Training session
Pulsation & Vibration Control

June 26th - 27th 2019
Delft, The Netherlands

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TNO innovation for life

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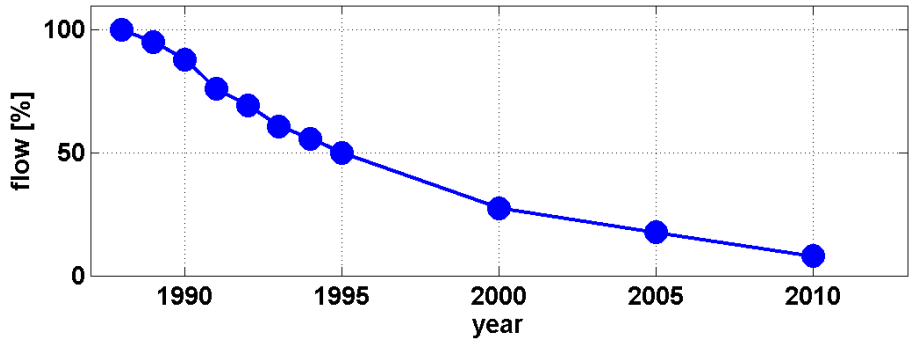
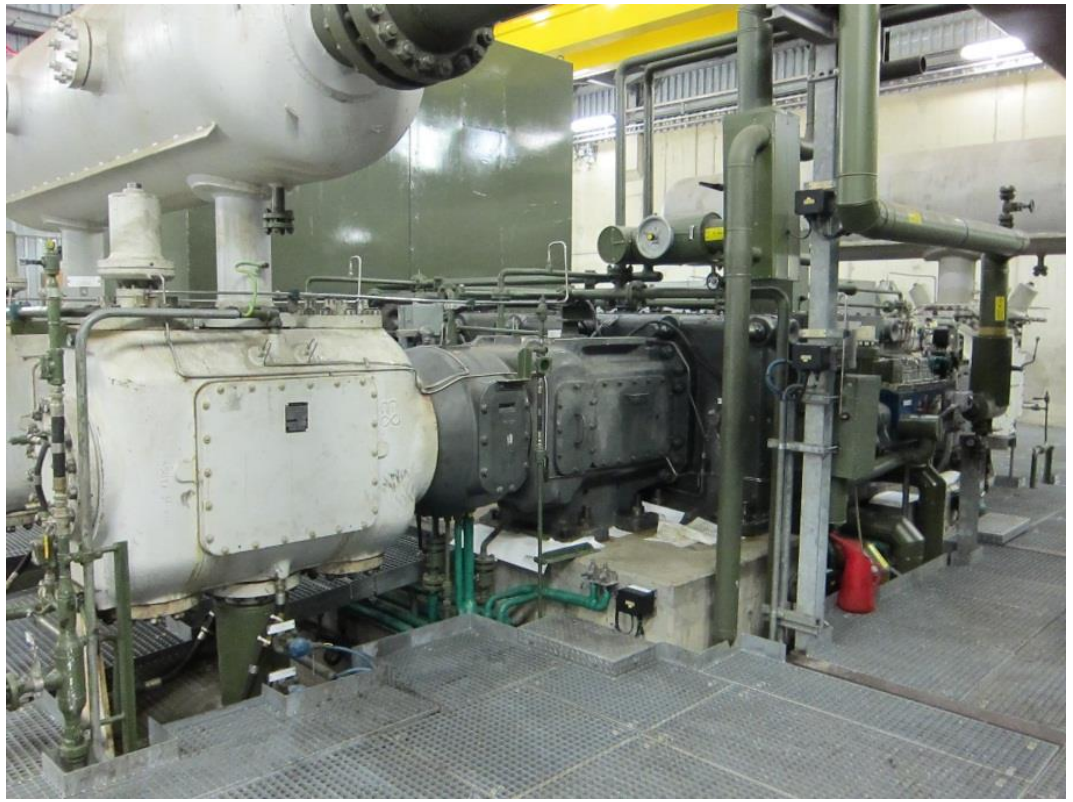
Field case 1

