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Thermal analysis of valve material of reciprocating compressor

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Abstract

The operation of a reciprocating compressor is closely linked to the performance of its valves, in terms of both life and efficiency. To better understand the factors that affect reciprocating compressor valve performance and life, a series of experiment is carried on kirloskar 3hp single stage compressor to systematically investigate the physical behavior of valve plates during compressor operation. A reciprocating compressor's valve plate life is generally considered to be a function of the plate's cyclic kinematics, transient stresses, and material properties. Thus, the valve research program aims to incorporate these fundamental factors into an analysis model that accurately predicts valve life for a given application, geometry, and plate material. The research will benefit users within the gas industry by providing a basis for improvements in applications engineering and operational decision-making related to reciprocating compressor valves. The analysis model developed by the research program is based on results from plate single impact tests, finite element (FE) calculations, optical valve plate straightness measurement, and material high cycle fatigue testing. Finite element analysis (FEA) has been done in ANSYS19.2 software to support the thesis work. The experimental and analytical results from the research are discussed herein

Keywords: Kirloskar 3hp single stage compressor, FE, FEA, ANSYS19.2

I. Introduction

In designing a reciprocating compressor valve, desirable functional attributes include good sealing, rapid opening and closing, sustained high flow area (when open), minimum bouncing upon impact, toleration of impact forces and maximum temperatures, and low flow resistance. Proper design choices, such as material, mass, spring constant, lift and flow area, will maximize the successfulness of the design. However, simple, passive valves do not tolerate wide operating ranges well. The challenge to Page 2 the current research program is to achieve longer valve life with low loss and acceptable valve operation (including leak potential). Design improvements often come at a price because low flow resistance, which adds to longer life, conversely leads to excessive impact forces. Valve manufacturers have made many advances in materials and configuration. Yet, design trade-offs, parameter selection, and operation of valves are often mismanaged because applications engineering tools are not readily available.

Valve failures can be divided into two major categories: Environmental and Mechanical. Compressor valve failure can also be the result of mechanical factors, some of which may develop internally unknown to the operator and others which are due to user negligence. If a valve incurs excessive levels of stress due to system overload or overheating, the valve could easily wear down and lose its ability to function as expected. If an air compressor is used in a manner that goes against the advice of the manufacturer, this too could lead to valve failure.

The following factors are among the more common mechanical causes of valve failure:

- **High-Cycle Fatigue**

If a reciprocating air compressor runs at high cycles over lengthy periods of time, the stress is liable to take its toll on various system components, including the valves. If you consistently run an air compressor at higher-than-average settings, you should keep an eye on the valves. If you run your air compressor nonstop for hours on end at high cycles, you should also inspect the valves more frequently.

- **Off-Design Operation**

When it comes to reciprocating air compressors, each model is designed for its own range of operations. If you use a compressor beyond its intended means, you are liable to run into performance issues after weeks or months of such overuse and abuse. If your air compressor has been used in ways that go against the recommendations of the manufacturer, performance issues that do emerge could be the result of valve failure.

- **Impact Stresses**

If an air compressor endures undue stress, the effects are liable to reverberate throughout the system and its various components, including the valves. Whether the impacts are physical or mechanical, a valve could easily wear down through repeated impact stress. If an air compressor is accidentally dropped or shoved around within its working space, these sudden movements may ultimately lead to weakened valves.

- **Spring Failure**

If the valve is attached to a spring, the assembly could fail to function properly if the spring wears down from accumulated stress. Springs are designed with specific levels of flexibility. If a spring becomes too soft or too firm for its intended function, it loses its ability to serve its corresponding components. If the valve relies on the functions of a spring, failure of the latter will have a detrimental effect on the former.

- **Pulsations**

If air travels through a compressed-air system at irregular intervals, the impact could be harmful to the valves. A reciprocating air compressor is designed to pressurize air at predictable frequencies, andeach part within the system is fitted for a certain level of performance consistency. If the system suddenly functions in abrupt or violent fits and starts, the valves are liable to incur unfavorable impacts.

II. Objectives

This project was developed to study about the thermal analysis of reciprocating compressor valve. The main purposes of this project are listedbelow:

a) To study about the influence of temperature and pressure on flap valve located in cylinder head of reciprocating compressor.

b) To design another flap valve and take series of experiments for determining life in with comparison of earlier.

c) To study about the best combination of solution for Material in manufacturing of valve plate.

