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Suction Valve Design Optimization To Improve Reliability

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ABSTRACT

Suction and discharge valves in a reciprocating compressor are the parts which make the opening and closing movements repeatedly. This movement characteristics results in a fatigue impact mechanism between steel valve reed and valve plate. Thus, reliability of valves should be guaranteed and improved in order to get the desired life cycle time of the product. This study aims to improve suction valve leaf reliability by making some changes on valve assembly characteristic dimensions. Performance and life cycle tests on compressors are conducted to make a comparison between different designs of valves. Additionally, solo tests on valves are applied by using an experimental setup including Laser Doppler Vibrometer and a precise solenoid valve that simulates hermetic reciprocating compressor's valve reed movement.

Keywords: Reciprocating compressor, valve, fatigue

1. INTRODUCTION

In a reciprocating compressor the refrigerant suction and discharge processes are realized by the continuous opening and closing mechanism of valve leaves. During this movement valve leaves are subjected to bending and impact fatigue stresses.

It is mentioned in the study of Svenzon (1976) that the impact fatigue stress results from repeating stroke of valve against the seat. Dusil and Johansson (1980) stated that valve positioning on the valve plate has an effect on fatigue strength. They explained the mechanism during hitting of valve on the seat compressive stresses are induced in the impact contact surfaces. These stresses spread through the material as elastic waves. As they reach a free surface, they are transformed into tensile stresses. When tensile stress waves reflected from different free surfaces are interfered, they create the stress peaks which results in initiation and growth of impact fatigue cracks.

Junior and his friends (2013) reported the results of their numerical model that simulates the seat impact of reed type valves. In their paper they made a parametric study based on dimensional analysis. They implied Buckingham's Pie Theorem in order to define the impact stress as a function of dimensionless groups formed from geometry and material of the valve system, initial velocity of the reed, initial displacement of the tip and reed torsion angle. They defined the parameter as $\Pi L = Lvalve/Dorif$. From their numerical study, they showed that depending on the geometric configuration progression of the impact causes to the different efforts.

In this study, it is aimed to make an optimization on the design of a suction valve in order to prevent fatigue failure and to improve reliability of the product. Position of the valve on the valve plate is described in Figure 1. Characteristics dimensions effecting the position of valve on the valve plate are changed to create a more realiable valve leaf. The current design is stated as D1 and the the alternative design is stated ad D2. Samples of each design are produced, and then solo valve failure tests are conducted in order to compare two designs. To understand whether that design change in valve leaf has a negative effect on overall compressor characteristics, performance tests are also conducted on prototype compressors produced using valves with alternative design.

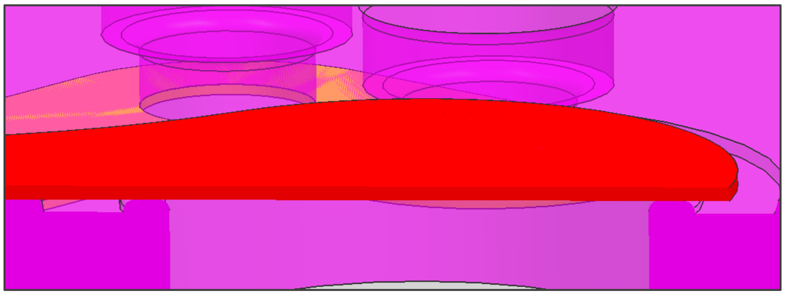

Figure 1: Valve position on the valve plate

2. EXPERIMENTAL SETUP

The experimental setup is the same as the one used in study of Altunlu et al. (2010). The setup includes solenoid valve, pressure regulator, filter, pressure sensor, function generator, DC power supply, cycle counter, PC & data acquisition system, microphone, signal input/out (I/O) connector block, transistor circuit, Laser Doppler Vibrometer (LDV) and LCD Screen for CCD camera in LDV, valve plate and fixture. Pressurized air is utilized to create a valve motion with desired frequency using a solenoid valve. Air is filtered to prevent any oscillation. The test setup is given in Figure 2 and Figure 3.