- Natural gas production plant
- Gas delivered to Dutch national grid
- Highly depleted conditions of the gas wells (capacity reduced to 10% of the initial production)
- Gas delivery with flow meters at outlet of compressors



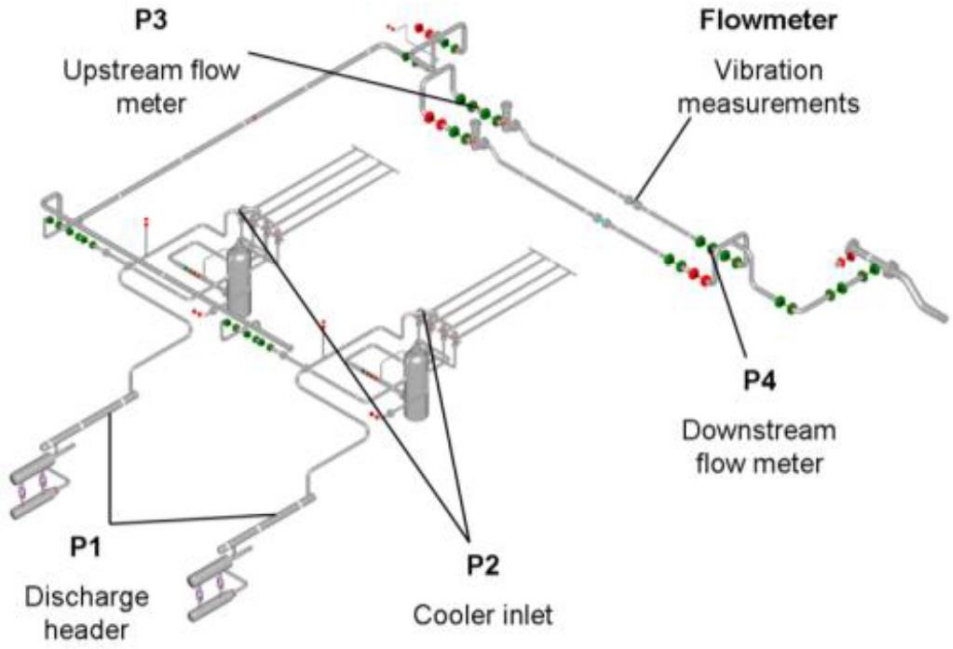
Compressor

- Two 4-cylinder reciprocating compressors
- Two stages, variable speed
- Turbine flow meters



System

- System designed & optimized in original pulsation study
- At first glance: robust design, no issues expected
- History of the system was free of trouble



Issues

- Vibrations, observed during annual joint inspection
- Large vibration displacements, in vicinity of flow meter building
- Concern with respect to accuracy of the flow meters

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Approach

- Field measurements
  - Assess the urgency of the issues
  - Validation data for numerical analysis
- Pulsation study, comparison with field data
- Formulation and validation of mitigation measures

