EFRC Training Workshop
Foundation design for reciprocating compressors

Excitation Loads

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innovation for life

EFRC Report

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Summary of international guidelines, standards and best practices of foundations, anchor bolts and grouting of reciprocating compressor systems

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- Summary of static loads
- Summary of dynamic loads

Introduction

- Foundation block and piles, anchor bolts, sole plates and grouting of reciprocating compressors shall be designed for all occurring static and dynamic loads (vibrations)
- Reciprocating compressors generate different dynamic loads which shall be taken into account in the design for the different parts of the system
- Most civil engineers use only the static loads e.g. to design the piles, mat and foundation block
- If dynamic loads are not taken into account in the design of the foundation, severe vibration problems can occur and cannot be solved easily after the system is built
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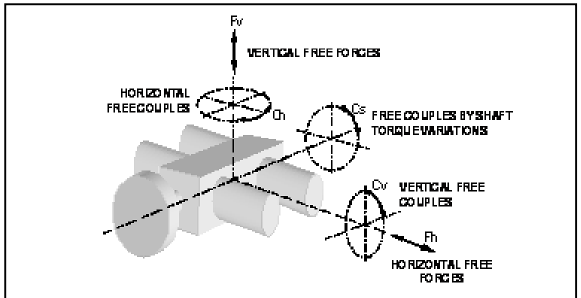
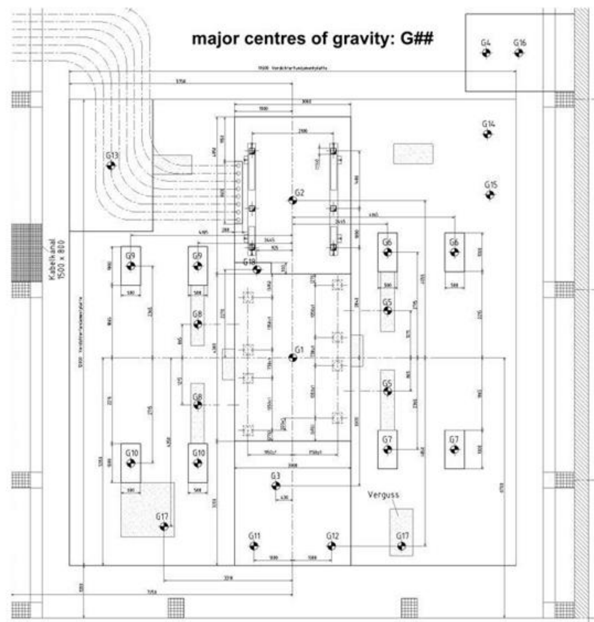
Introduction

- The unbalanced loads, the anchor bolt size and the anchor bolt loads (static and dynamic) shall be specified by the compressor OEM (at maximum speed and load)
- Dead weight loads shall be indicated on a foundation plan



1	PRIMARY FORCES AND COUPLES HAVE A FREQUENCY EQUAL TO COMPRESSOR SPEED. SECONDARY FORCES AND COUPLES HAVE A FREQUENCY TWICE TO COMPRESSOR SPEED						
2	POINT OF APPLICATION OF ALL FREE FORCES AND COUPLES IS THE GEOMETRICAL CENTRE OF THE CRANKSHAFT.						
3	AMPLITUDES OF FREE FORCES AND COUPLES VARY SINUSOIDALLY.PEAK VALUE						
COMPRESSOR SPEED n_0 = 990 RPM							
F_{h1}	($n = n_0$)	= CONF.	kN	C_{h1}	($n = n_0$)	= CONF.	kNm
F_{h2}	($n = 2 \times n_0$)	= CONF	kN	C_{h2}	($n = 2 \times n_0$)	= CONF	kNm
F_{v1}	($n = n_0$)	=	kN	C_{v1}	($n = n_0$)	=	kNm
HIGHEST OCCURING VALUES OF C_s HARMONICS:PEAK VALUE							
C_{s1}	($n = n_0$)	= CONF	kNm				
C_{s2}	($n = 2 \times n_0$)	= CONF	kNm				
C_{s3}	($n = 3 \times n_0$)	=	kNm				
C_{s4}	($n = 4 \times n_0$)	= CONF	kNm				
HIGHEST VALUE OF SHA[FT TORQ]UE VARIATION, PEAK TO PEAK						= CONF	kNm
STEADY TORQUE BETWEEN COMPRESSOR AND DRIVER,					C_{s0}	=	kNm
MOTOR SHORT CIRCUIT TORQUE					C_{sm}	=	kNm

