Air Compressor Site Performance Testing: Apparent Simplicity & Practical Complexity

by

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ABSTRACT - CASE STUDY 06

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The performance of a steam turbine driven air compressor deteriorated by 35% over a span of four months. This Case Study elaborates on the identification, analysis and restoration of performance.

Compressor Rating:

Casings: 2 with intercooler.
Speed: 8400 rpm.
Power: 2.3 MW.

Capacity: 19,497 Inlet m^3/hr [11,476 ICFM]
Rated mass flow: 21,585 Kg/hr [793 lb/min]
Discharge pressure: 10.6 bara. [152.3 Psia]

The subject air compressor forms part of the utility and instrumentation air supply system to an oil refinery. Constant pressure at header that supplies air to instrumentation system is very important. Any reduction in mass flow of dry air to the air supply system will result in reduction of the header pressure. Drop in air header pressure was experienced that prompted potential deterioration in air compressor performance.

Performance testing at site indicated operating points almost on the design surge curve. The difference between the design polytropic efficiency and the polytropic efficiency calculated from data collected during operation at comparable operating points for the first and second casings were marginal, 0.3 to 0.7 percent.

The calibration of the instrumentation used during testing was verified and the air inlet filter elements were replaced. After examining other possible causes the compressor was opened and it was found to be clean. The root-cause was found to be an unexpected obstruction.

The Case Study shows how important it is to measure the inlet conditions as close to the compressor inlet nozzle as possible besides emphasizing on thorough compressor system analysis.

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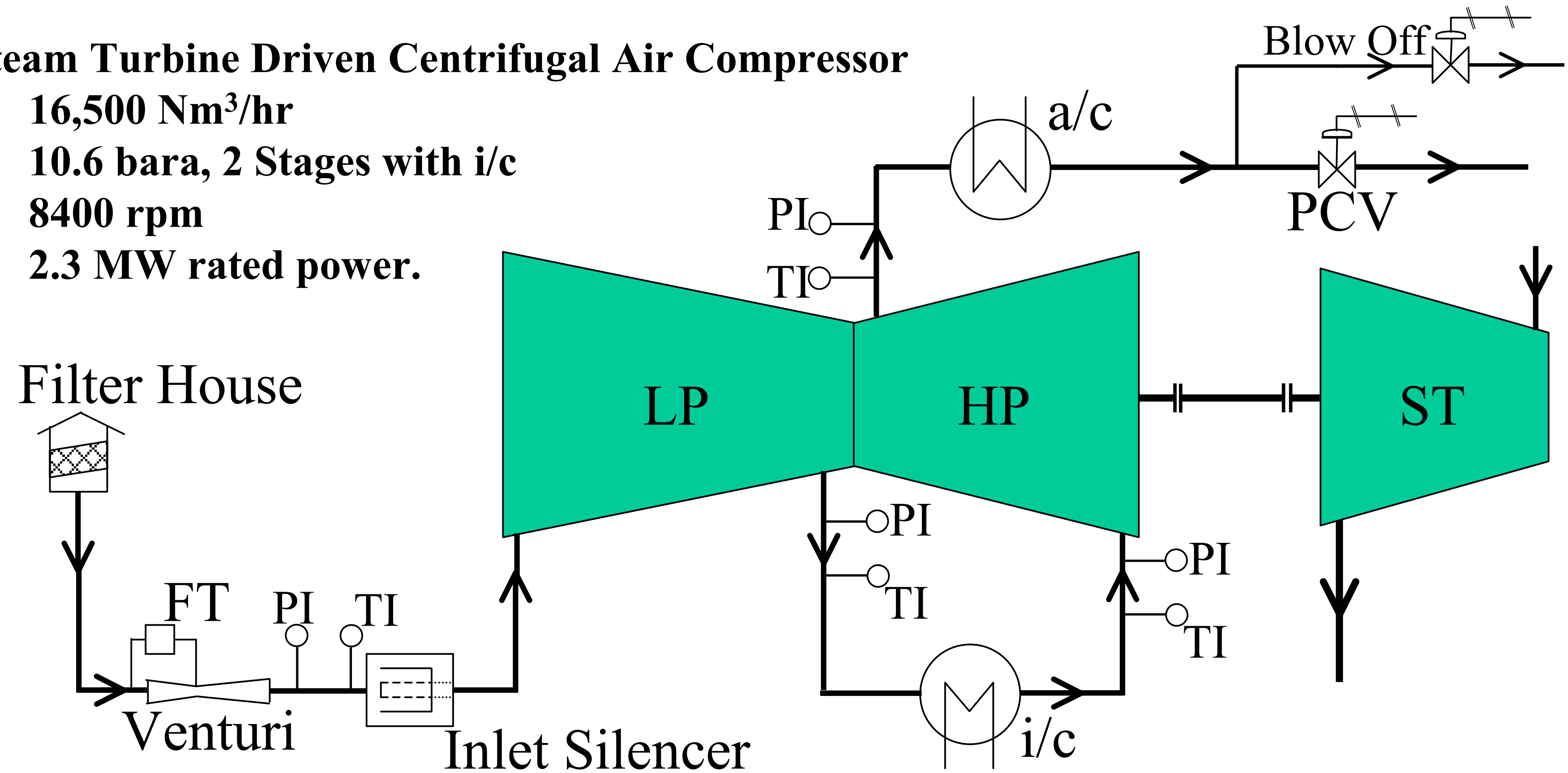
Steam Turbine Driven Centrifugal Air Compressor

