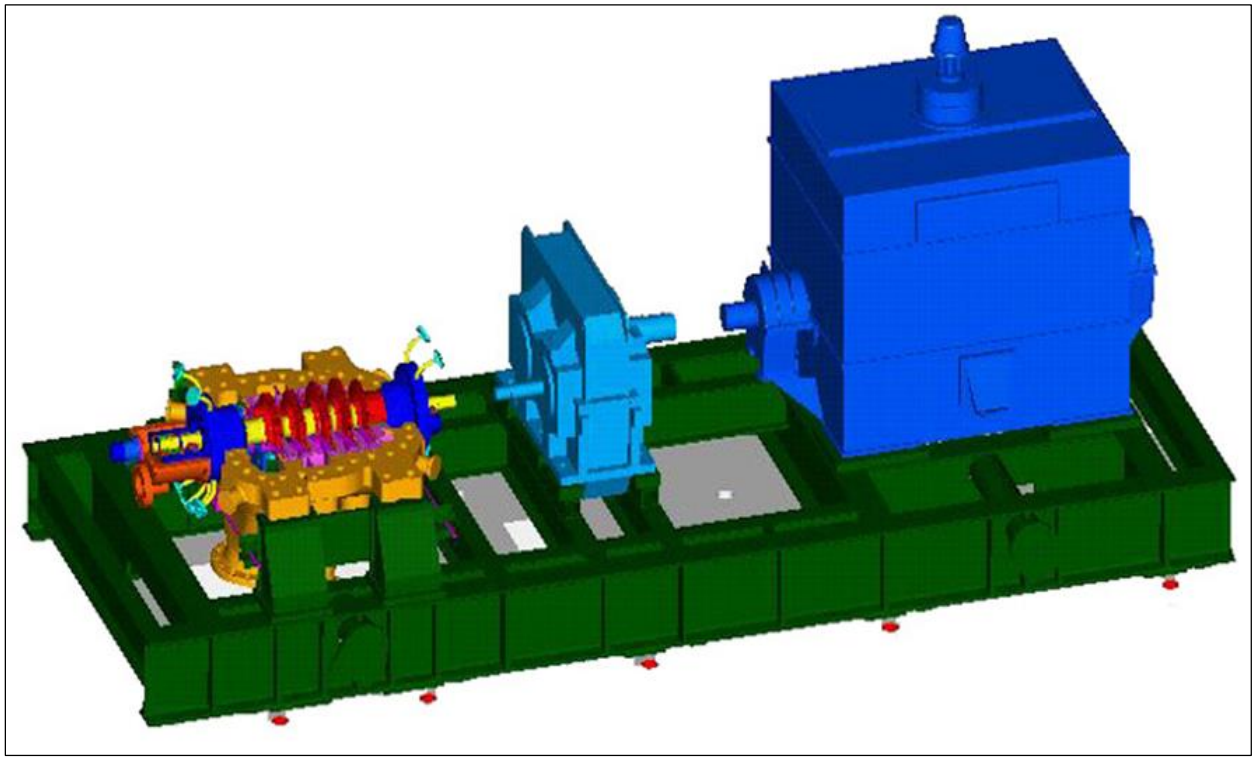
Failure Analysis: 12,780 RPM Ethane Refrigeration Compressor Major Reliability-Safety Improvement

By Abdulrahman Alkhowaiter & Minwer Juhani



Problem: Low Temperature Refrigeration compressors are equipped with slow rolling devices to prevent shaft bowing before startup. But in this case, multiple failure incidents occurred since installation in 1983 on Ethane Compressor turning gear mechanism. It failed to disengage during startup at least three times historically which led to failure and severe damage to the main compressor shaft and bearings. Consultant was requested to study problem in 2007.

From: Khowaiter, Abdulrahman O
Sent: Sunday, July 01, 2007 5:48 PM
To: Gas Plant Machinery Engineer
Subject: Ethane Liquefaction compressor K-141 Bearings & Eliminating Slow Roll Mechanism

We have been studying several options for resolving the K-141 slow roll mechanism failures, as this system has caused compressor rotor damage at least three times since installation.

1. Upgrade the turning gear and its clutch to newer design from OEM.
2. Install an engaging indication at Control room: Not a highly reliable solution.
3. Eliminate the turning gear mechanism completely: This is an innovation idea.