Summary table with unbalanced loads

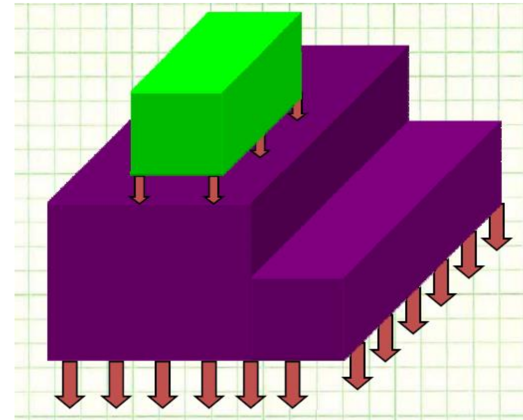


Typical foundation plan with an indication of dead weight (static) loads (denoted as GXX)

Static Loads

- Summary of *most important* ***static*** *loads*:
  – weight of the compressor, skid, driver, coolers, separators, piping, etc..
  – anchor bolt preload
  – weight of concrete block and mat

- The weight of compressor & driver are used to determine:
  - dimensions of soleplates, chocks & grout
  - concrete block design



Compressors mounted on soleplates

Static Loads

- The total dead weight (compressor system & concrete block and mat) is used to determine:
  - soil bearing capacity load (allowable value≈ 72 kPa)
  - soil settlement (allowable value ≈13 mm)
  - if necessary (depends on soil): pile design

- The anchor bolt preload is used:

– to generate friction between the frame and foundation to keep the compressor tight to its supporting structure

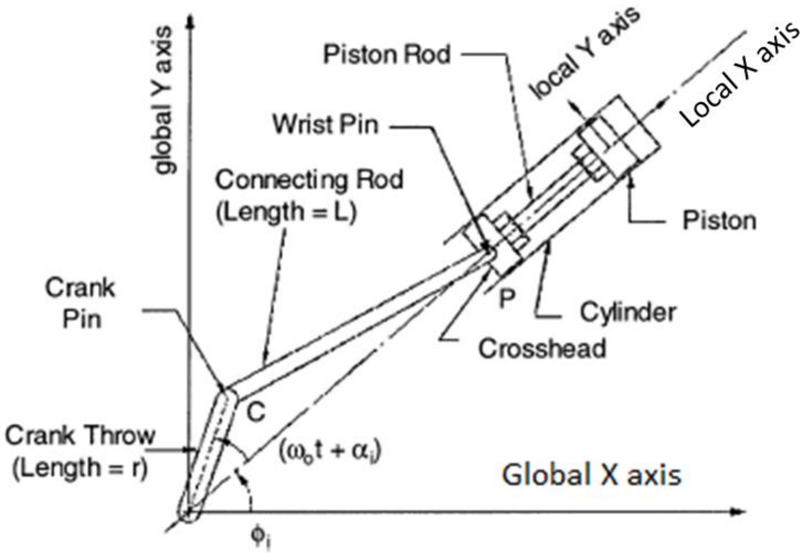
– to limit the fatigue stress in the bolts

Dynamic Loads

- The **dynamic** loads of compressor and engine shall be used to:
  - Design the foundation to keep vibration levels acceptable.
  - Determine the anchor bolt preload to achieve a high enough friction force to keep the compressor tight to its foundation.
  - Determine the anchor bolt fatigue strength
- Summary of most important **dynamic** loads:
  - Unbalanced free forces and moments (foundation and anchor bolts design)
  - Crosshead guide forces (anchor bolt design)
  - Cylinder stretch (anchor bolt design)

Dynamic Loads

Free forces & moments caused by rotating and translating parts



Working principle of a crank mechanism

Inertia force in piston direction:

$$F_{localx} = (m_{rec} + m_{rot}) r \omega_0^{\,2} \cos \omega_0 t + m_{rec} \frac{r^2}{L} \omega^2 \cos 2\omega_0 t$$