III. Background

Pioneering Work: The work of Westphal in 1893 became a milestone for the computation of valve openings; see e.g. Thiel (1990). The model contained an equation of motion for the valve plate, using a spring force, gravity force and flow force. The flow force was modeled as the valve pressure difference times the port area. The continuity equation, assuming incompressible flow, contained the change of flow rate caused by the plate motion. Costagliola (1950) was the first to model the behavior of compressor valves in the full environment of a reciprocating compressor. The flow through the valves is modeled based on steady isentropic flow through an orifice, thus taking into account subsonic compressibility effects. It is assumed that the valve plate does not rebound, when reaching the limiter. Two empirical coefficients had to be found from steady flow experiments. Costagliola compared his theory with experiments and assumed the discrepancies to be caused by leakage and heat transfer. The valve opening was recorded as function of time by making use of a mechanical device. In the following decades Costagliola's work forms a starting point for numerical simulations (first on analog-, later on digital computers) of reciprocating compressors. In the middle of the 20th century, compressor valve theories were at the dawn of evolution in many directions.

Flap valves are widely used in air compressor for delivering medium pressure range from last decades.performance of flap valves depends on working temperature and internal pressure of compressor.Physical damages are observed many times on flapper plates due excessive pressure and flow. To minimize the tendency of rapid failure there exist a need to develop flapper valves by changing material properties.Reciprocating compressor performance can sometimes be improved by subtle changes in valve design. Modeling valve behavior can lead to optimum performance without resorting to a field trial and error approach.

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IV. Design and selection

AD design of flap is made in siemens NX11 software by considering existing valve dimensions.

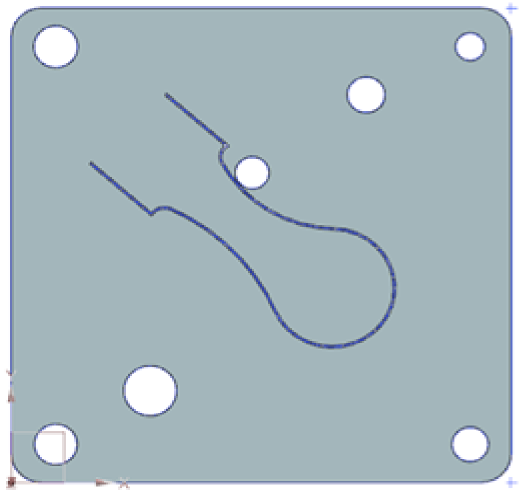

FIGURE: Flap valve in CAD model

Material selection for manufacturing valve flap- ASTM 301 material is normally used for manufacturing valve flaps, but due to excessive suction and discharge pressure limits the flap valve gets deformed, so there is need to develop flapper valves which can sustain in high pressure range and deliver maximum efficiency of compressor without leakage of medium. Significantly ASTM1095 spring steel i.e., SANDVIK 20c can be used to develop the valve flap as material properties of ASTM 1095 dominates ASTM301.

Two test valve specimens were prepared for the experimental work. The material valve was standard spring steel ASTM301 and Sandvik ASTM1095 spring steel 20C..

