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Harmonic Analysis of Reciprocating Compressor Crankcase Assembly

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Abstract : *Two cylinders double acting reciprocating compressor consists of reciprocating parts, due to reciprocating action of piston and cylinder, there is vibration. Vibration created by crankshaft transferred to crankcase, this vibration created must be under allowable limits defined by EFRC [1] (European Forum for Reciprocating Compressors). In this paper we have two crankcase, existing having offset balanced opposite piston cylinder arrangement and modified having inline balanced opposite piston cylinder arrangement. The forces developed due to rotation of crankshaft and reciprocating action are given to harmonic response module in Ansys Software and results are compared.*
Keywords - *Compressor, crankcase, harmonic, vibration, reciprocating, Ansys*

I. INTRODUCTION

Compressors are widely used in chemical, petroleum refineries. In all the reciprocating compressors the main component is located in crankcase which is crankshaft which is driven by motor through belt or sometimes directly coupled. There are number factors that cause air compression equipment to vibrate and finally break-down. In order to regulate the vibration of reciprocating compressor, crankcase assembly which can effect vibration and noise in the compressor assembly, and some even can destroy components of crankcase assembly like bearing and crankshaft must be estimated and analyzed. So early in design stage, computations of natural frequencies, mode shapes, and critical speeds of crankshaft, static analysis of crankcase system are necessary. Thus, an accurate model for prediction of the vibration in the crankcase assembly is essential for reciprocating compressor. Vibration in the crankcase assembly is a complex three-dimensional coupled vibration under running conditions, including the torsional, longitudinal and lateral vibrations. Hence these vibrations are calculated with the help of harmonic response as module in Ansys v18.2. Design of new products today deals many challenges that they must be strong, light, safe, quiet, or use new materials. Products have to fulfill a wide range of design criteria, including environmental impacts. To keep design and development time and cost effective, companies trust on analysis tools and past experiences. Finite element analysis (FEA) is a abundant technique to analyze the mechanical behavior of a product. The FEA method has been developed to a point where design, meshing, analysis and post-processing are highly integrated and automated. In arrangement with numerical optimization, the FEA technique can also be used to optimize existing designs or even propose modification in designs. However, a successful application of this approach needs a continuous integration of the optimization routines into the FEA-analysis software. Many attempts were made to rectify the vibration problems and analyze as mentioned in [2, 3, 4 and 5]. Reference [2, 3] analyzed the crankshaft through modal and harmonic analysis for design of crankshaft and also calculated the stresses and deflection in the crankshaft. Reference [4] provided the wide calculation for design of crankshaft along with transient analysis. Reference 5 calculated the dynamic loads through Matlab software and applied in ABAQUS.

II. VIBRATION ANALYSIS OF CRANKCASE ASSEMBLY

Crankcase assembly consists of crankcase, crankshaft, bearings, closing plate, etc. This crankcase assembly is connected by bolted joints to the crankcase mounting. All the Radial and Tangential forces acting on the crankshaft must be taken into consideration for maximum loading condition while performing the harmonic response analysis reciprocating compressor's crankcase assembly. The goal of harmonic analysis is to find out the vibration amplitude coming at foundation bolting of crankcase assembly, whose validity can be checked by general testing procedure.

2.1 Modeling: Modeling of reciprocating compressor requires much experience and imagination power. The model of crankcase assembly should be as simple as possible to reduce the computation time and on the other hand model should be as fine as possible to get practical results.

2.1.1 Existing Crankcase assembly: Offset Balanced opposite piston cylinder arrangement is having 135mm which was causing galloping, turning and swaying couple leads to high vibration as mentioned in testing report. This crankcase assembly is having two connecting rods i.e. on LP and HP side.

2.1.2 Modified Crankcase assembly: This crankcase assembly as shown in Fig.1 is having inline balanced opposite piston arrangement, which was developed by adding extra connecting rod on HP side whose weight is balanced on LP side.

2.2 Forces Calculation: In harmonic analysis, all the practically occurring forces needed to be given so that we will get solution near to experimentation. Now, the forces are calculated for both cases i.e. existing (balanced opposite piston at offset distance) and modified i.e. (inline balanced opposite piston). The equations are formulated from Fig.2.

The general procedure to get forces on the main journal of crankshaft is to calculate maximum force in the connecting rod. Then we find at which angle we are getting this maximum force, that all forces are applied in the structural and harmonic analysis.