Inertia force in perpendicular_direction:

$$F_{localy} = m_{rot} r \omega_0^{\,2} \sin \omega_0 t$$

<u>In which:</u>

- F_x : load in piston direction as a function of crank angle
- $F_{y:}$ load in perpendicular to cylinder as a function of crank angle
- m_{rec}: reciprocating mass
- m_{rot}: rotating mass
- r: stroke
- L: connection rod length
- $\omega_{0:\,:}$circular velocity
- t: time

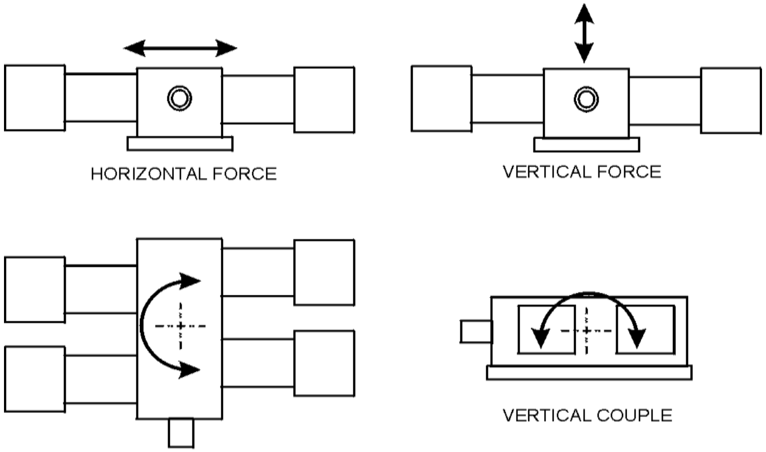
Dynamic Loads

Free forces & moments caused by rotating and translating parts

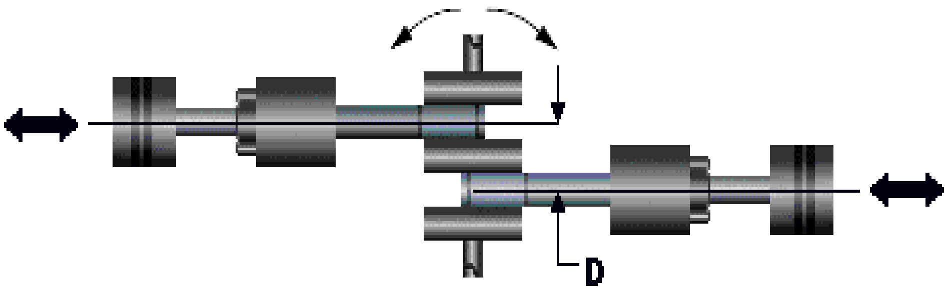
- Some unbalance is inevitable.
- Slow speed process compressors mounted on massive concrete foundations will accept large unbalance forces
- Balancing opposing throws so that the (1x + 2x) unbalance force is less than 5% of the machine rod load rating is typical and usually adequate to achieve acceptable vibration
- Skid mounted and compressors mounted on poor foundations require closer balancing.
- Compressors mounted on offshore platforms require close balancing.

Dynamic Loads

Free forces & moments caused by rotating and translating parts



Summary of free forces and moments



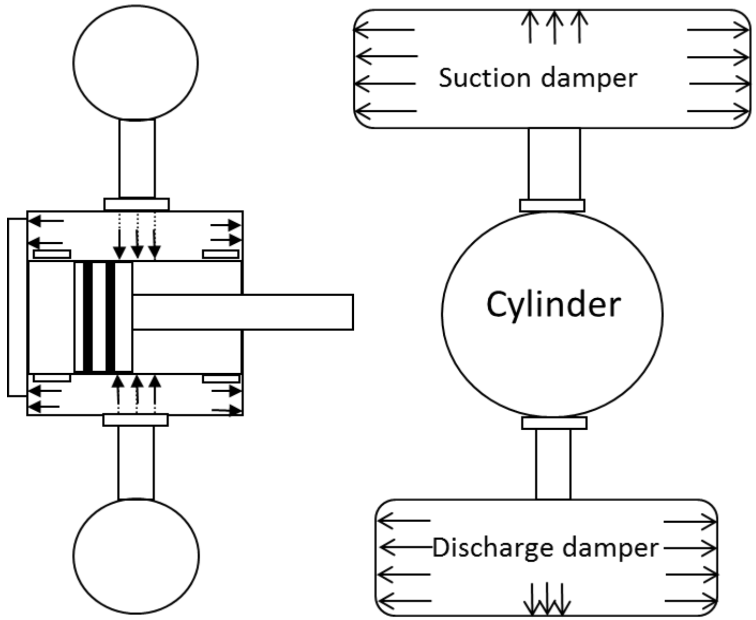
Multiple cylinder configuration

Forces (local) of each <u>individual</u> cylinder shall be used for anchor bolt design