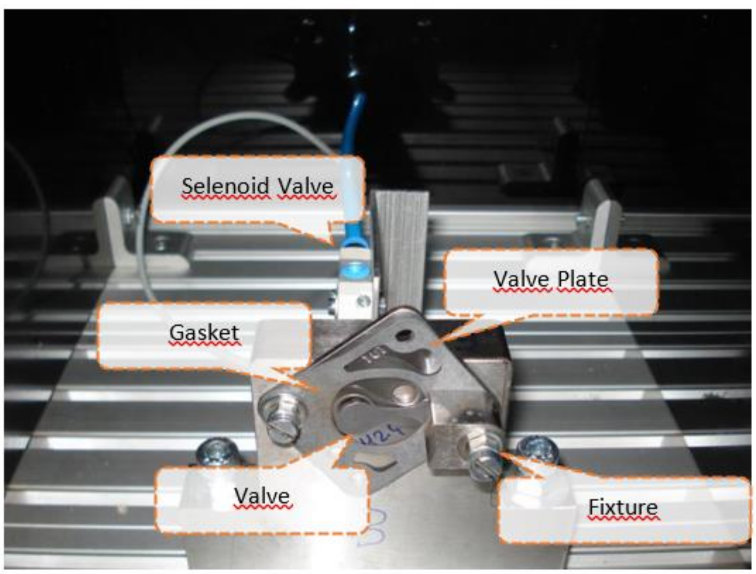

Figure 2: Valve plate on the experimental setup

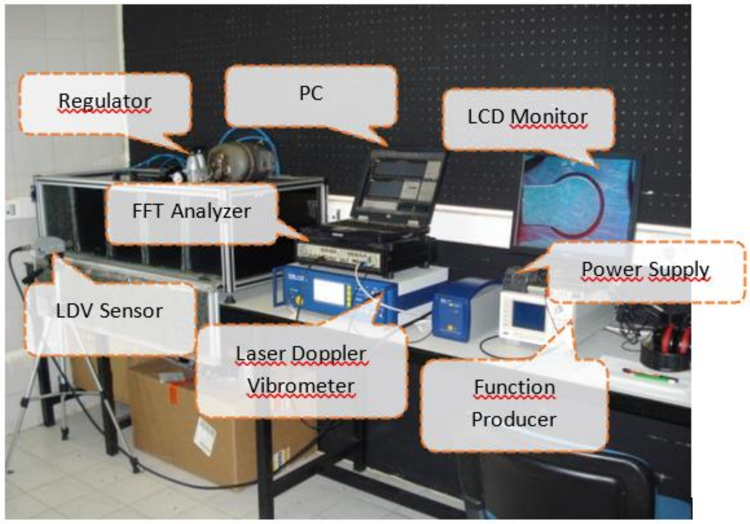

Figure 3: Data collection system of the experimental setup

LDV is used to measure the impact velocity and displacement of the specimens. Laser beam is directed at the center of the valve leaf impact region. The velocity data is collected in order to get fatigue lifetime graph. The purpose of the microphone is to detect the fracture. The test is terminated when the fracture is occurred. Valve movement is monitored and recorded on the LCD screen with a CCD camera during the test. LabVIEW software is used to create graphics for data acquisition, signal processing and triggering mechanism.

The output of the experiment is a velocity data collected during the test and a video record showing the valve movement. By analyzing the velocity using an excel macro, the velocity at the fracture point is determined. From the video record, the fracture time is noted.

The material of the tested valves is a kind of high grade stainless steel mechanical properties and chemical composition of which is given in Table 1 from Sandvik datasheet (2021).