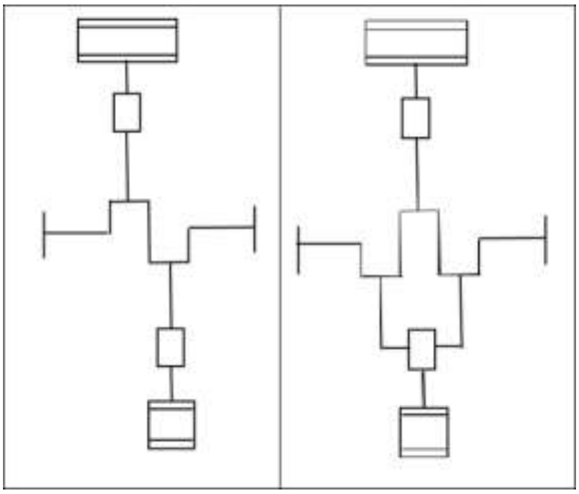

Figure 2 crankcase assembly

Following are the Equations to be used for getting maximum force on connecting rod, after getting this find angle at which these forces are maximum and apply all forces related to that angle. In our case we are getting maximum angle at 30^0.

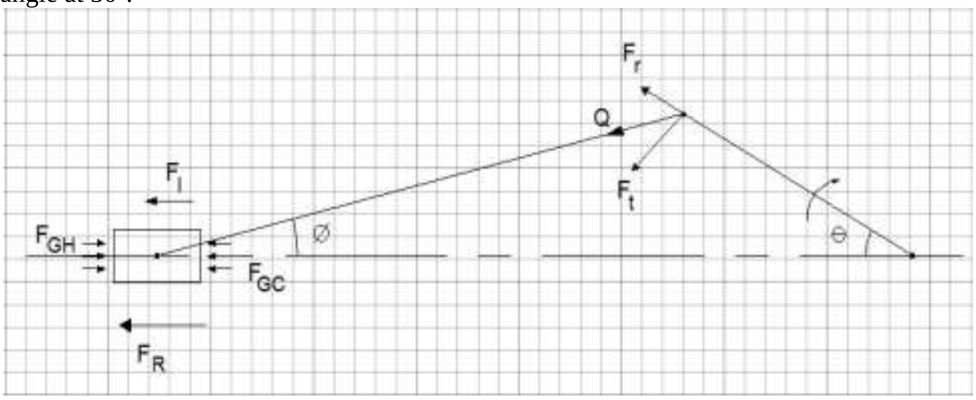

Figure 2 Forces associated with mechanism

Where,
F_{GH} = Gas force at HE in *kg.*
F_{GC} = Gas force at CE in *kg.*
F_I = Inertia force in *kg.*
F_R = Resultant force in *kg.*
Q = Force in connecting rod in *kg.*
F_t = Tangential force in *kg.*
F_r = Radial force in *kg.*

Before moving towards force analysis, its important to finde out intermidiate pressure (P_2) i.e. intercooler pressure. For minimum work and maximum efficiency, intermediate pressure must be geometric mean of initial and final pressure. Therefore, Based on above pressure ranges force[2] analysis is carried out for I^{st} and II^{nd} stage. Following procedure explores step by step force analysis.

: Gas Force - HE (F_{GHE})
…………………………………………Equation (1)
: Inertia Force (F_I)
……………………………...Equation (2)
: Total Force (F_R)
……………………………………………………Equation (3)
: Force in Connecting rod (Q)
………………………………………………………………...Equation (4)
: Normal Force (F_N)
……………………………………………………….Equation (5)
: Radial Force (F_r)
……………………………………………………Equation (6)
: Tangential Force (F_t)
……………………………………………………….Equation (7)
From above equation we get maximum connecting rod force at 30^0.

III. PREPROCESSING

Preprocessing is very important step in harmonic analysis. It includes the contacts, joints, meshing, analysis setting, loading and boundary conditions.

3.1 Connections: Proper contacts should be given which should be practically applicable. Sometimes it is very important to provide joints when there is gap between two bodies which may occur by simplifying the geometries. In both geometries there is joint between crankshaft and crankcase bearing.

3.2 Meshing: In finite element analysis discretization of geometry which can be done by meshing, should have element size less than thickness, so that we get maximum elements and nodes shown in Fig.3 & Fig.4. Hence we will get solution near to exact solution. In our case we have provided Adaptive meshing with element size 8mm.

Meshing	Existing Model	Modified Model
Elements	444538	243085
Nodes	723730	436761

3.3 Structural Boundary Condition : All the forces calculated from the equations are applied on the crankshaft in both case shown in Fig.3 and Fig.4. Here weight of both cylinders are considered in analysis.

