Impact of liquids and dynamic phenomena on integrity

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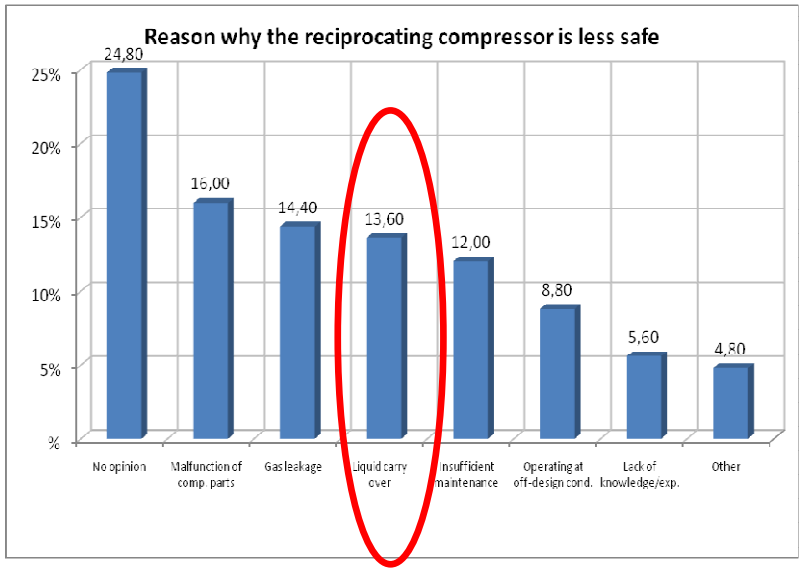
Introduction

- The reciprocating compressor is a very reliable piece of machinery, if well designed and operated
- To ensure optimum reliability care should be taken to avoid erroneous process conditions or a harsh dynamic environment (pulsation and vibrations).
- If the compressor is exposed to challenging conditions: take care of it in the design phase!

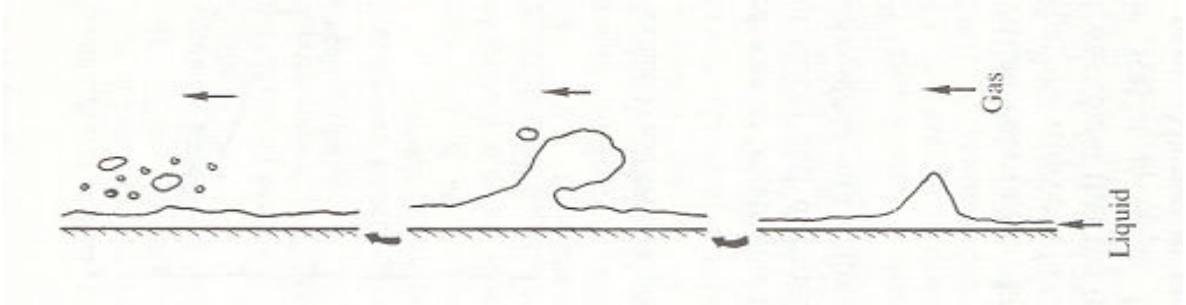
Impact of liquid on compressor integrity

- EFRC reliability survey project 2009 indicates a prominent cause for unscheduled shutdown: liquid carry-over.
- Also important item for compressor safety
- Careful dew-point analysis
- Adequate filter design



Example of impact of liquid

- Pulsations caused by compressor may deteriorate the efficiency of separators
- EFRC research project in 2005
  - Root cause analysis of mechanisms
  - Experimental validation
  - Criterion/guideline for onset of decrease in efficiency (allowable speeds and pulsation levels)
- For special / critical systems, this shall be taken into account in the pulsation analysis, *in addition to* the API 618 criteria