Table 1: Mechanical properties and chemical composition of test specimen

Sandvik Hiflex®							
Chemical Composition (nominal) %	C	Si	Mn	P	S	Cr	Mo
	0.38	0.40	0.55	≤ 0.025	≤ 0.010	13.5	1.0
Tensile strength (nominal)	1900 MPa						
Modulus of elasticity, static properties at 20°C	210000 MPa						

Two different alternative designs of valve leaf are compared in this study. They are stated as D1 & D2.

3. EXPERIMENT RESULTS

The number of test specimens is 10 for both D1 and D2 designs. The fracture velocity and the fracture time data are collected for each specimen and then scatter plotted. Curve fitting method is used to estimate the behavior of each valve design. Power equation of 2nd order is used to make curve fitting. Curves are graphed in Figure 4.

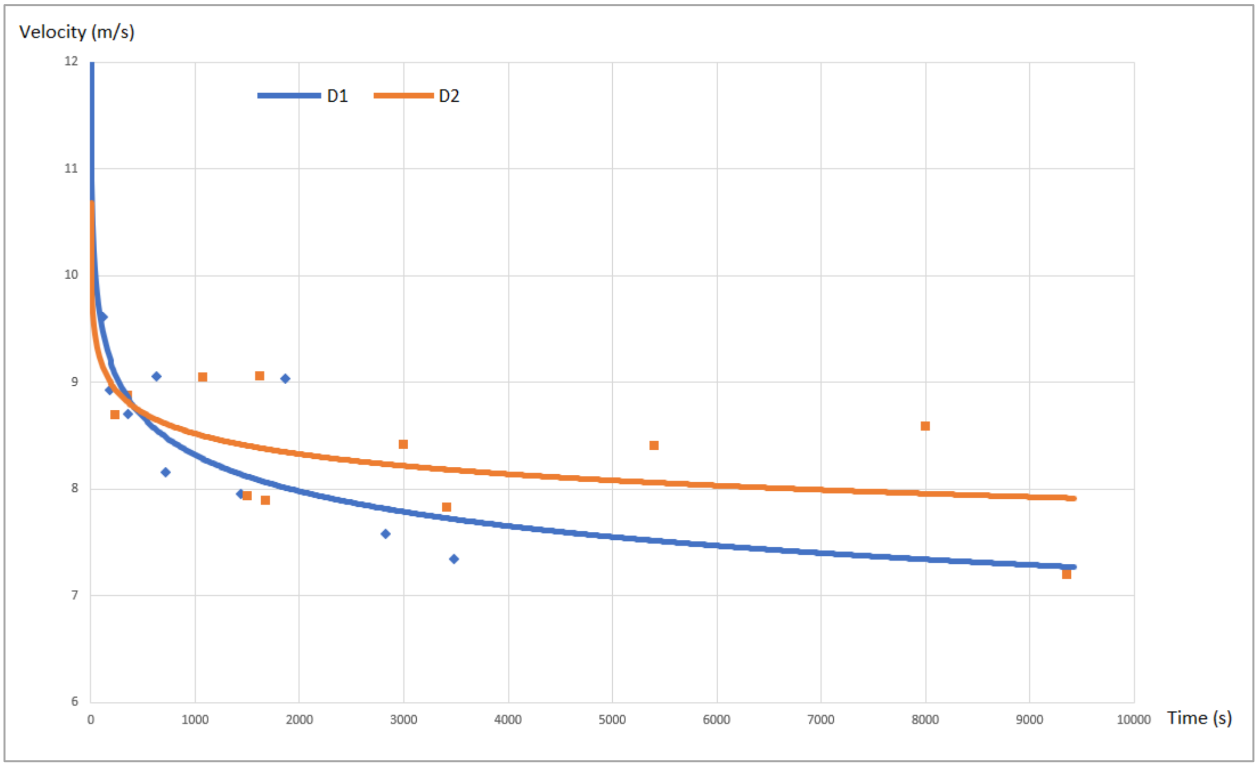

Figure 4: Life cycle curves of D1 and D2 specimen

The aim of the study is to have a valve which can be durable to higher velocities and longer fracture time. Therefore, it can be said that a curve which is on the upper and right side of the graph is more reliable. This graph shows that D2 design is a better choice for a long life cycle.