FIGURE: Test Specimen Sandvik 20C

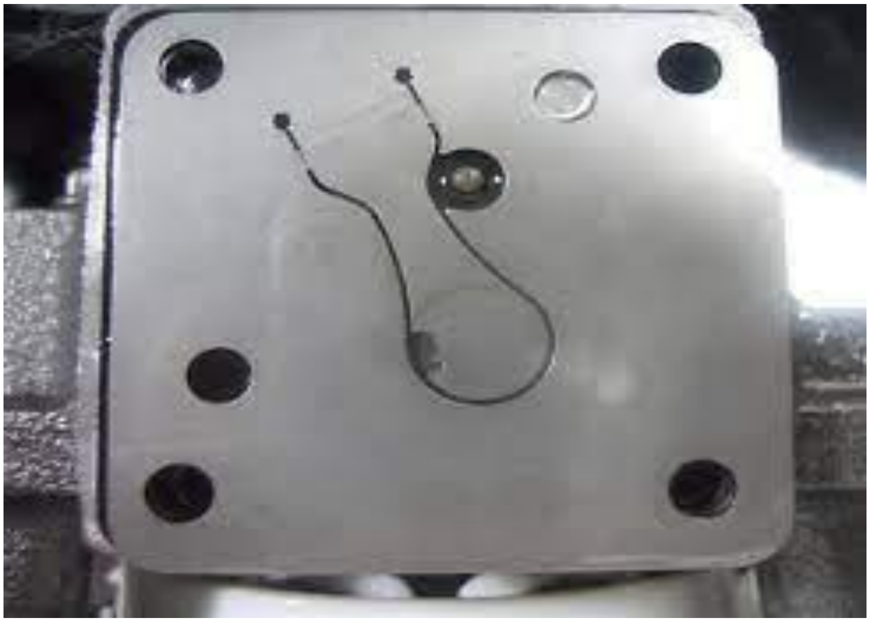

FIGURE: Test Specimen ASTM301

V. Experimental analysis:

TABLE Values of variables at different level

Parameter	Unit	Level 1	Level 2	DOF
Atmospheric temperature	Deg. C	25	40	1
Valve plate thickness	Mm	0.8	1.2	1

After deciding parameters and levels as shown, Data of parameter was collected in such a way that it shouldn't damage or cause any accident to operator and as per stated mechanical damages. Now perform experiment on **Kirloskar 3HP Single Stage Compressor**, output like valve straightness and surface deformation due to excessive suction pressure and excessive discharge pressure is being given in tabulated form. After the experimental results have been obtained, analysis of the results was carried out in ANSYS soft also.

Then we obtain optimal conditions has been calculated for Total deformation of specimen. The following table shows readings of Temperature deformation and surface straightness at each experiment.

- Series of experiment carried out for understanding behavior of both materials under various working temperature

TABLE: Calculation Sheet for Deformation due to temperature and Surface straightness for SANDVIK 20C

Experiment series	Temperature of valve flap (Deg C)	Surface straightness(mm)
1	25	.01
2	40	0.15
3	60	0.18
4	75	0.2
5	120	0.8
6	150	1.33

TABLE: Calculation Sheet for Deformation due to temperature and Surface straightness for ASTM301

Experiment series	Temperature of valve flap (Deg C)	Surface straightness(mm)
1	25	.01
2	40	0.2
3	60	0.27
4	75	0.32
5	120	0.96
6	150	2.1

- Series of experiment carried out for understanding behavior of both materials under various working suction pressure

TABLE: Experimental Layout for suction pressure and valve plate deformation (Actual Factor Levels) for SANDVIK20C

Experiment series	Suction pressure (psi)	Flap deformation(mm)
1	1	0.001
2	3	0.0025
3	5	0.0041
4	8	0.005
5	11	0.0052
6	14	0.0067

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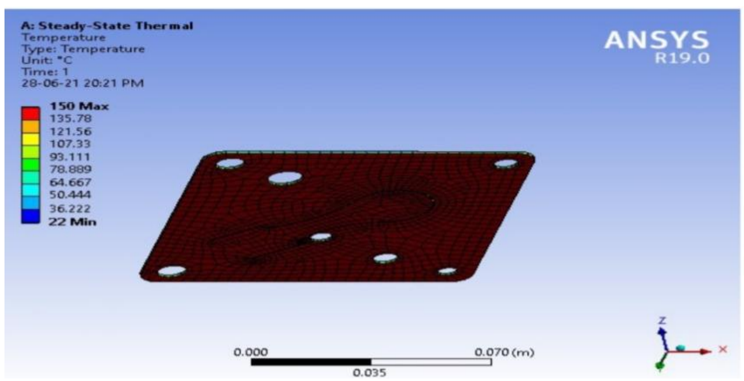
TABLE: Experimental Layout for suction pressure and valve plate deformation (Actual Factor Levels) for ASTM301

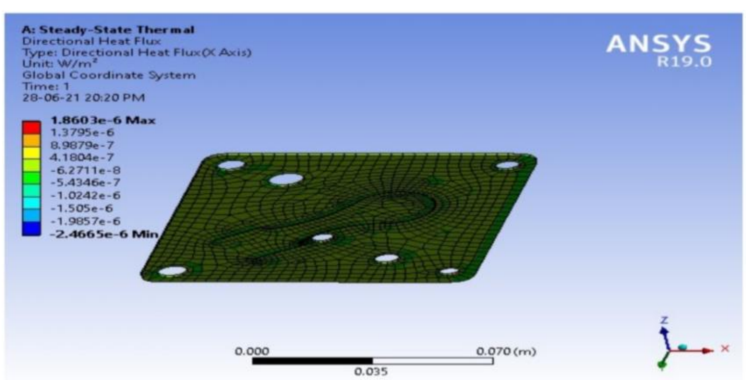
Experiment series	Suction pressure (psi)	Flap deformation(mm)
1	1	0.002
2	3	0.0033
3	5	0.0048
4	8	0.0063
5	11	0.008
6	14	0.0098

VI. Finite Element Analysis: Finite element analysis (FEA) is a numerical tool, used for simulation of components(ASTM1095) and systems, to provide an accurate prediction of a component's response subjected to different kinds of loadings and boundary conditions .