Figure 1 Existing Model of Offset BOP

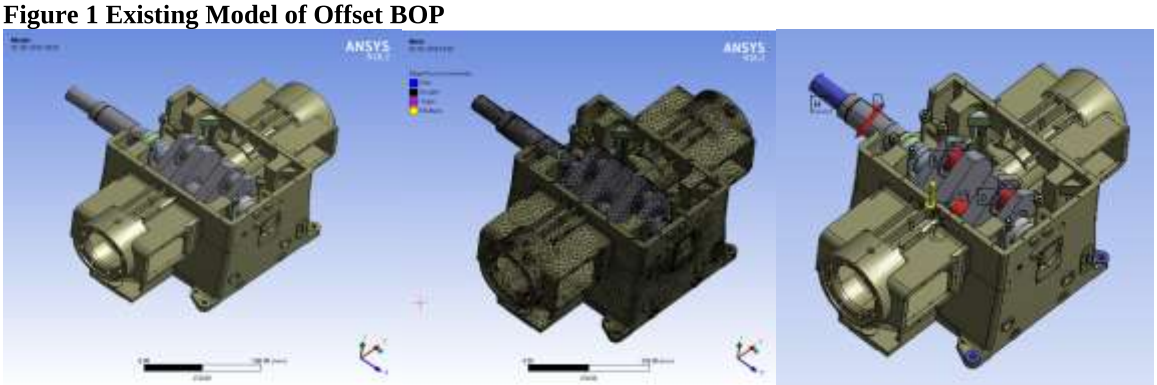

Figure 2 Modified Model of Inline BOP

IV. POST PROCESSING

After providing the analysis setting, as Full method and enabling the output controls. We get the solution. Fig.5 shows the result of von-mises stress on crankshaft which are low but vibration produced by it was large which get transmitted to crankcase foot. Now we need to calculate the frequency at various locations where we have done the testing through the tool called vibrometer. Following are the response calculated at foot of crankcase.

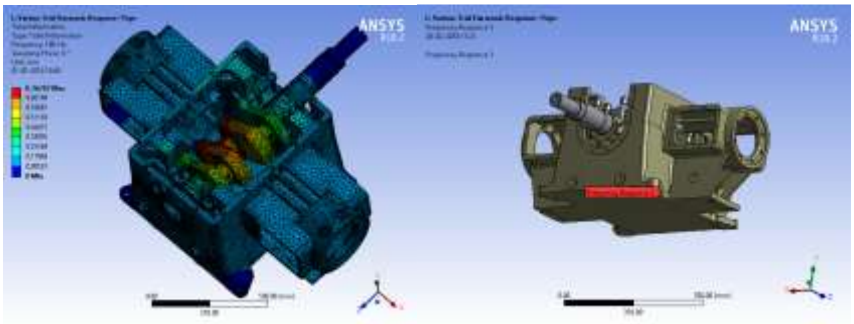

Figure 3 Result of Modified BOP Model

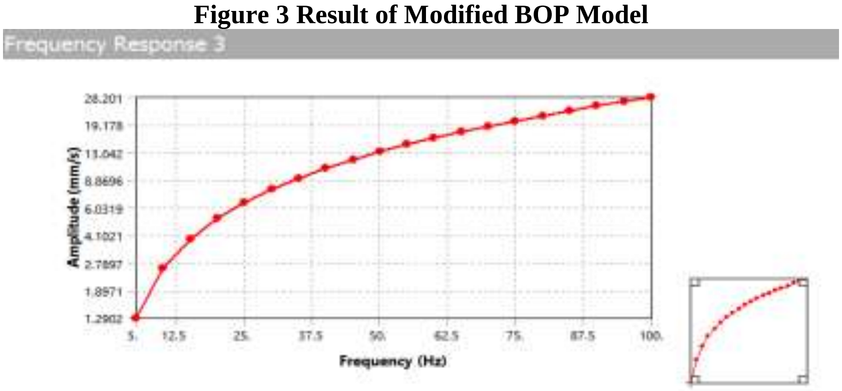

Figure 4 Harmonic Response at Crankcase Foot

As shown in Fig.6 we get the harmonic response curve at crankcase foot which is dictated in TABLE 1. Compressor operating frequency is 13.33 Hz (i.e.800 rpm). Hence by linear interpolation we get vibration amplitude to be 3.427 mm/sec.

Frequency	5	10	15	20	25	30	35
Velocity(mm/sec)	1.2902	2.582	3.8772	5.1772	6.4843	7.7997	9.1253

Table 1: Frequency Response from Harmonic Analysis in Ansys 18.2

Sr. No.	Location	Velocity (mm/sec)		
		Vertical	Horizontal	Axial
1	Crankcase foot (LP)	2.9	4.5	6.2
2	Crankcase foot (HP)	3.3	3.9	7.9

Table 2: Test Report of Velocity Amplitude in Existing Model

Sr. No.	Location	Velocity (mm/sec)		
		Vertical	Horizontal	Axial
1	Crankcase foot (LP)	2.26	3.28	3.59
2	Crankcase foot (HP)	2.98	2.93	4.82

Table 3: Test Report of Velocity Amplitude in Modified Model

V. CONCLUSION

According to EFRC Guidelines [1], acceptable vibration amplitude near crankcase foundation bolts must be less than 3mm/sec (RMS). TABLE 2 shows very high amplitude of vibration. TABLE 3 Test Report shows that vibration in the modified case is near about the marginal value mentioned in the EFRC guideline [1] which matches with the analysis solution. Further vibration can be reduced by providing resting plate during casting only in middle of the crankcase or else can provide anti-vibration sheet below crankcase to absorb the vibration.

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