- **16,500 Nm³/hr**
- **10.6 bara, 2 Stages with i/c**
- **8400 rpm**
- **2.3 MW rated power.**



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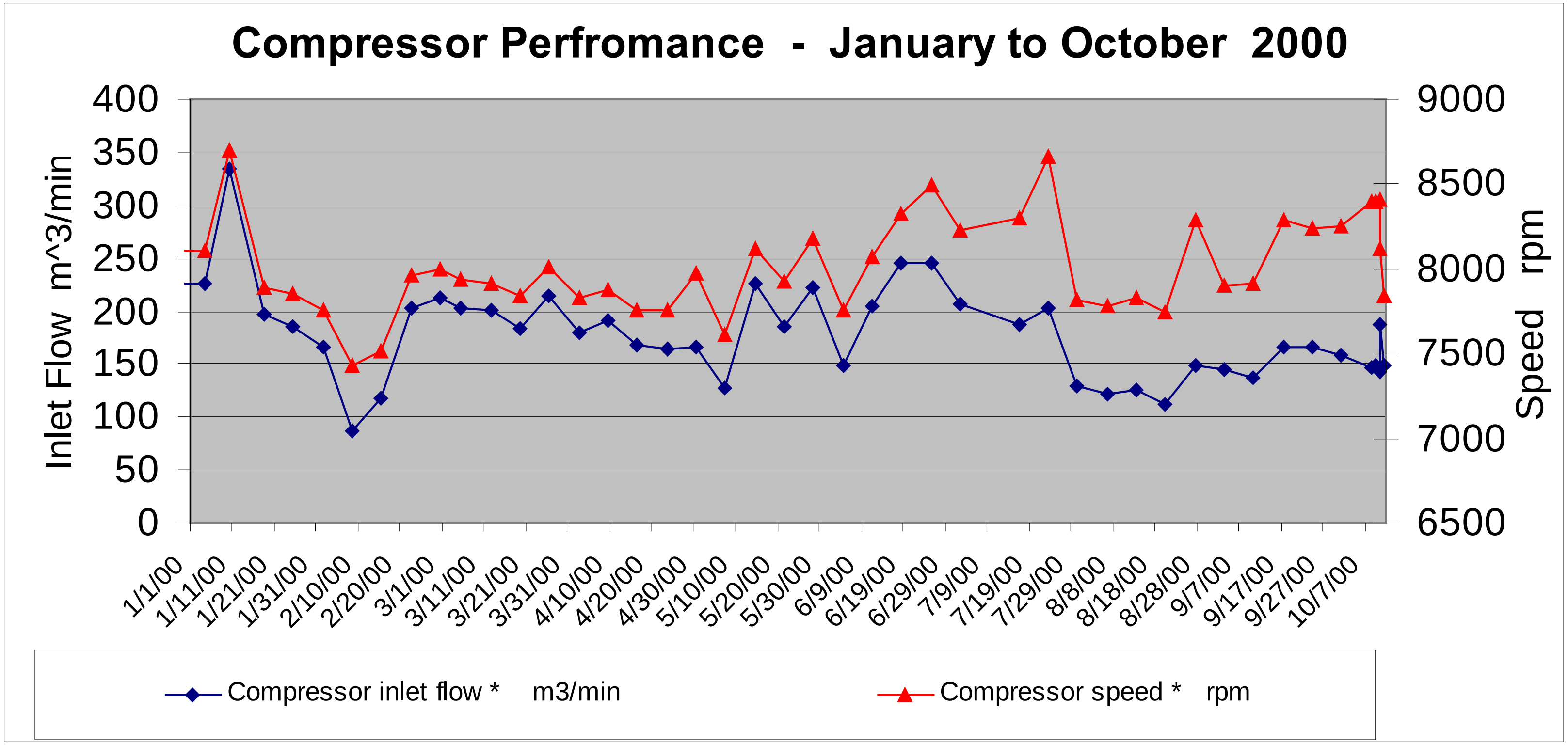
- **Compressor flow decreased considerably even at higher than normal operating speed**