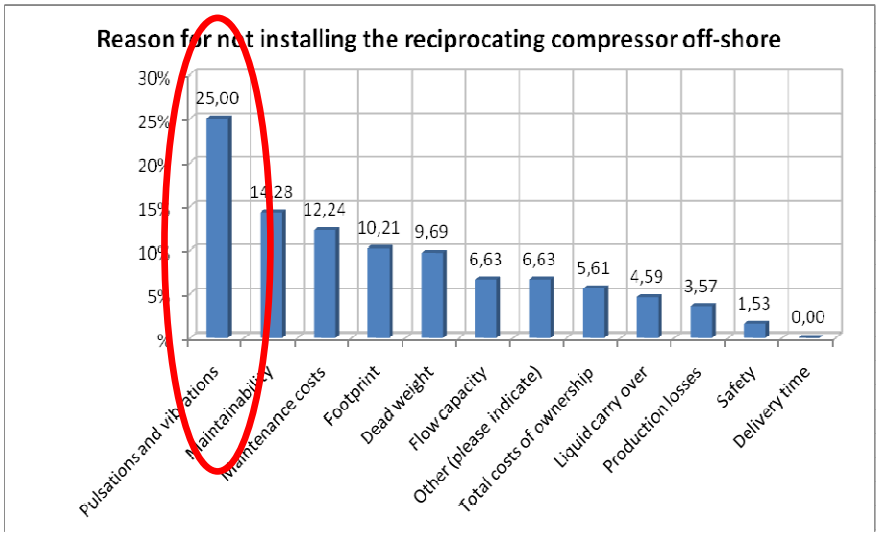


Impact of pulsations on compressor integrity

- API 618 standard describes the general approach to control pulsation and vibrations in reciprocating compressor systems
- For *special* environments, special effort and care shall be taken to comply with the generic approach in API 618
- For these special cases, finding the correct boundary conditions in the modeling approach is a non-trivial task
- Over-simplifications may lead to gross errors in the analysis and subsequent recommendations
- Retrofit measures are expensive and frustrating …

Recips installed offshore

- EFRC reliability survey: the inherent generation of pulsations and vibrations is often a reason **not** to apply a reciprocating compressor offshore.
- Though challenging, a robust design evaluation is possible since adequate tools and expertise are available
- Challenges offshore:
  - Mechanical flexible environment
  - High stacking of equipment and piping due to limited space
  - Strict noise guidelines for accommodation areas



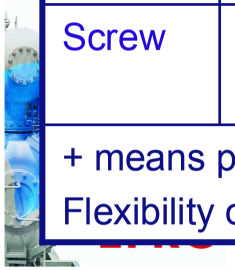
Compressors installed offshore

- Following type of compressors can be applied for gas injection and/or gas lift:
  - Turbo
  - Reciprocating
  - Screw (only suitable for booster applications)
  - Combination of reciprocating, screw and/or turbo

	Flexibility to gas MW variation	Efficiency at high pressure	Weight & Size/ capacity ratio	Vibration levels	Sensitivity to liquid	Air borne noise	Structure borne noise
Turbo	-	-	+ +	+ +	+	- -	+
Recip	+ +	+	- -	- -	-	+	- -
Screw	+ +	- - Only low pressure	+/-	- -	++	- -	+

+ means positive; - means negative

Flexibility of centrifugal compressors to MW variation increases by variable speed drive



Recips installed offshore

- **Mechanical flexibility of the platform** is an essential boundary condition in the mechanical analysis. Problems will occur if is not adequately taken into account in the analysis.
- **Ship movement** and deformation may lead to unallowable loads on nozzles and the machine.
- **Noise** due to the compressor in living quarters must comply with strict guidelines, e.g. 45 dB(A)
  - Air-borne noise (direct radiation)
  - Structure-borne noise (transfer via deck structures)

Recips installed offshore

- If possible:
  - install compressor system on stiffest part of deck
  - try to avoid variable speed (more change on vibration problems)
  - Optimize driver (for noise and vibrations: E-motor)

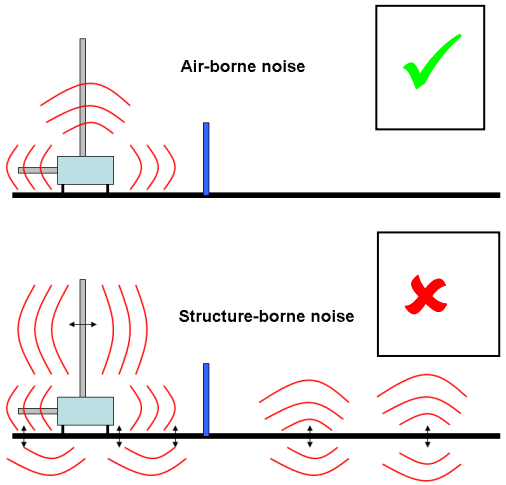
- If noise is not an important issue, the compressors shall be mounted *rigidly* to the deck

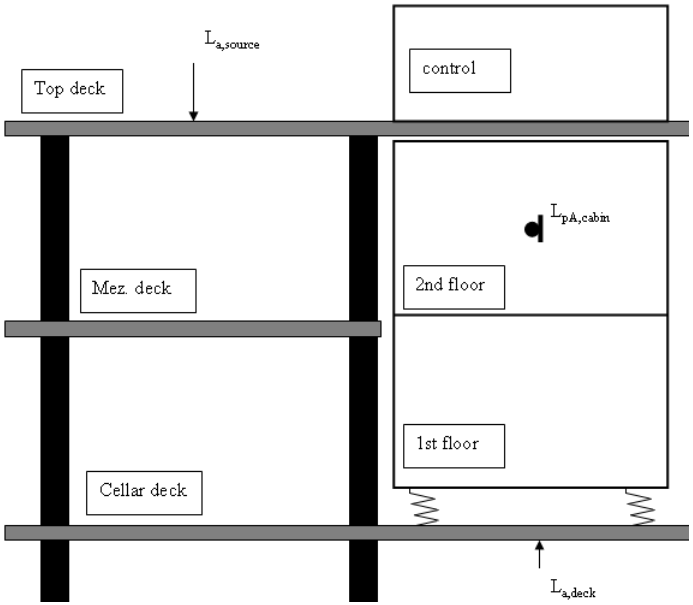
- To keep the pulsations and vibrations to acceptable values the following API 618 analysis have to be carried out minimum:

  - Pulsation damper optimization (lower allowable levels in comparison with on-shore systems, e.g. 10-50% of API 618)
  - Pulsation analysis of piping (same levels as in damper check)
  - Mechanical response analysis of piping, including a part of the deck structure (integrity analysis)

Recips installed offshore

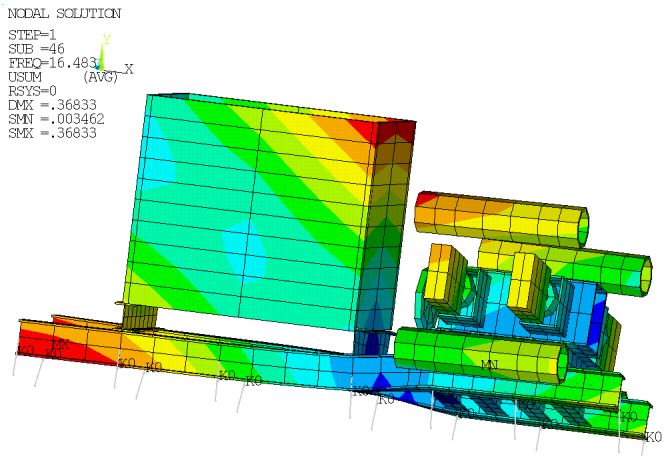
- Prognosis of noise levels:
  - Air-borne noise: direct radiation from compressor
  - Structure-borne noise: noise transfer via deck structure
  - Noise targets are in dB(A) → relevant frequency range is the audio range (100 Hz-10 kHz)
  - Accomodation (noise target is 40-45 dB(A)) in most cases critical
- Input data
  - Manufacturers specification, database
  - Validation with measurements is highly recommended!





Recips installed offshore

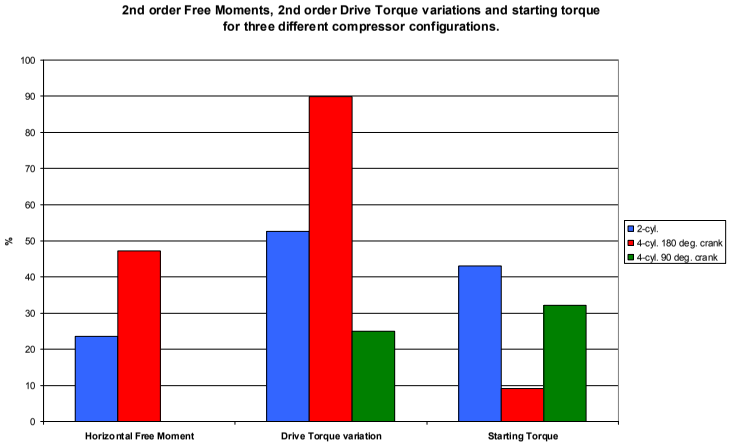
- If noise in the living quarters is a problem:
  - compressor system must be mounted flexible to the deck with anti-vibration mounts (AVM's)
  - living quarters must be *resiliently* mounted to deck
- Target is "mechanical separation" of deck and compressor skid
- Structure below (deck) and above (compressor skid) must be stiff in comparison the stiffness of the AVM's (avoid excitation of mechanical natural frequencies)



Recips installed offshore

- Disadvantages of mounting the compressor with AVM's to deck:
  - In general the vibrations of compressor system (skid, dampers, piping) will increase
  - Vibrations of compressor system during start-up will increase

- Possible solutions:
  - Addition of mass (e.g. concrete)
  - Decrease mechanical excitation with a special type of crank shaft configuration (e.g. "flat" geometry, counterweights, dummy cylinders)
  - Soft starters for smooth start-up



