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Design and Development of Crankshaft to Improve the Rod Load Capacity of the Compressor Frame Size (HA-ZC): State of the Art

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***Abstract*— The piston compressor is a type of positive displacement compressor. The basic components of a piston compressor are the crankshaft, connecting rod, crankcase, piston, and so on. The zero coupled compressors is a breakthrough technology in the compressor business that reduces overall system vibrations by practically eliminating swaying couple and galloping couple. The rod load has a significant impact on the compressor's capacity and efficiency. This paper examines a variety of projects that have been undertaken in the areas of zero coupled compressor technology, rod load improvement, and crankshaft design. The focus of the review is on the design and optimization of crankshafts. This review article can aid in the comprehension of the crankshaft's materials, manufacturing process, failure analysis, and design considerations, among other things.**

***Keywords*— Compressor, crankshaft, static analysis, transient analysis, rod load, FEA analysis, modal analysis etc**

I. INTRODUCTION

A compressor is a device that uses supplied working energy to increase the pressure of a fluid. Compressors are frequently one of the most significant and costly systems in manufacturing and industry, and therefore demand special attention. This equipment is used in natural gas pipelines, petrochemical facilities, refineries, and a variety of other sectors. Modern reciprocating compressors must be designed to produce as little noise and vibration as feasible. The zero coupled compressor is a breakthrough technology in the compressor business that reduces overall system vibrations by practically eliminating swaying couple and galloping couple. The rod load has a significant impact on the compressor's capacity and efficiency. The zero coupled compressor with HA frame is commonly used in industry for rod load capacity up to 2500 kgf.force. A crankshaft is a key component that must work consistently, therefore quality control is critical [7]. By altering the material and manufacturing technique of the crankshaft, the rod load capacity can be increased by up to 3000 kgf, resulting in a 20 percent increase in overall loading capacity. "Material testing revealed that forged steel had a 26% greater tensile strength and 37% higher fatigue strength than ductile cast iron, and it was demonstrated that the forged steel was stronger than the ductile cast iron." [2].Throughout its lifetime, the crankshaft is subjected to cyclic loads such as bending and twisting. It must be able to bear the piston's downward force while bending less" [8] .

II. LITERATURE REVIEW

C. Azoury et al. [1] conducted an experimental and model investigation of a casted crankshaft in their study. The ultrasonic approach was used to determine the young's modulus of the crankshaft. Impact testing was done to verify the material's dynamic behavior as well as its geometric qualities. Modal analysis was used to generate natural frequencies after 3D modelling was completed. The EMA was found to validate the FEA modal analysis. FEA validates natural frequencies as well as mode shapes. The computed frequencies from the FEA and EMA are shown in Table 1.1.

TABLE.1.1 CALCULATED FREQUENCIES FROM THE EMA AND FEA.

Mode	Frequencies EMA (Hz)	Frequencies FEA (Hz)	Description of the mode
1.	350.7	367.7	First vertical deflection
2.	481.8	496.1	First horizontal deflection
3.	799.6	859.2	Second vertical deflection
4.	874.5	972.6	First Longitudinal
5.	965.3	991.2	First twisting mode
6.	1127.8	1284.0	Second Longitudinal

This shows that the model is appropriate for crankshaft dynamic analysis. The validated finite element model can be utilised for more dynamic analysis and structural performance evaluations due to loadings.

In their article, L karthcik et al. [2] said that the characteristics of forged steel and EN8 are comparable. When all factors such as cost, production rate, strength, and deformation are considered, forged steel emerges as the most suited material for the crankshaft. The results of the investigation were afterwards used to determine overall deformation and stress conditions in the crankshaft. This may open up new opportunities for weight reduction and cost reduction in the crankshaft manufacturing process.

TABLE 1.2 COMPARISON OF VARIOUS PROPERTIES OF FORGED STEEL AND EN8

Properties	Forged Steel	En8
Total Deformation	0.01712	0.017289
Von Mises Stress (Mpa)	1.1956E9	1.1956E9
Von Mises Elastic Strain	6.595	6.6602

R. K. Patel [3] et Al. in their paper did modal and fatigue analysis of crankshaft with Ansys software. 3D modeling of the component was done on the CATIA and further analysis was performed on the ANSYS 15.0. The purpose behind this was to find the fatigue life under complex loading condition crankshafts fails at the crack of formed in the fillet area due to repetitive bending and twisting force material used were structural steel. The study was concerned about the load acting on the crankshaft which makes upheld because of gas force and inertia force. After static analysis maximum deformation was about 0.1577 mm. in fatigue failure analysis it was found that The maximum alternating stress is 3999 MPa and minimum stress is found 86.2 MPa and the number of cycles is 106. Figure 1.3 shows the life, damage, biaxiality indication, safety factor of the crankshaft.

