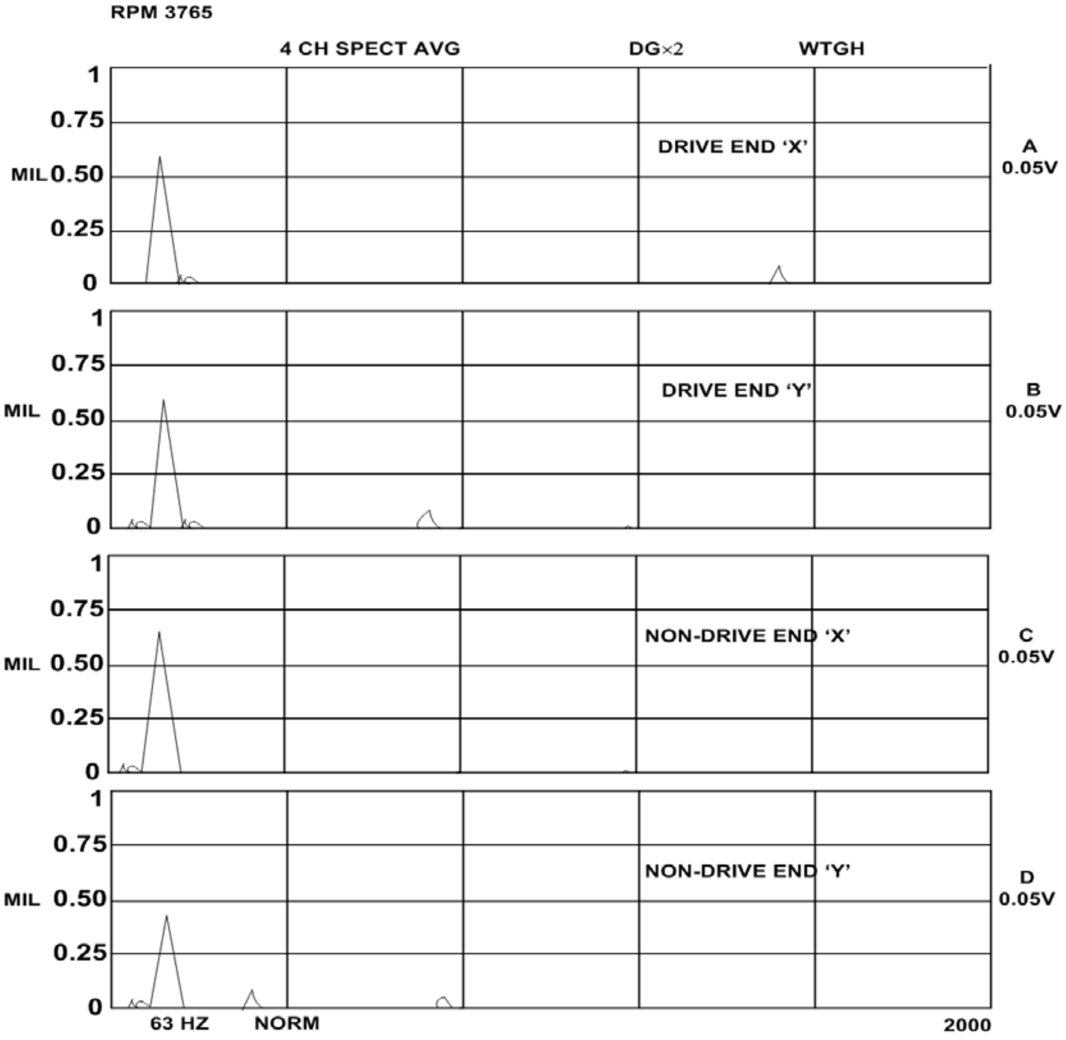


4. Corrective Actions and Results

- Damage to the compressor's rotor and balance piston static seal required a complete overhaul of the machine. The replaced components included the spare rotor, new mechanical contact shaft end seals, interstage labyrinth seals and lead lined seal for the balance piston.
- After verifying the clearances and completing dimensional and visual checks, radial bearings and thrust bearing were re-installed in the compressor.
- The machine was assembled, coupled and restored into service after this overhaul. It is since operating normal, with steady-state overall vibration amplitude of 0.63 mil (16 microns p-p). Compressor rotor's thrust position is 8 mil in normal direction (0.20 mm) and bearing metal temperatures are at pre-shutdown level,162 ºF (72 ºC).

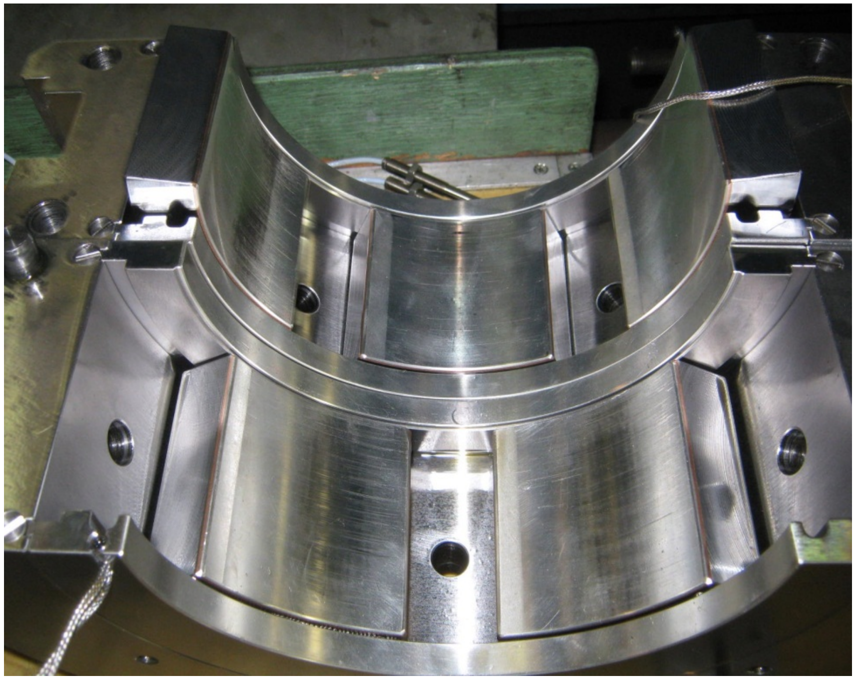
4. Corrective Actions and Results

Amplitude *vs* Frequency Spectrum after overhaul



4. Corrective Actions and Results contd..

New Drive End Radial Bearing



New Active Side Thrust Bearing

4. Corrective Actions and Results contd..

Spare Rotor installed in the casing

5. Lessons Learned

a. Start-up and shutdown of plant's critical machines must be carried out by experienced people and during normal day hours when support technical staff is available.

b. Periodic refresher training for the operating personnel is essential to highlight the significance of automated control and safety systems.

c. Equally important is their understanding of the machine's response to disturbances and the potential for damage if they fail to take timely corrective actions.

Thank You for Your Attention