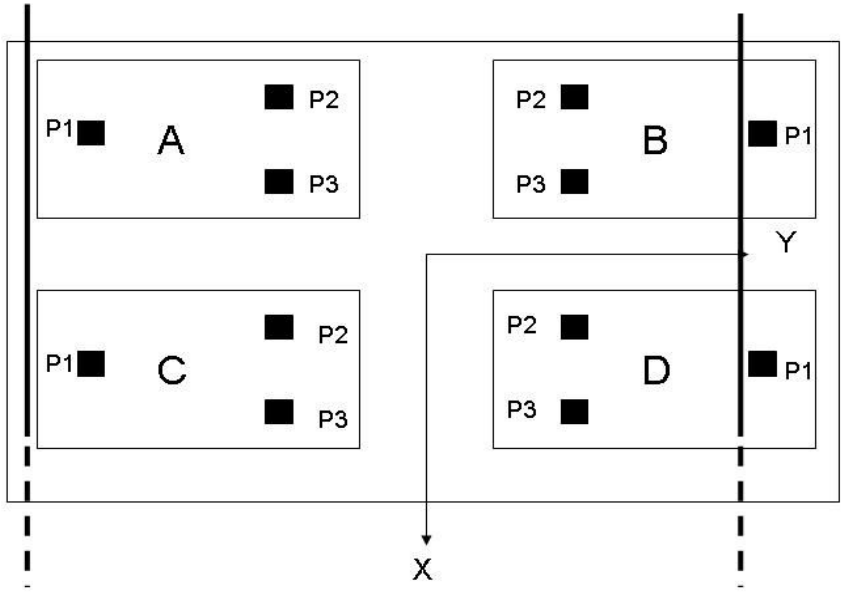
Effect of crankshaft configuration on mechanical loads

Recips mounted on FPSO's

- Important issues for compressor systems mounted on FPSO's:
- Failure of compressor system (driver, compressor, piping) due to ship movement (roll, pitch, yaw) must be avoided
- Two common applied mounting systems:
  - Three-point gimbal joint mounting system
  - Flexible mounting of the compressor system with AVM's

Recips mounted on FPSO's

Example of "Pancake" with 4 compressor skids mounted on an FPSO with a three-point gimbal mounting system

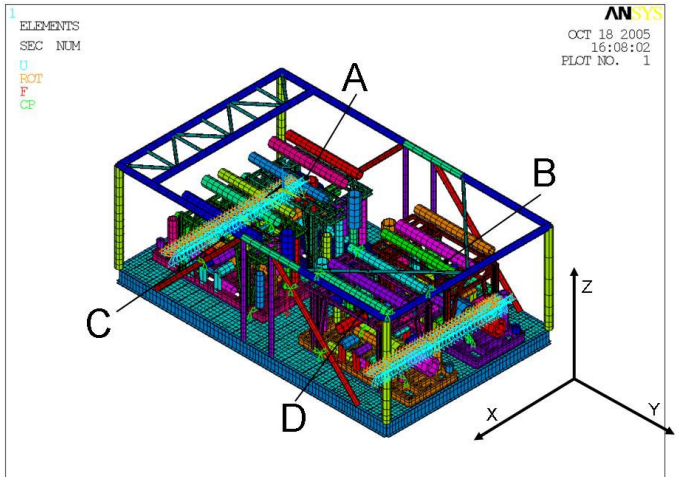


Main ship structure:

Frame 79

Main ship structure:

Frame 83

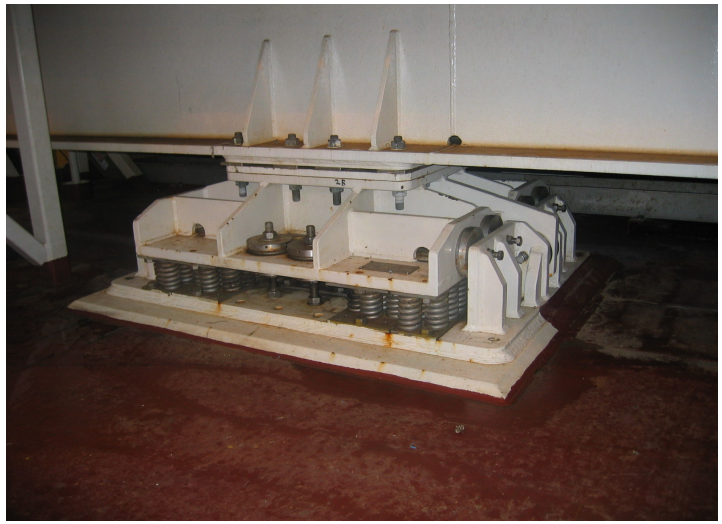


Hinge	X	Y	Z
P1	1	0	1
P2	1	1	1
P3	0	1	1

0= free 1=fixed

Recips mounted on FPSO's

- Example of a compressor system mounted on AVM's



- Disadvantage:
  - Vibrations of machine/skid will increase

- Solution:
  - Install viscous dampers

Conclusions

- Many challenging environments, like liquid carry-over, noise and vibrations may occur that are a potential threat to the compressor's reliability, if ignored in the design phase
- Tools and expertise are available to resolve the challenging issues in the design phase
- A well-defined specification, including input from end-user, engineering contractor and OEM shall safeguard an adequate design evaluation.