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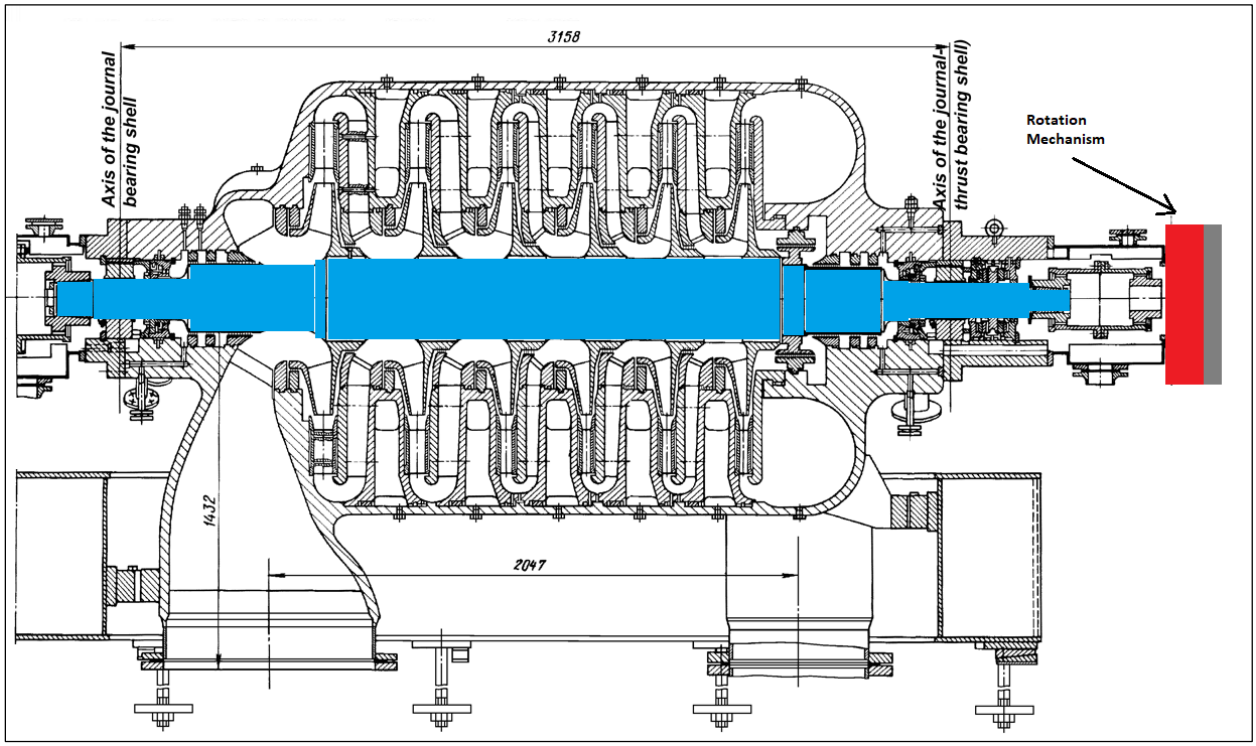

1. Before shutdown, allow the compressor to operate for 10 minutes on **hot** recycle, by temporarily disabling the recycle cooling. This gas heating would eliminate the need for slow rolling. However, a study by my colleague & I led to the following conclusions: The existing recycle system is a dual recycle system (two streams) and is complicated, therefore, difficult to modify. In addition, an emergency ESD shutdown would not allow a 10-minute warm down period, so that in such shutdowns, the rotor will still be cold. Conclusion: This concept was considered not to be a fully practical solution to the problem. **Idea Rejected.**

2. The other concept is to notice that the requirement for slow rolling warm-down is only for maintaining the balance mass concentricity of the rotor after shutdown. This means maintaining the shaft straight with a minimum of allowable bow. The coldest end, suction, is at -126 DegF, and during a warm down cycle, the rotor will heat up to 110 DegF ambient. This maximum temperature gradient is equal to 126 + 110 = 236 DegF. This temperature gradient is manageable, and we believe that there is a strong chance that an actual trial shutdown without slow rolling, will lead to very small shaft deviations from original balance. By studying the rotor drawing below, it can be seen that this specific Ethane compressor rotor has a thick shaft, giving it high stiffness. This large shaft diameter leads to high resistance to bending and deflection caused by temperature changes. **Idea Must Be Proven by Safe Field Testing.**