Multiple cylinder configuration: vector summation (global forces) of all individual cylinder forces shall be used in foundation design

Dynamic Loads

Pulsation-induced shaking forces
(mostly not known during early design)

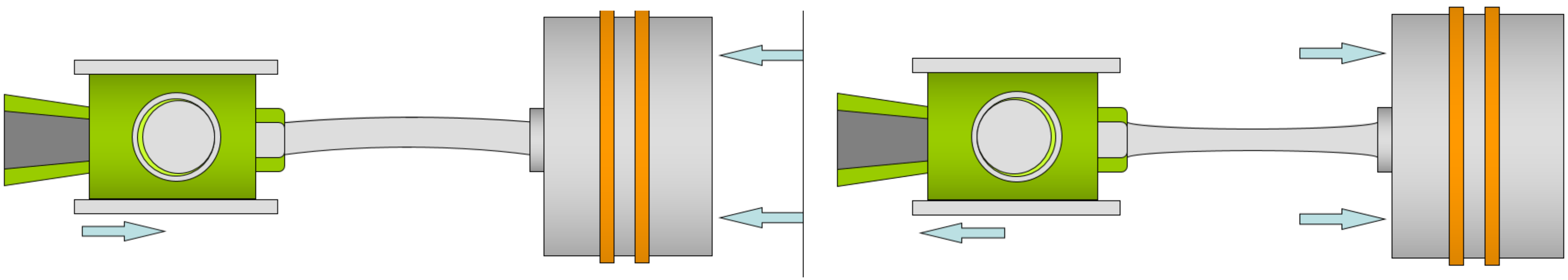


Pulsation-induced shaking forces on dampers and cylinder

If available:
Pulsation-induced shaking forces are to be considered in foundation & anchor bolt design