4. PERFORMANCE VERIFICATION

Since the valve has a critical importance on the capacity, coefficient of performance (COP) and noise characteristics of the compressor, these tests also should be conducted whenever there is going to be a design change on valve.

Calorimeter and noise tests are realized on compressor prototypes produced using D1 and D2 valves. Tests are realized at ASHRAE conditions. 5 protypes of each configuration are tested and results are given as averages to eliminate production variabilities. COP, power and capacity rates of D1 &D2 are given in Figure 5 and noise characteristics are given in Figure 6.

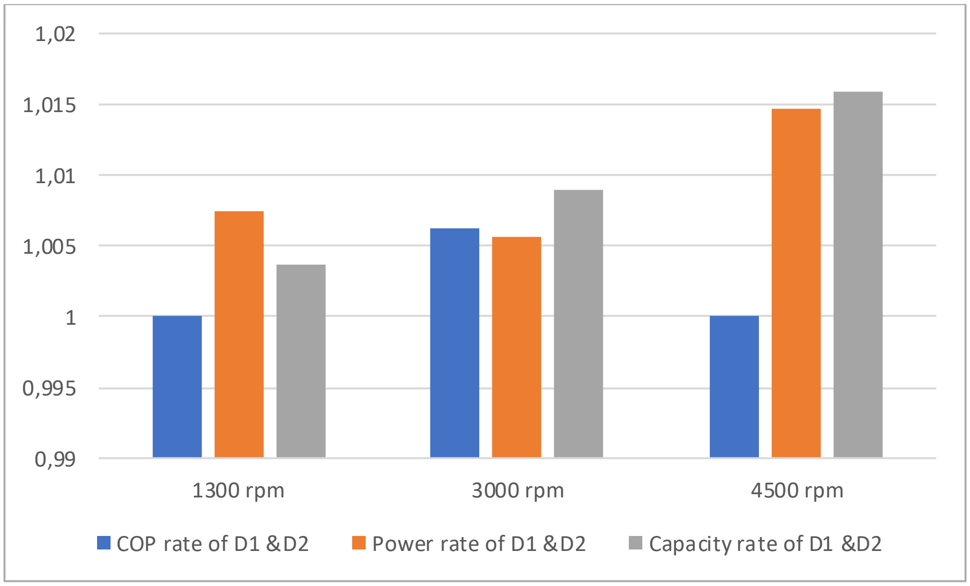

Figure 5: Relative calorimeter test results of prototypes with D1 and D2 valves

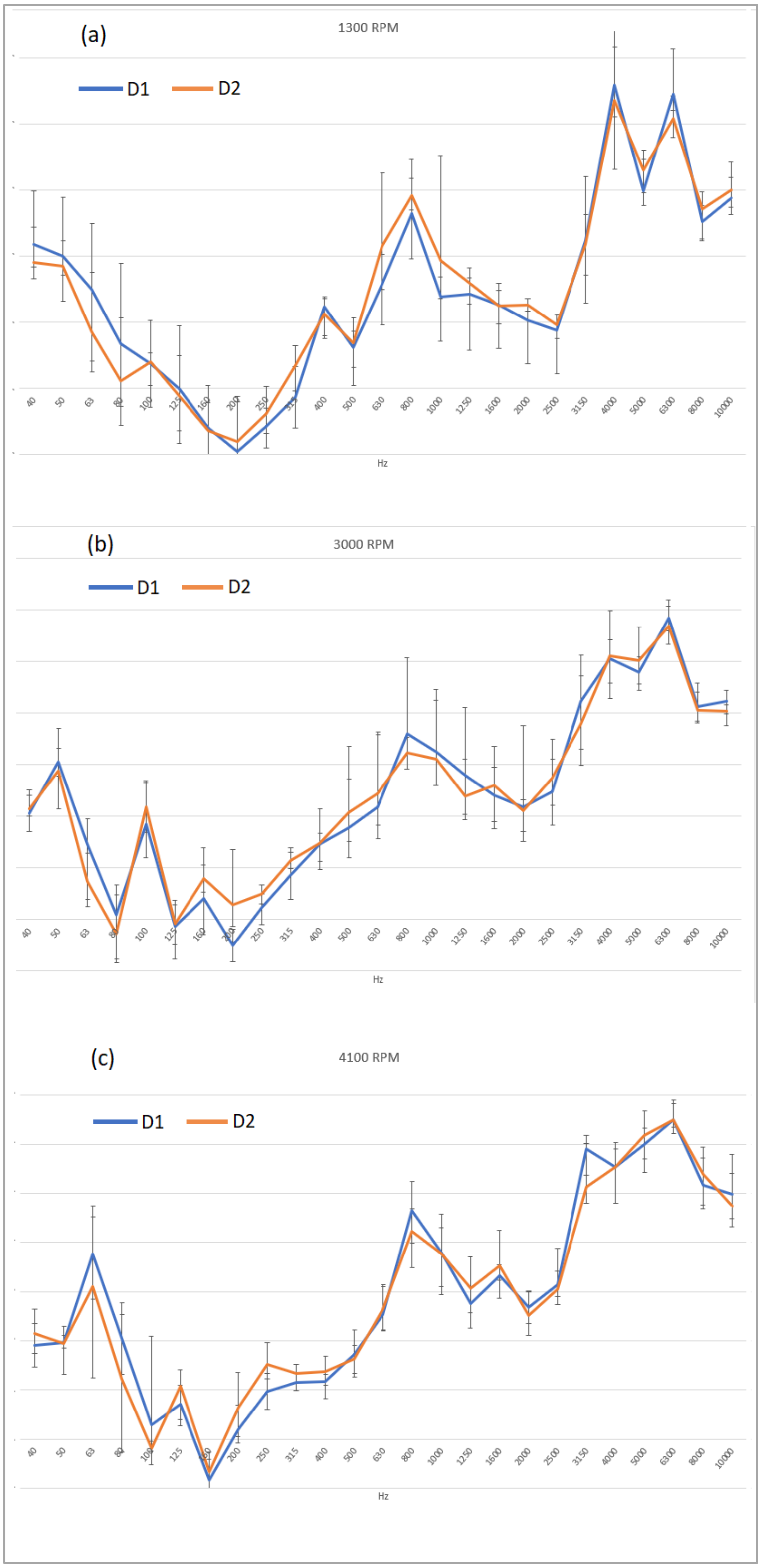

Figure 6: (a) Noise characteristics at 1300 rpm (b) Noise characteristics at 3000 rpm (c) Noise characteristics at 4500 rpm

When COP, capacity and power values obtained from performance tests are rated, the maximum difference is 1,5% at 4500 rpm capacity as can be seen in Figure 4. In Figure 5 it can be interpreted that, there is not any significant noise characteristics differences and fluctuations between D1 & D2.

5. DISCUSSION AND CONCLUSION

The experimental setup utilized in this study is very useful to determine valve leaf and reliability. This setup makes it possible to simulate service life in a very short time by making an opening and closing movement with high frequency.

Results of the study show that the position of the valve on the seat has a high effect on impact fatigue failure. By optimizing the geometry of the valve, it is possible to get a higher reliability and longer service life. Performance tests also verified that making such a design change for valve is safe since there is not any side effect in terms of COP and noise characteristics.

As a further study the other design parameters affecting the position of the valve on seat can be evaluated by using the same experiment setup. By making such a study at the design stage of a new product will be useful to get desired service life.

NOMENCLATURE

COP	Coefficient of Performance
LDV	Laser Doppler Vibrometer
CCD	Charge Coupled Device

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