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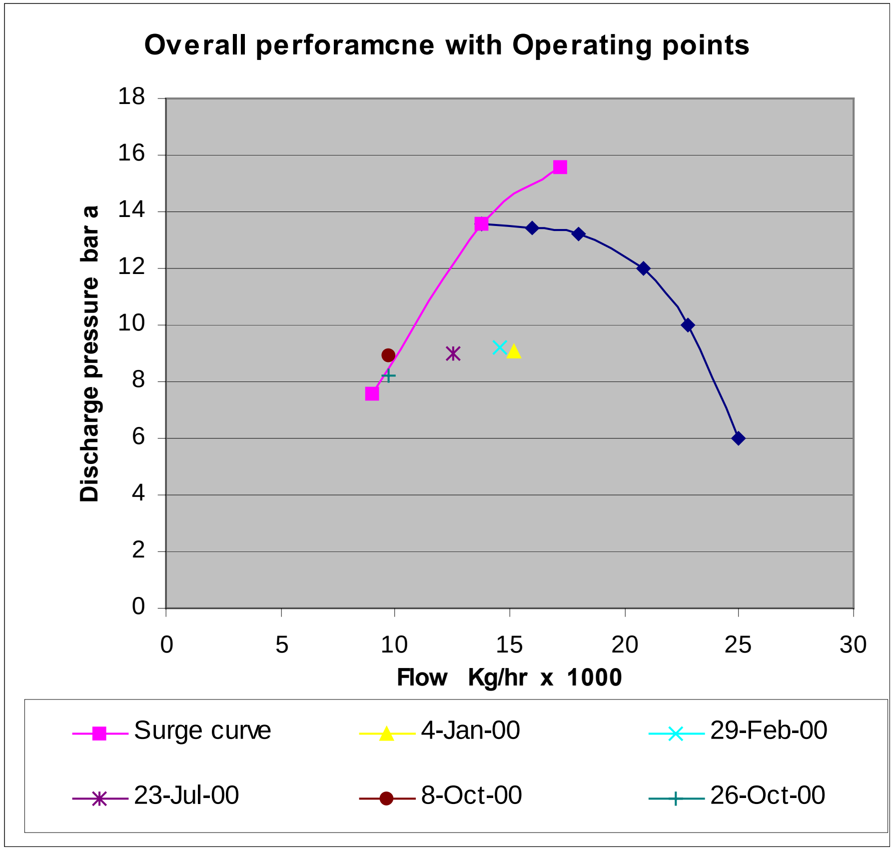
- Compared to design spec. there was 35 % to 40 % deficiency in mass flow.
- Mass flow and discharge pressure were corrected for operating speed and air inlet conditions.
- Couple of operating points were on the surge curve. No real surging occurred.