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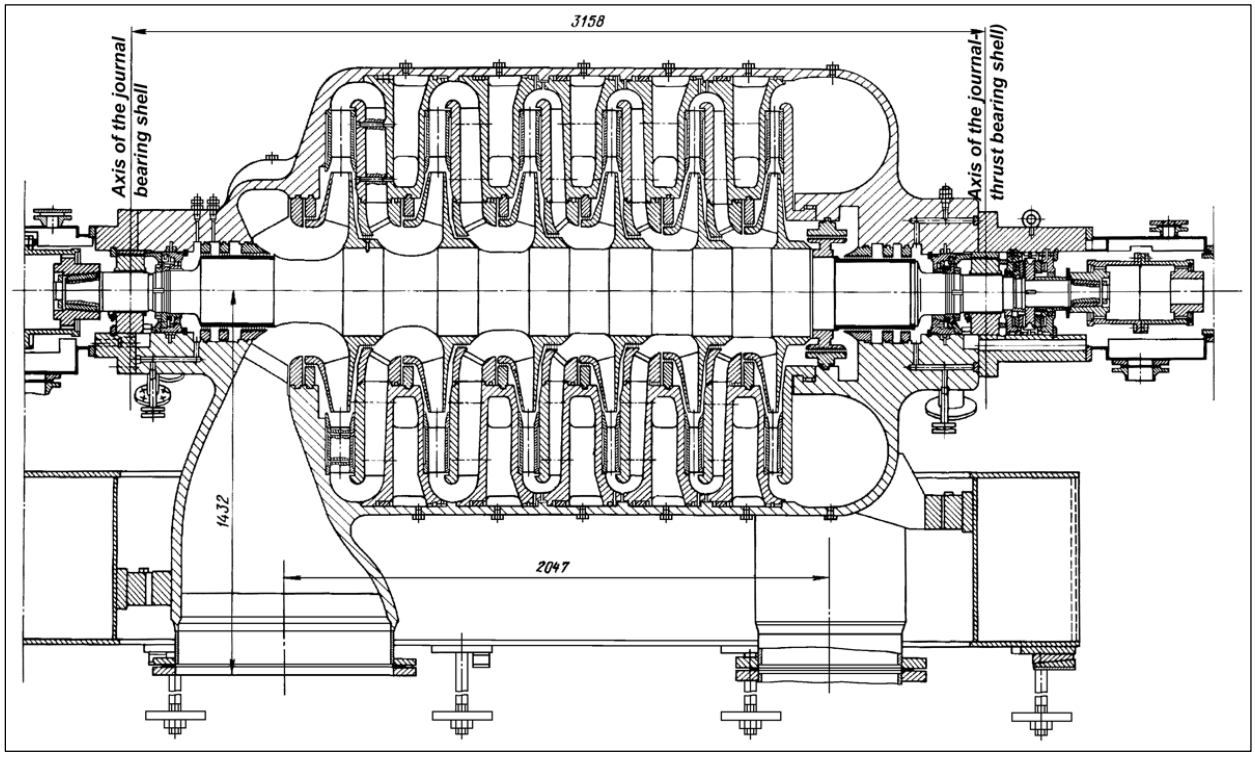

Note: Below are pictures of failed motor driven slow roll gear unit. Ethane Compressor Trial Run: Operate the compressor at normal conditions for 24 hours, then shut down for 48 hours, and isolate the slow-roll motor at the electric breaker. The following are the critical steps:

1. Remove coupling guard top half. Place red color match marks on 0, 90, 180, 270 degree locations. Rotate shaft and obtain dial indicator radial runout reading of compressor shaft just before coupling hub. Return guard.
2. Start compressor and operate normally for 24 hrs. Shutdown without slow roll.
3. After 48 hours in off mode, remove coupling guard and again measure the shaft radial runout by rotation. The maximum allowable increase is 0.0005 inch, or half thou.
4. If runout increase is greater than 0.0005 inch, then set rotor 180 degrees opposite the maximum deflection point, and allow 48 hours for gravity forces to straighten any bow. Re-measure after 48 hours.
5. If the runout increase is within limits, then start machine, and record vibration.
6. If step five is successful, and vibration is relatively smooth, then the slow roll mechanism can be deleted. If not, then we recommend maintaining the slow roll mechanism.