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Issues

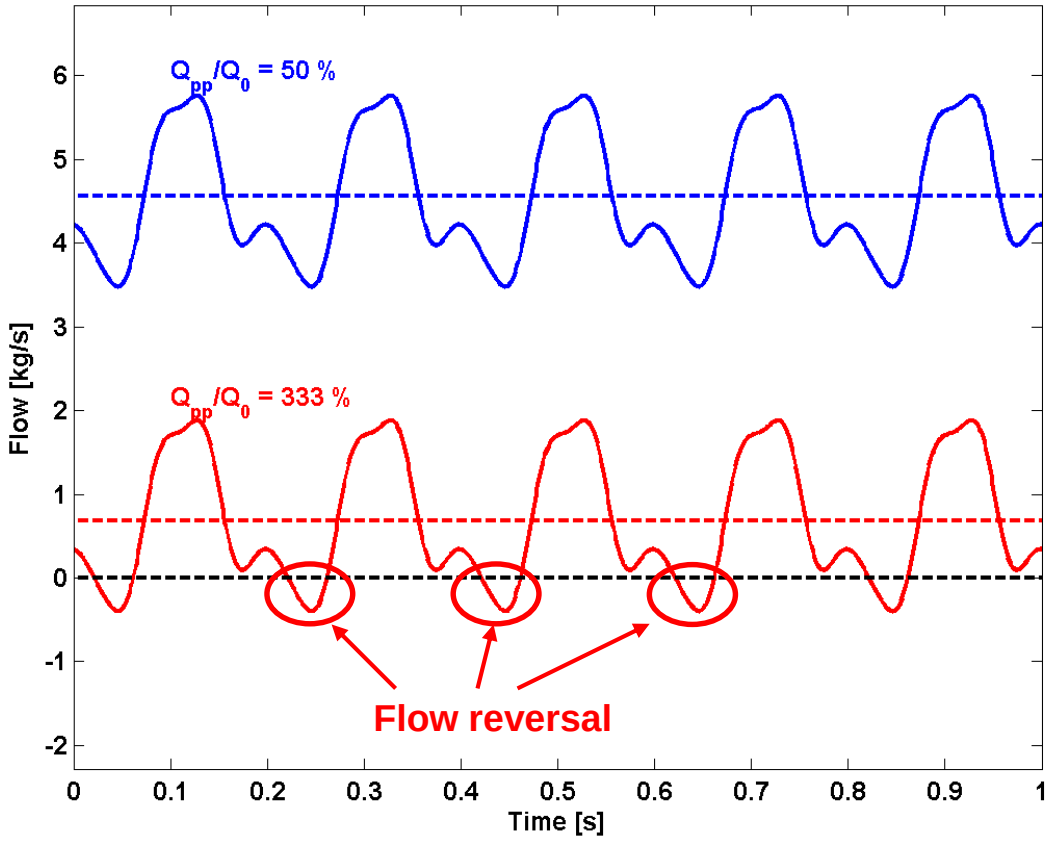
- Vibrations
- Accuracy of the flow meters

Tentative root cause analysis

- In any reciprocating compressor system, pulsations will be present
- Pressure and flow pulsations are related
- Pressure pulsations; may cause large shaking forces and vibration issues
- Flow pulsations; may disturb the reading of flow meters

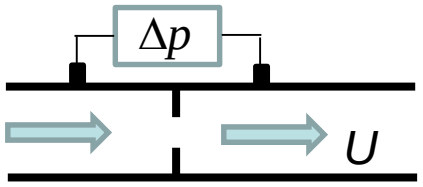
Impact of flow pulsations on flow meters

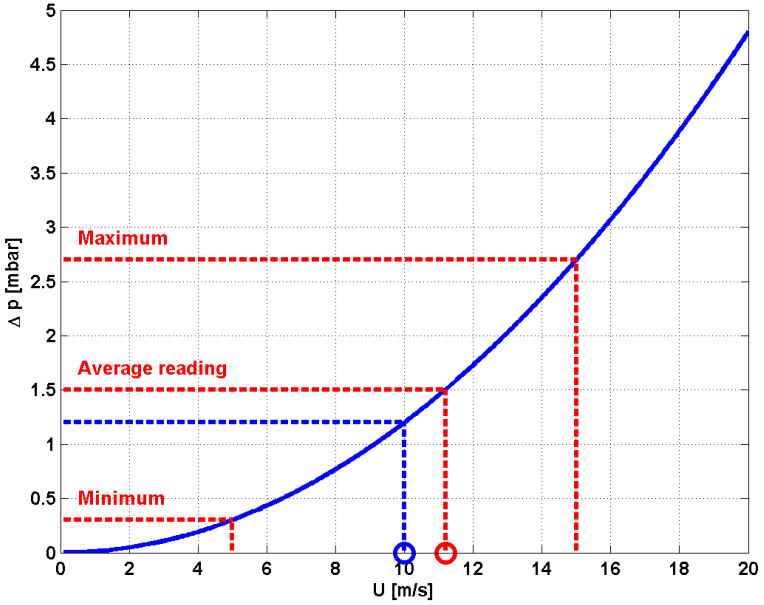
- Relative flow pulsation level is essential
- In case of low mean flow, the most urgent issues are expected
  - Depleting conditions
  - Part-load conditions
- Also non-return valves may suffer from (extreme) flow pulsations
  - Hammering, failure, noise