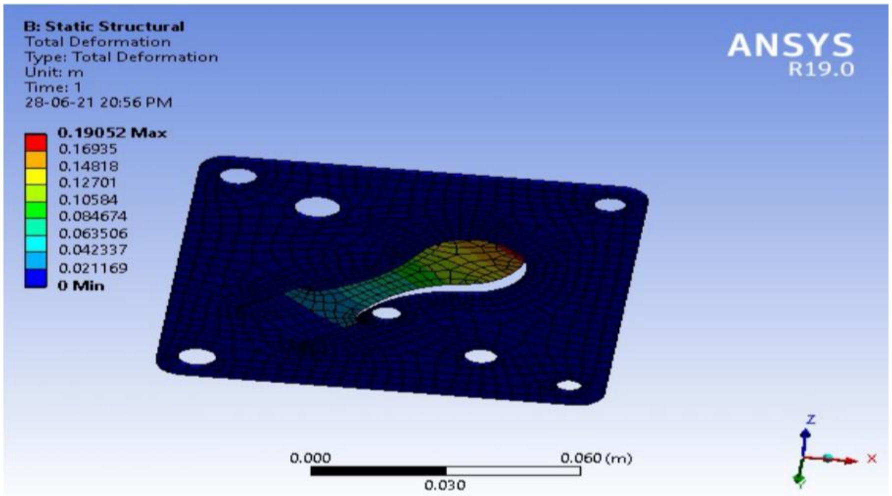
Temperature distribution on flap valve min 22 deg C and max 150degC



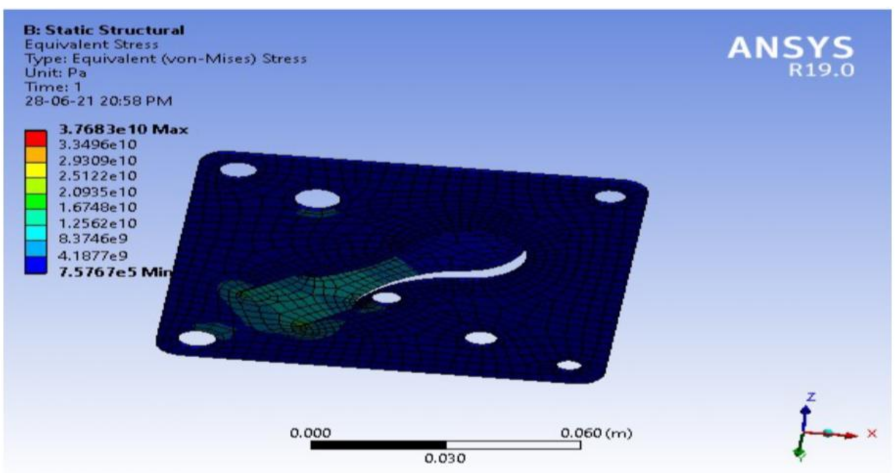
Directional heat flux:



Total deformation:



Equivalent stress:



VII. Result and conclusion

- Observing ASTM301 valve and Sandvik 20C valve by normal eye contact and as checked for straightness. It is found that ASTM 1095 valve deforms in range of 1.33mm to 1.9mm and ASTM 301 valve shows maximum total deformation of 2.3mm.
- Sandvik 20C material valve shows minimum deformation in comparison of ASTM 301 valve. So ASTM 1095 can be considered as best replacement for ASTM301 As per results obtained by comparing ANSYS results with practical demonstration.

- This thesis has presented for optimization best suited material for flap valves of reciprocating compressor. As shown in this study, method provides a systematic and efficient methodology for determining optimal parameters with far less work than would be required for most optimization techniques. The confirmation experiments were conducted to verify the optimal parameters. It has been shown that Total deformation can be significantly improved inFlap valve materials using the optimum level ofparameters.

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