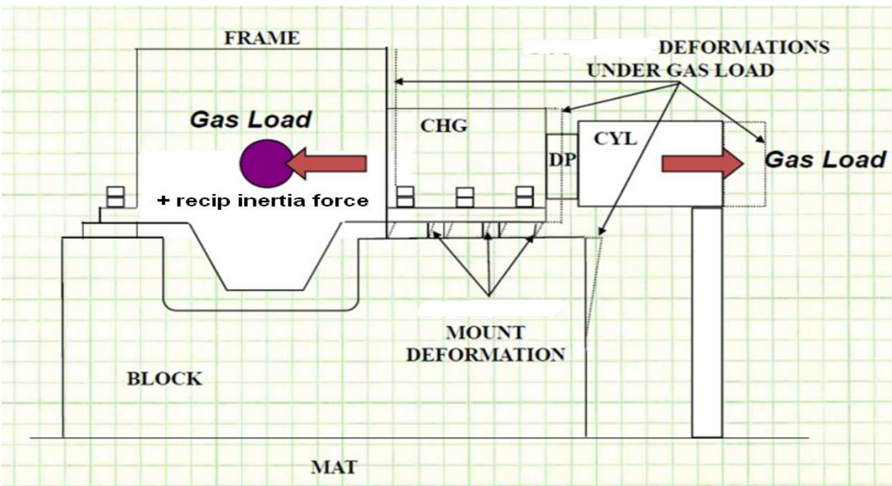
Dynamic Loads
Gas stretching Forces

Compression force **Tension force**

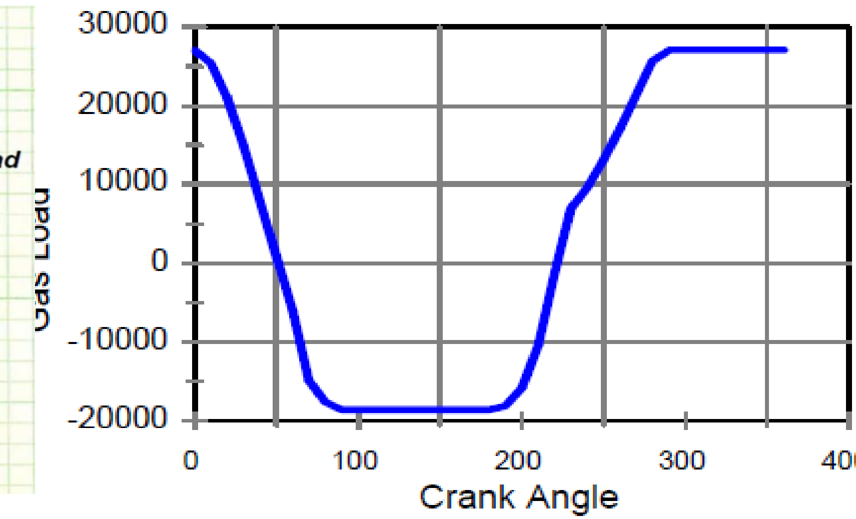


The cylinder stretch forces are balanced by an equal and opposite force on the cylinder distance piece

Dynamic Loads
Gas stretching Forces



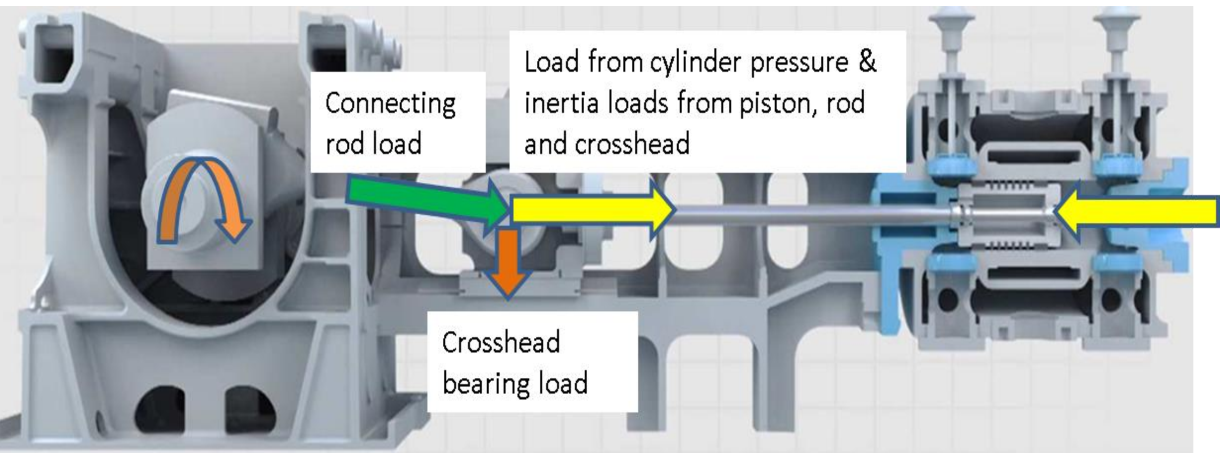
Gas load transmission and deformation

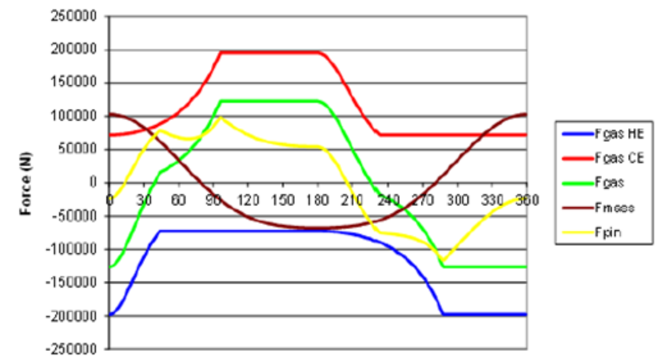


Horizontal rod gas load as a function of crank angle

Dynamic Loads

Crosshead guide (CG) forces





Example of gas & inertia loads on crosshead pin (yellow line indicates total pin load)

- **CG forces shall be considered in anchor bolt design**
- **CG forces are local: there is an equal and opposite force at the big end of the conrod and acts at the main bearings into the frame.**

Any Questions ?