From: Field Engineer
Sent: Sunday, November 18, 2007 8:06 AM
To: Abdulrahman Alkhowaiter
Subject: Ethane Liquefaction Compressor K-141 Eliminating the Slow Roll Mechanism

The following are the compressor shaft deflection measurements after the trial test that was carried last week on the V85-K141. Please review the measurements:

- Before Startup: Dial Indicator Shaft Run out maximum readings are: 0.00025 inch
- The second action is to start the machine without slow rolling [Barring gear is disengaged during the chilling down] for trial test and with attendance of Reliability Unit.
- The machine was kept running for 22 hours. After shutdown by two hours, readings found were: Maximum runout 0.0003 inch
- The machine was kept down for 48 hours and run-out re-measured: 0.0002 inch

From: Khowaiter, Abdulrahman O
Sent: Sunday, November 18, 2007 9:49 AM
To: Field Engineer
Subject: Ethane Liquefaction Compressor K-141 Eliminating the Slow Roll Mechanism

Based upon the measured field data test, the compressor is still maintaining extremely small deflection at the coupling area, meaning that the rotor has minimal internal lateral bending.

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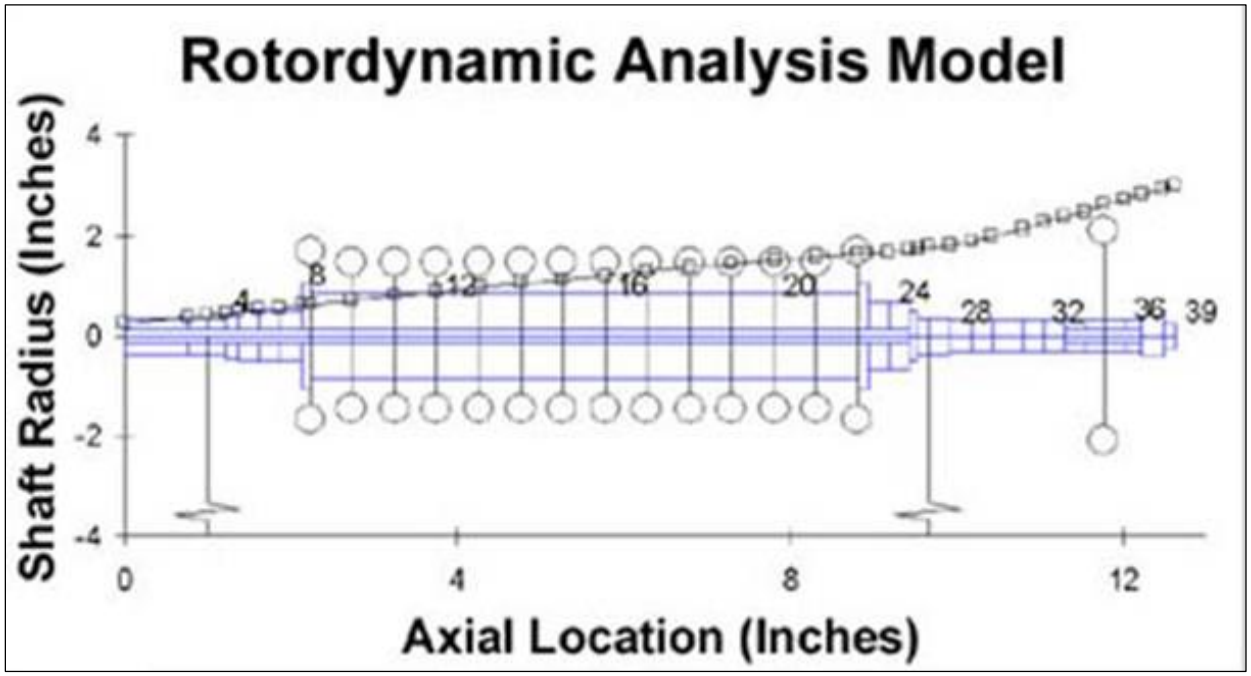

The maximum allowable shaft deflection variation on such a 12,800 RPM rotor, would be about 0.0005 inch, or 0.50 mills, at the shaft coupling zone. In your case, physical tests have shown a maximum Delta of: + 0.0001 – [-0.0002] = 0.30 mills maximum, as measured before the trial and after 48 hours of non-rotation shutdown. This level of change is well within our limits, therefore, **the next step is to proceed to start the compressor [no slow rolling before startup] and observe the machinery vibration response.** It is preferred not to use any vibration monitor bypass during startup of any compressor; instead, trip multipliers are available on the vibration monitors.