Methodology and Basis of Analysis

- **Polytropic Head and Polytropic Efficiency formulae were used for thermodynamic evaluation.**
- **Fan laws were used to correlate flow and pressure.**
- **Not an ASME - PTC 10 performance test. Performance trend was focused.**
- **Field instruments installed as per original P&ID were used.**
- **1st and 2nd Stage parameters and performance were considered separately to pin point the cause.**

Formulae Used in Evaluation

- **Poly. Head H_p = $(n/n-1)*Z_1*R*T_1*[(P_2/P_1)^{(n-1/n)} -1]$**
- **Poly. Efficiency η_p = $[n/(n-1)] / [k/(k-1)]$**
- **Poly. Exponent = $\ln (P_2/P_1) / [\ln\{(Z_1*T_1)/Z_2*T_2)\} + \ln(P_2/P_1)]$**
- **Pressure ratio = P_2/P_1 ; Temperature ratio = T_2/T_1**

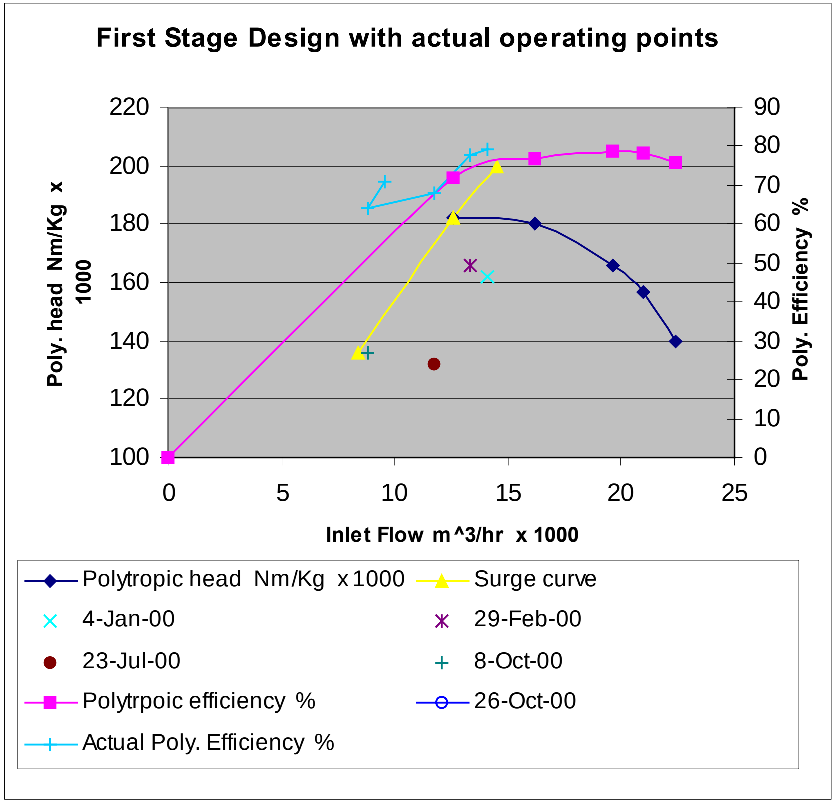
Notes: Suffix 1 and 2 represent suction and discharge conditions