Error of flowmeters

- Relation between measurement quantity and flow is non-linear
- Example: differential pressure flow measurement
- Quadratic relation for pressure loss: $\Delta p = K \cdot \frac{1}{2} \rho U^2$
- Time-averaged Δp does not correctly represent the actual flow
- The off-set is <u>systematic</u> and <u>positive</u>
- The <u>square-root error</u> depends on $(u'_{RMS}/U_{mean})^2$
- ISO/TR 3313: $E_T = \sqrt{1 + \left(\frac{U_{RMS}}{U_{mean}}\right)^2} - 1$



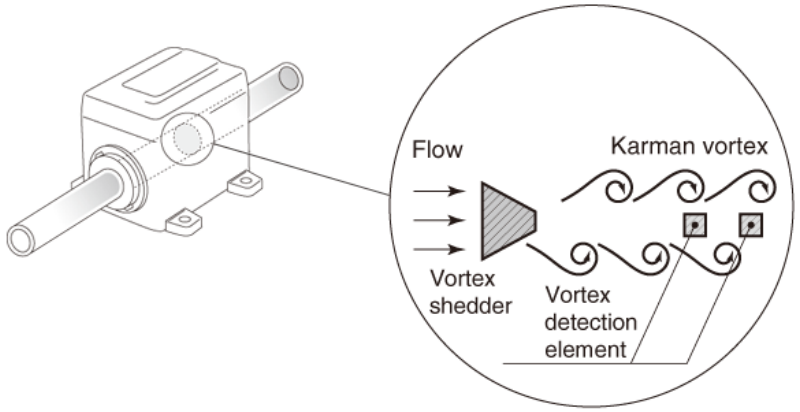


Type of flowmeters (ISO/TR 3313)

- Turbine flow meter:
  - Non-symmetric rotor interia
  - Similar, systematic, off-set

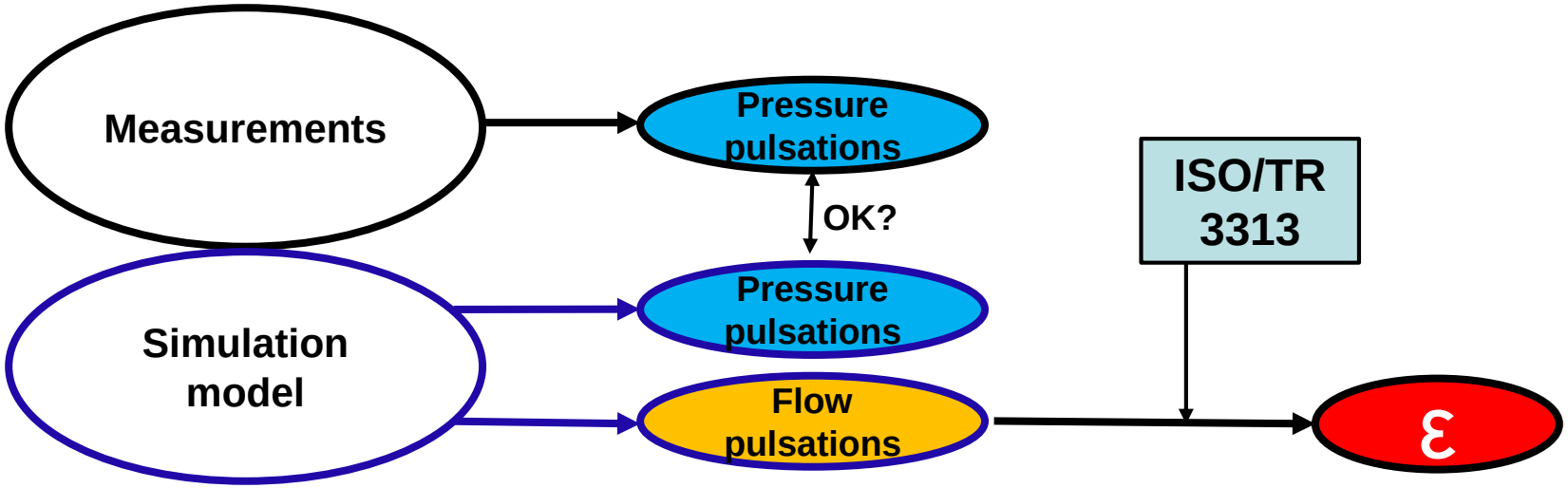
$$I = \frac{\Delta Q}{Q_0} \longrightarrow E_Q = \frac{1}{2} I^2$$