From: Khowaiter, Abdulrahman O
Sent: Tuesday, November 20, 2007 12:48 PM
To: Consulting Engineers
Subject: Ethane Liquefaction Compressor K-141 Eliminating the Slow Roll Mechanism

Modification: Compressor Slow Roll Motor-Gear Removed from NDE Bearing Housing: This machine has always been reported difficult and unsafe to operate by field operators. The innovative idea of eliminating the low temperature Ethane compressor slow rolling motor mechanism has succeeded well, and field tests have proven it can be operated normally without slow rolling. Decision was based upon studying the compressor temperature differentials, analyzing the rotor stiffness, and making field deflection measurements and actual testing.

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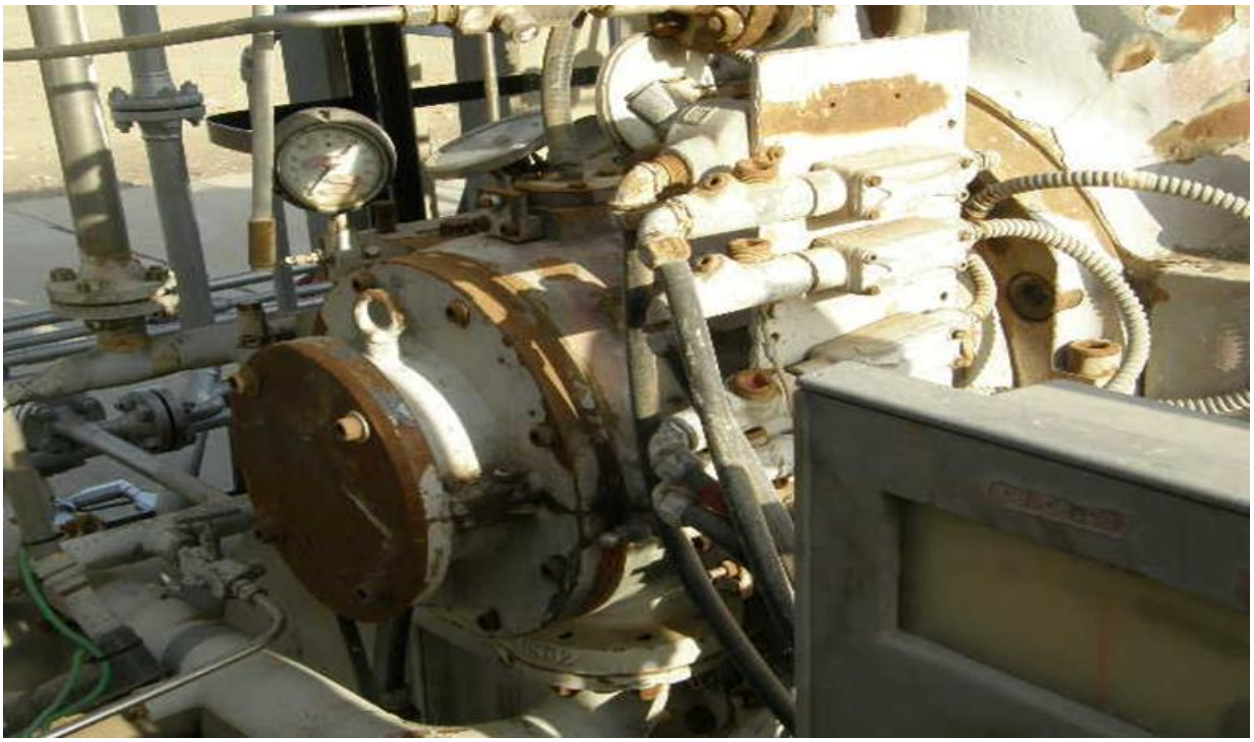

Picture Above: Drive Mechanism Removed at NDE Bearing Housing, Blinded with Flange

The K-141 compressor was started at normal conditions with minimal impact on radial vibration not exceeding 0.10 to 0.20 mills above past operation according to Vibration data. The outboard end mechanism has been removed from the machine permanently, and the compressor reliability and operation procedures will be improved greatly. The compressor is now safer and more reliable; the original OEM intent to apply the mechanism was good, but it is not required.

Conclusion: Three Years After Removal of Slow Roll Mechanism

1. In year 2010 the modified machine was reported running for more than three years with very stable operation. Zero vibration problems with multiple startups.
2. The compressor shaft maximum radial vibration has not changed; about 1.25 mills.
3. No trip was recorded for the last three years, and over 15 start-stop cycles.
4. With this modification the maintenance cost avoidance in 2007 alone was USD $260,000 and expected lifetime savings of USD 1.0 MM.
5. Note: Compressor modification requires design knowledge and mechanical analysis skills.