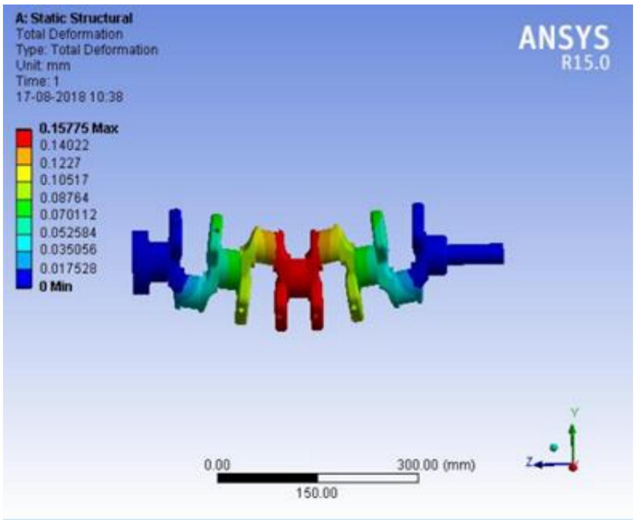

Fig 1. Total Deformation

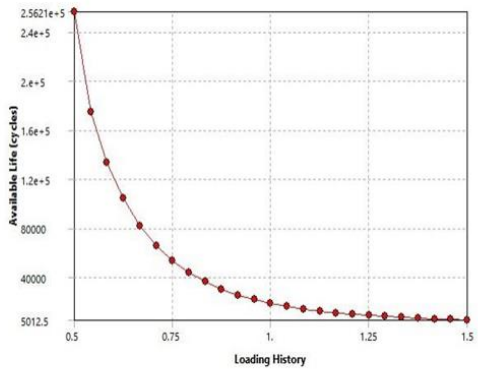

Fig 2. Stress Sensitivity

The Piston with Connecting Rod and Crankshaft is modelled and assembled by Prasanna Nagasai Bellamkonda et al [4] in their article. "Comparison of the Structural Analysis and Modal Analysis on two distinct materials such as (Aluminum Alloy – Cast iron) for Piston, (Aluminium Alloy – Manganese steel) for Connecting Rod, and (Nickel Chromium steel – High carbon steel) for Crankshaft"[4]. Modeling and assembly of the Piston, Connecting rod, and Crankshaft are done with Creo/Engineering software. For the analysis, ANSYS is employed. The ANSYS programme is used to undertake structural, modal, and thermal analysis. The displacement and stress data showed that the ideal combination for assembly is Cast Iron for the piston, Manganese Steel for the connecting rod, and High Carbon Steel for the crankshaft. Based on the findings of this research, it can be determined that the stress values for both materials are less than the yield stress values. The stress values for the Aluminum alloy were found to be 360 degrees. The deformation values for aluminium alloy 360 in mode 3 are somewhat higher in modal analysis. Crankshafts made of high carbon steel are ideal.

TABLE 1.3 STATIC ANALYSIS RESULTS

materials for piston and connecting rod and crankshaft	Deformation (mm)	Stress (MPa)	strain
Materials combination aluminum alloy 360 and nickel chromium	0.27974	246.46	0.0025696
Materials combination aluminum alloy6061 and Nickel chromium	0.28667	246.51	0.0026479
Materials combination manganese steel and carbon steel	0.12928	257.72	0.0021572

TABLE 1.3 MODAL ANALYSIS RESULTS

Mode shapes	**Results**	**"Materials for piston and connecting rod aluminum alloy 360 for crankshaft nickel-chromium"[4]**	**Nickel-chromium**	**"Materials for piston – cast iron and connecting rod manganese steel For crankshaft high carbon steel"[4]**
Mode1	Deformation (mm)	73.191	72.894	42.923
	Frequency(Hz)	229.36	225.43	219.08
Mode2	Deformation (mm)	66.492	66.335	37.784
	Frequency(Hz)	440.07	435.49	318.48
Mode3	Deformation (mm)	80.36	80.063	46.984
	Frequency(Hz)	1302.18	1277.8	1326.5

In this article, Stewart [5] illustrates the loads that act on a compressor. The number of phases is affected by limiting the load on the rod. The differential pressure is related to the overall load on the rod in the cylinder. By increasing the number of phases, the differential pressure can be reduced. The rod load problem is typically overcome by employing two cylinders for one compression stage. The pressure drop will be the same in this instance, but the piston area for the pressure drop will be smaller. During the compression of the gas, the rod that provides the reciprocating motion of the piston can resist considerable stresses. The load on the rod is determined by the cylinder's function. All structures are constructed by the compressor manufacturer to achieve maximum continuous power, which is defined by the maximum power that the crankshaft can supply to the compressor cylinders, or by the pressure differential between the two sides of the piston at the design speed.