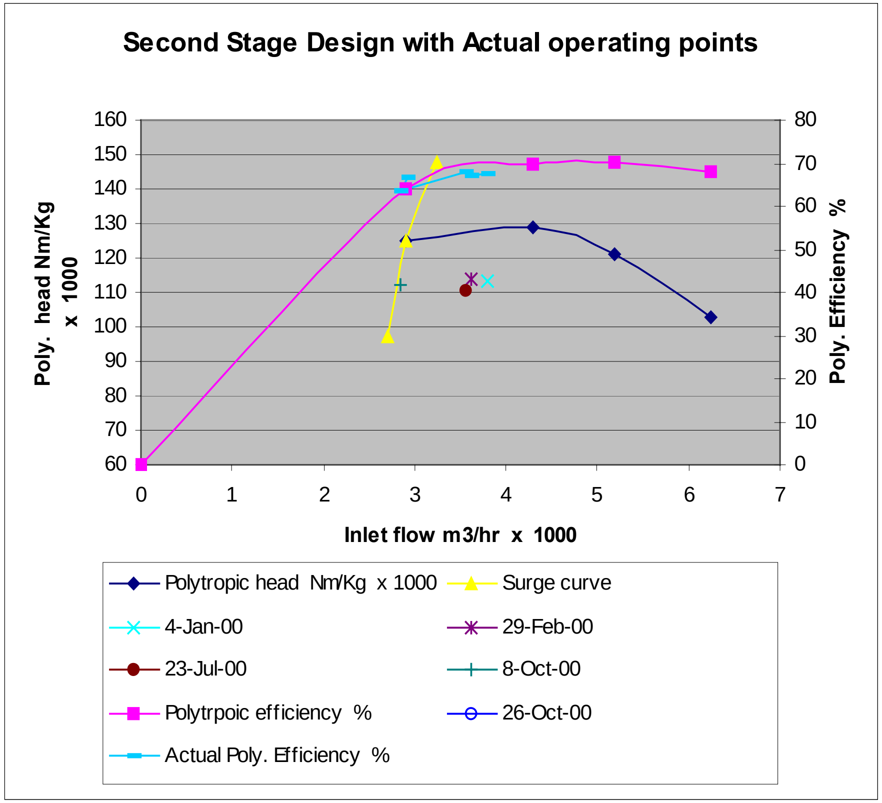
Pressure and temperature in absolute units

Consistent units of measure is observed.

n and k are polytropic and adiabatic exponents.

Poly. η Matched the Design (Δη 0.7%) on Both Stages





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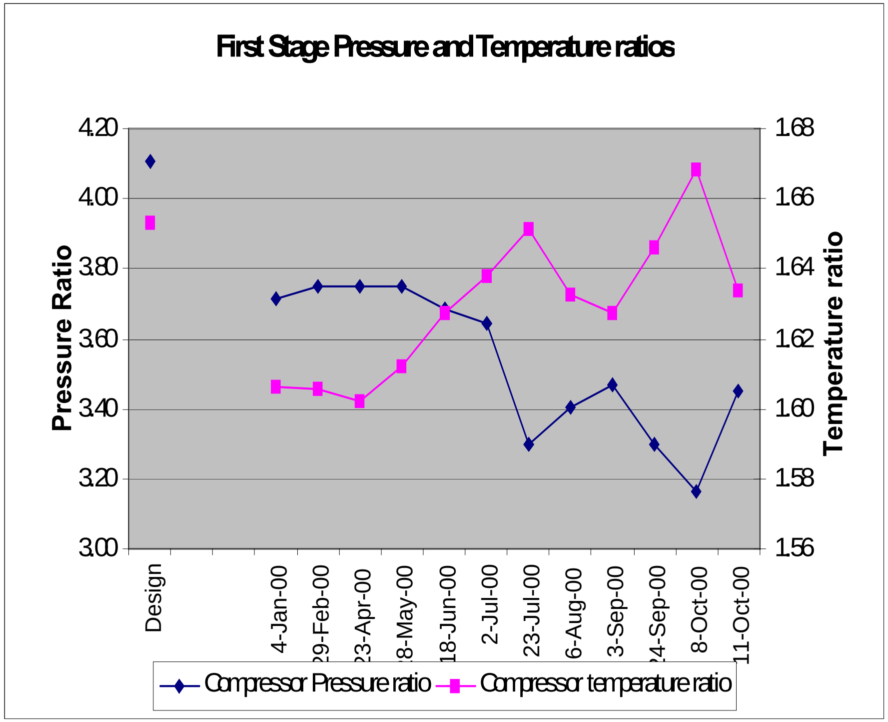