- Vortex flow meters:
  - may suffer from flow pulsations (lock-in)
- Coriolis flow meter:
  - may suffer from vibrations
- Ultrasonic flow meter:
  - may suffer from high-frequency noise (control valve)

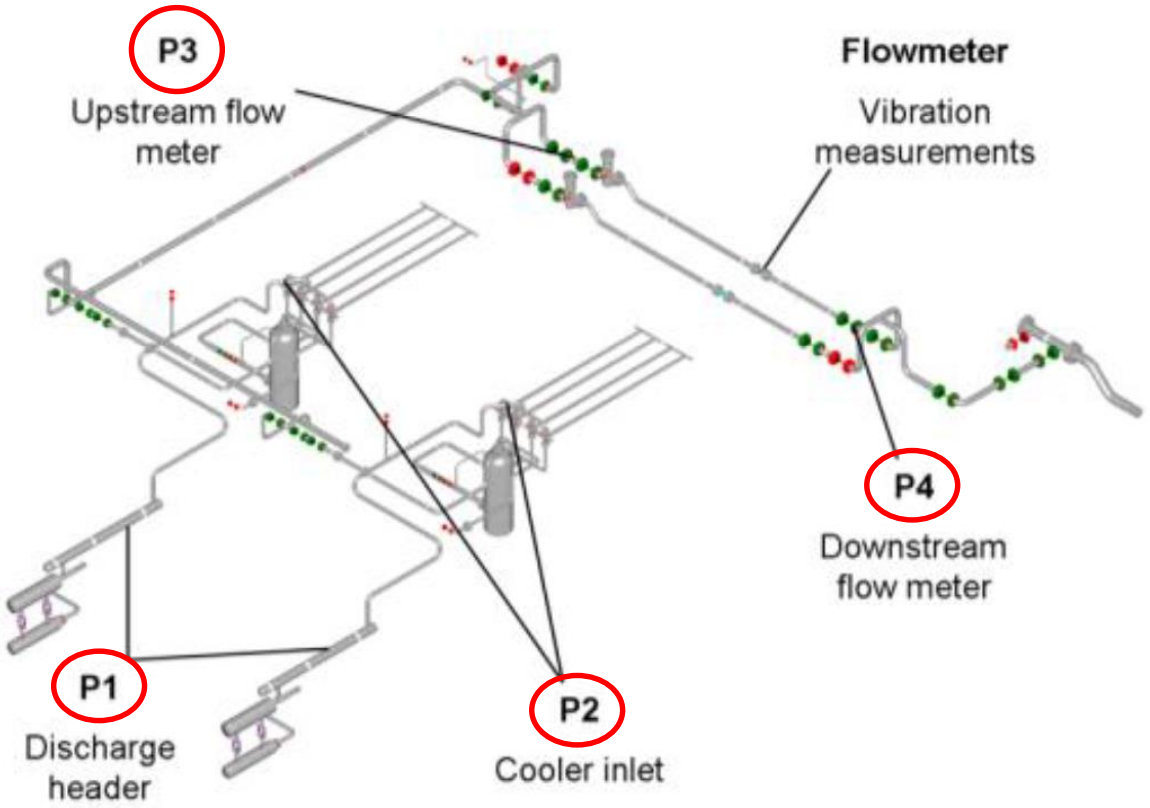


Verification

- Pulsation and vibration measurements
- Pressure pulsations can be directly measured
- Flow pulsations can not
- Verification required



Pulsation measurements



Observations from measurements

- Low pulsations near the turbine flow meters < 10% of API 618
- Higher pulsations near the compressors ~100% of API 618
- Spectral signature typical for part load operation
- No excessive vibrations near flow meters