Haruyosh Kubo et.Al.[7] their paper talked about the semi-built up and solid crankshafts of diesel engines. Crankshafts need to withstand various loads. Fatigue strength as well as quality, reliability of the crankshafts should be good. The journals of built-up type crankshafts are made of material forged steel. Solid type crankshafts are manufactured from steel ingots that are forged into pre-designed geometries using specialised forging equipment. Built-up type crankshafts with cast-steel crank throws were found to be superior in productivity but inferior in fatigue strength when compared to those with forged-steel crank throws. Fatigue strength is an important characteristic of the crankshaft and to improve the same external forces were applied to the material surface. Cold rolling the fillets helped to improve the fatigue performance by 78%.

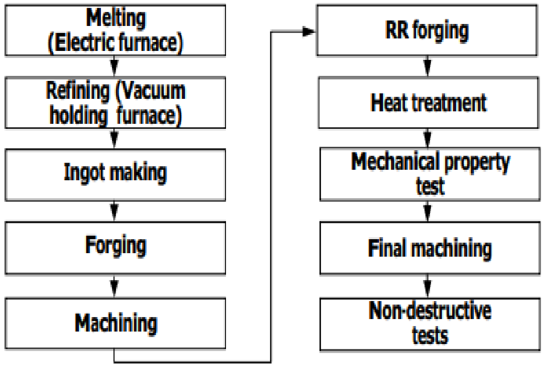

Fig 3. Manufacturing process for solid crankshaft

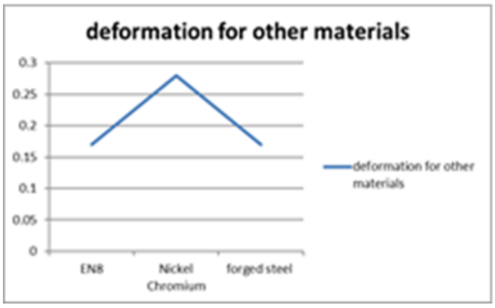

Fig.4.Deformation observed for other materials

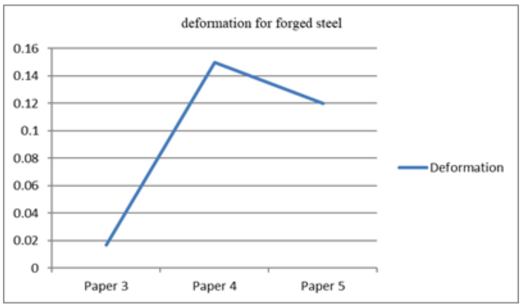

Fig.5. Deformation observed for forged steel

The above fig 4. shows that the deformation observed for the materials like EN8 and nickel-chromium was more as compared to the forged steel
Fig 5 shows the deformation values of material forged steel collected from reviewing the papers.

From this, it can be concluded that the forged steel deforms less means it can withstand the same quantity of load without getting more affected.

During my research on the fatigue performance of forged steel and ductile cast iron crankshafts, I discovered that forged steel had a significantly higher strength than ductile cast iron. "Forged steel has a yield strength of 52 percent higher than cast iron and an ultimate strength of 26 percent higher than ductile cast iron . "The forged steel material is also more ductile than the ductile cast iron, as indicated by the 58 percent reduction in area for the forged steel against 6 percent for the ductile cast iron." [10] The fatigue strength of forged steel is 36 percent higher than that of ductile cast iron after 10^6 cycles.

III. RESEARCH GAP:

During my study, it was observed that there is more scope as well as a need to work on the concept of zero coupling of the compressor. More work can be done to improve the rod load capacity of the compressor.

IV. PROBLEM STATEMENT:

The crankshaft is a major component of zero coupled compressors. If we need to increase the rod load capacity of HA-ZC then the need for change in the frame arises. This option can be eliminated by changing the material of the crankshaft i.e. choosing the material of higher grade can increase the strength and load-carrying capacity.

V. OBJECTIVES:

1) To increase allowable rod load of HA-ZC from 2500 kg to 3000 kg force
2) Design of crankshaft for ZC with 3000 kgf rod load capacity.
3) Check compatibility of existing casted crankshaft and introduce forged crankshaft.
4) Static and transient analysis of crankshaft.
5) Make the entry-level in the next frame size of the compressor.

VI. CONCLUSION:

The crankshaft is one of the major components of zero-coupled compressors. If we want to improve the rod load, then the need for change in material and manufacturing process arises. By shifting to forging rather than casting we can improve material properties. Also instead of S.G. Iron if we use forged steel need for improvement in the strength can be fulfilled. Transient analysis and static analysis are preferred for the stress analysis of components. Modal analysis can be useful to check the resonant frequency.

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