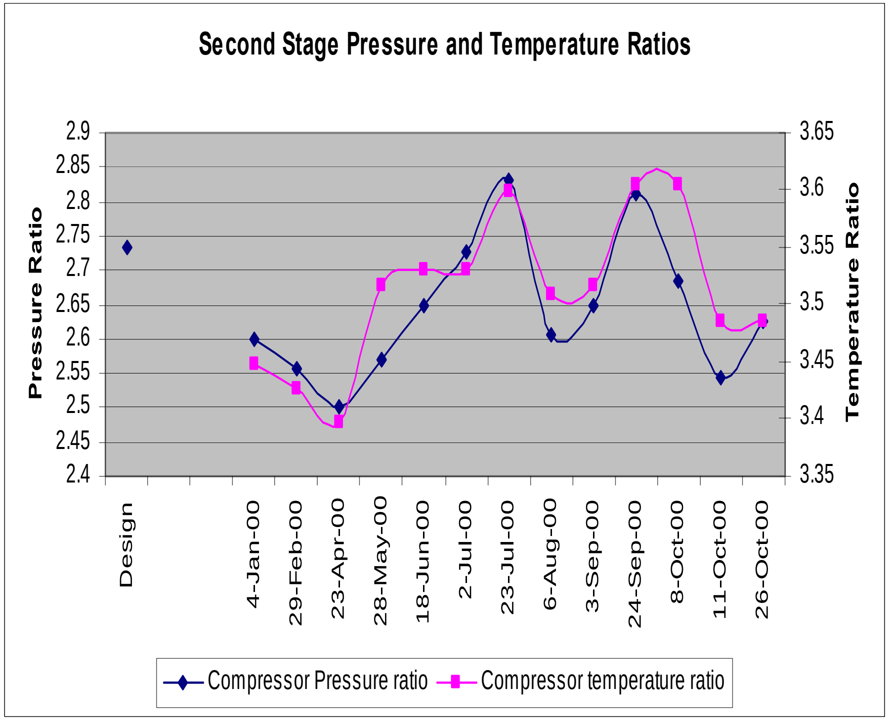

- **Stage 1 – Pr. ratio (P_r) does not correlate to temp. ratio (T_r). As P_r decreases T_r increases**
- **Stage 2 – Pr. ratio correlates to temp. ratio**

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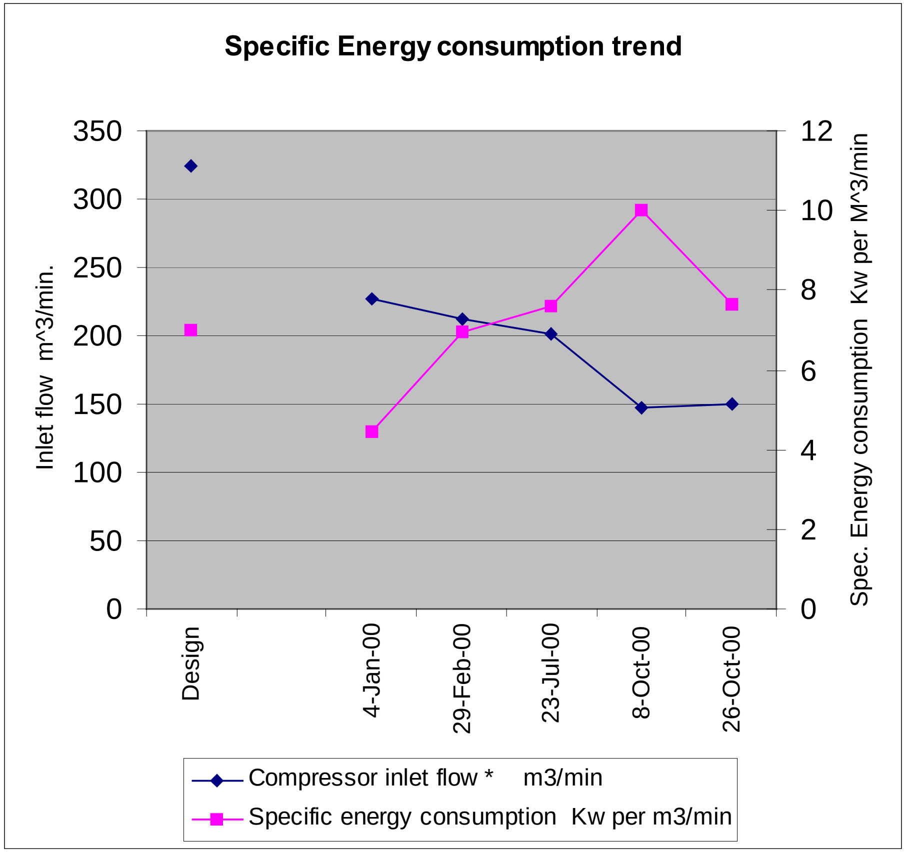
- **Specific energy {Kw/(m^3/min)} consumption showed increasing trend from January 2000.**
- **Compressor inlet and discharge conditions – NO significant change.**