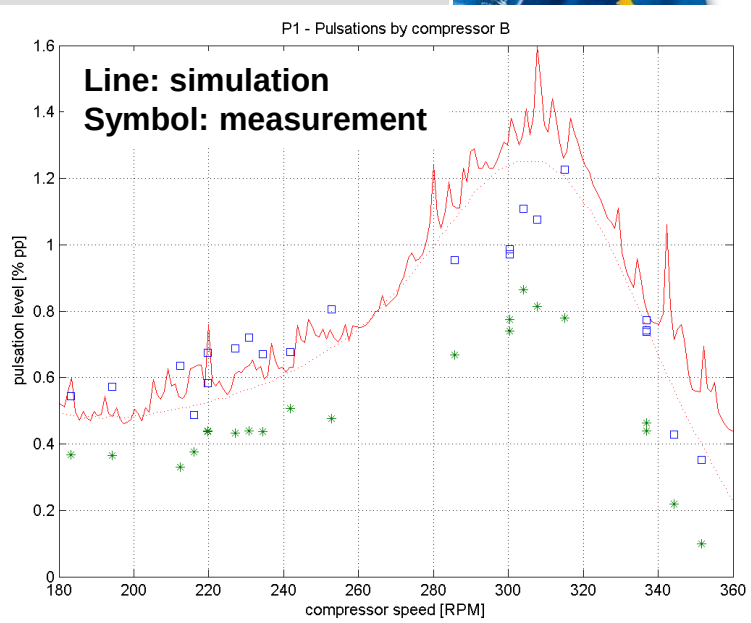
Compressor running	Location	pressure pulsations		
		measurements		API allowable level for the 1st harmonic [% pp]
		overall [% pp]	1st harmonic [% pp]	
A	p1	1.2	0.9	0.96
A	p2	1.1	0.8	1.34
A	p3	0.08	0.05	1.11
A	p4	0.03	0.02	1.11
B	p1	1.2	0.9	0.96
B	p2	1.1	0.9	1.34
B	p3	0.15	0.08	1.11
B	p4	0.05	0.02	1.11

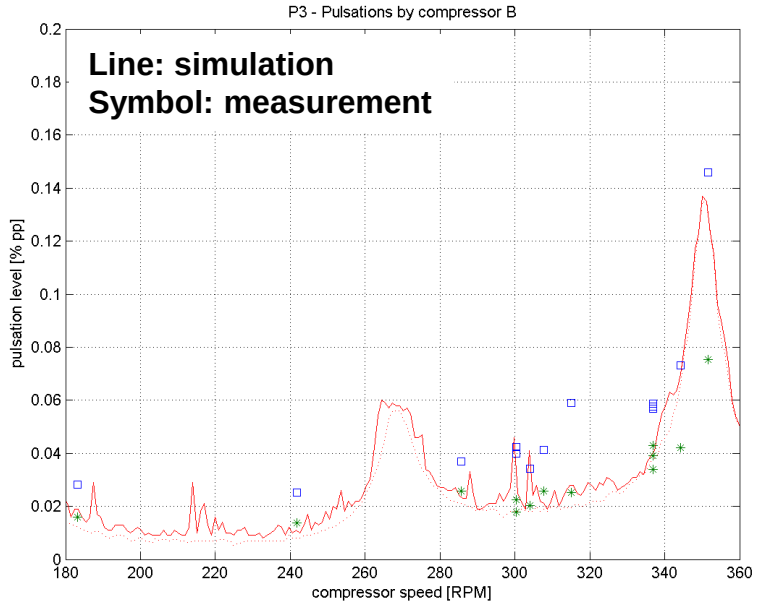
Preliminary root cause analysis

- Large vibration displacements in piping (1st order), caused by pulsations and mechanical response
- Vibration levels near flow meters are low; no disturbance expected
- Pulsation levels near compressors are of the order of API 618
- Pulsation levels near flow meters are low, but flow pulsations may be considerable
- → Use numerical model to calculate flow pulsation levels and explore options to reduce pulsations

Comparison measurements - simulation

- A satisfactory match was found, assuming that the compressor was running at 50% capacity.
- (initially, the compressor load was not clear. End user finally confirmed indeed part-load operation of the compressors)
- It was noted that the existing restriction orifices had very low pressure loss (< 0.05%), and were not effective

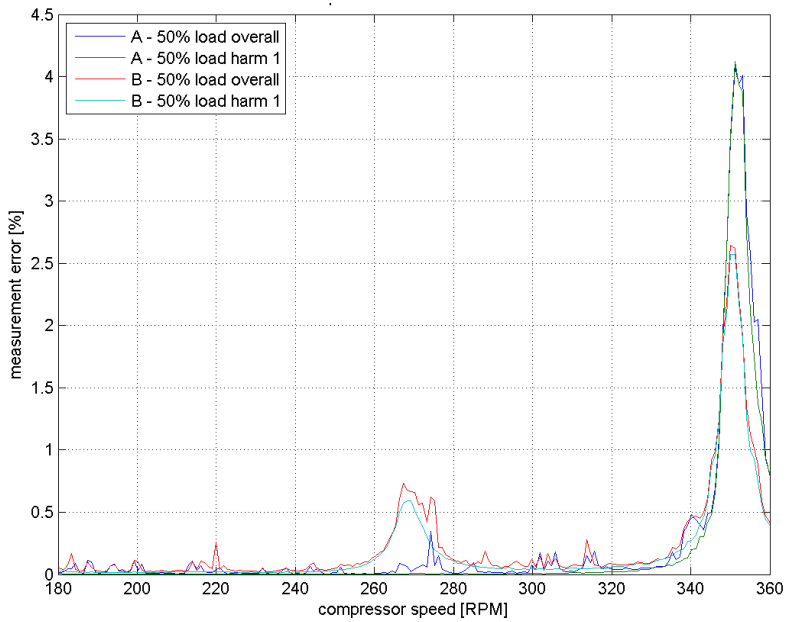




Root cause analysis

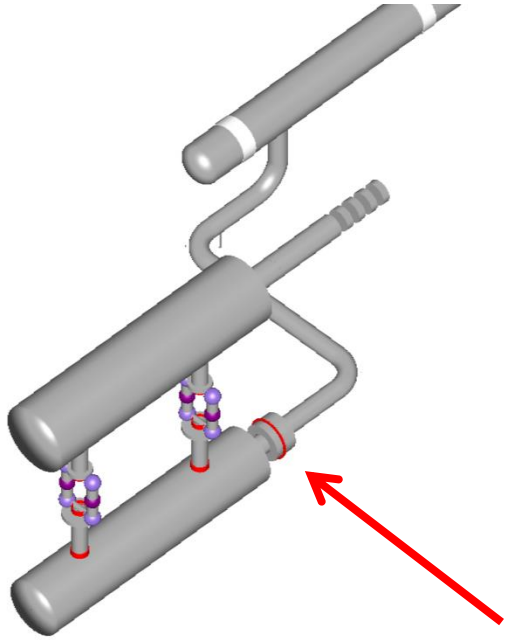
- Despite low pulsation levels near flow meters, maximum flow pulsation amplitude can reach ~45% peak-peak
- This may cause considerable flow metering error
- Based on information of the vendor:
  maximum error estimated at 4%

- Large vibration displacement: caused by loose pipe support, in combination with mechanical resonance frequency triggered by 1st order



Solution

- Re-fit of restriction orifice plates at 2nd stage outlet
- Pressure loss at maximal compressor speed: ~1%
- Reduction of flow meter error < 0.1%
- Reduction of pulsations and shaking forces



Lessons learned (1)

- During design, the future operating envelope shall be carefully considered in the prognosis and control strategy for pulsations
- In depleting conditions, dedicated re-fits may be recommended
- Even at low pulsation amplitudes, severe consequences may be observed
  - Vibration issues
  - Issues with flow metering accuracy

Lessons learned (2)

- Target levels in API 618 for flow pulsations may be very demanding in depleting conditions
  - Non-custody transfer < 1%
  - Custody transfer < 0.125%
- Flow pulsation issues are hard to detect in the field (while a lot of € may be involved)
- Relatively easy re-fits in the system may result in a considerable reduction of pulsations
- Joint NAM-TNO publication at EFRC conference 2012