Actions to Resolve Anomalies (of Test findings)

- Flow instrument, speed, pressure and temperature indications were checked for calibration. No major defect was found.
- Air inlet filter elements were renewed.
- Inlet flow venturi and impulse lines were checked and found O.K.
- Air inlet silencer was inspected via entry nozzle (inlet section) and it was found clean.

No resolution on anomalies. Internal circulation or fouling could not be determined. Decided to open the compressor.

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Machine Opened - Observations

Clean Rotor

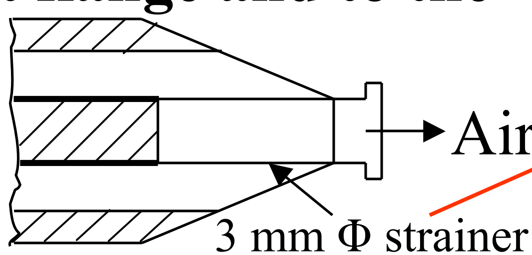
Clean Casing

Dislocated Balancing Drum Laby Segment

Damaged Laby Spring

Further Inspection At Compressor Inlet Section

- **Balancing drum laby clearance 0.56 mm. Design spec. 0.30 mm. – 2 X the design level – leakage calculation 4.4 % of design mass flow.**
- **Inlet section venturi, silencer inlet and outlet, piping from silencer to compressor inlet.**
- **Inlet silencer – 3 mm mesh strainer welded to the outlet flange and to the internal element.**



Root-Cause Identified

- Strainer at inlet silencer – plugged severely.
- Strainer was welded to the internal element of the silencer.

- No pressure indication downstream of the silencer.

Remedy and Modifications

- **3 mm strainer could not be removed.**
- **Large segments were cut and removed and stiffeners were welded.**
- **10 mm removable conical bolt-catcher with ear was installed downstream of the Silencer.**

- **Pressure indicator was provided upstream of the compressor inlet.**

Performance Post-Modification and Conclusion

- **Compressor performance was restored to original design level.**
- **Evaluation of polytropic η, pressure ratio and temperature ratio behavior during thermodynamic analysis presented anomalies since the compressor inlet pressure was incorrect.**
- **Surge points defined in the tested curve appears to be very conservative. Redefinition was not taken up due to significant margin with the normal operating point and because of service conditions.**

Lessons Learned

- **Pressures as close to the compressor flange as possible should be taken for performance evaluation.**
- **Be thorough in system analysis before concluding that the compressor performance deficiencies are a result of deficiencies of the compressor itself. Correlation of thermodynamic parameters like pressure and temperature ratios is important part of performance analysis.**