MEASURING HERMETIC COMPRESSOR VALVE LIFT USING FIBEROPTIC SENSORS

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Abstract

One of the most important factors to be considered in the project of a refrigerating compressor is the discharge and suction valves design. The operation of the valves influences the volumetric efficiency and so, the compressor performance is greatly affected by how efficiently the valves can admit and deliver the fluid. In hermetic compressors, it is very important to understand the behavior of the suction and discharge valves to maximize the efficiency of the refrigeration systems, as well as, preventing pressure instabilities that may cause undesirable vibrations in the mechanical set with significant increase of the noise levels. This work develops and makes use of a measurement technique using fiber optic displacement sensors, with goal to quantify the admission and discharge valves displacement during the work cycle of alternative hermetic compressors. All the measurements had as reference the angular position of the compressor's crankshaft what allowed the monitoring of all the events as a function of its angular displacement. For the development of the present work it was necessary to plan a robust measurement system, not vulnerable to the ambient factors, inside a hermetic housing.

1 Introduction

One of the most relevant factors to be considered in the refrigeration compressor project is the discharge and suction valves design. The compressor performance is greatly affected by how efficiently the valves can admit and deliver the refrigerant fluid. In hermetic compressors, it is very important to understand the behavior of the suction and discharge valves to maximize the efficiency of the refrigeration systems, as well as prevent pressure instabilities that may cause undesirable vibrations in the mechanical set with significant increase in the sound levels.

The suction and discharge valve works due to the pressure differential by the alternative movement of the piston. The suction valve allows the refrigerant fluid to go to the compression chamber (cylinder) and the discharge valve delivers the flow to the refrigerating system. The valves are designed to close quickly to avoid backflow, and to open easily. They are built from light material, designed to provide fast dynamic response and positioned to minimize the dead volume of the system.

The reed valve is widely used in small compressors. It is a thin sheet metal, firmly fixed at an end while the opposing, free, remains in the valve seat. The free end bends to release or restrict the flow due to the pressure differential, which is submitted. Due to the valve characteristics and dimensions it is not possible to mount any sensor coupled directly in the valve (1).

During the valve development numerical modeling is applied to simulate the valve motion and vibration, but the validation of these numerical models requires valve motion measurement at working conditions.

1.2 State of the art

Because of the valve characteristics, only contactless measurement methods can fulfill the requirements. Capacitive and inductive transducers are the simplest ways for contactless measurement. Nevertheless, capacitive transducers must be installed near the valve, which can cause considerable changes in the gas flow.

Inductive transducers are more compact and can be installed with only a small influence on the working conditions, but their high non-linear characteristic makes this type of transducer not recommended for the valve lift measurement.

Nagy *et al* (2008) (2) and Buligan *et al.* (2002) (3) reported the use of a Laser Doppler Vibrometer (LDV) for the valve lift measurement in hermetic piston compressors. An LDV is an instrument, which can measure the laser beam direction component of the velocity of a moving reflective solid surface. The laser beam is focused on a surface and the reflected beam is detected. In the case of a moving surface – due to the Doppler effect – the frequency of the reflected light compared to the source light is shifted. This frequency shift is then evaluated by an interferometer and converted into a voltage signal. The output voltage signal is a function of the velocity of the moving surface. The range of velocity and distance in which the signal shows a high quality result depends on the optical equipment and the signal processor of the LDV. The effects of optical disturbances (like light scattering, reflection) and the problem of light scattering on the oil particles were analyzed by Buligan (2002).

Ludu *et al.* (2000) (4) visualized the suction and discharge valve motion using an endoscope video system. Two endoscopes using a thin fiber-optic bundle were installed in a compressor and CCD camera with the aid of stroboscopic light filmed the valves movement. High accuracy, piezoelectric pressure transducers were installed to measure the dynamic suction and discharge pressure as well as the cylinder pressure . A crank angle position marker was installed so that the signals could all be related to piston position and to each other on a time basis. The compressor was installed in a special hermetic shell, which was larger than the original shell. The test conditions were kept constant.

Prasad and Woollatt (2000) (5) used the fiberoptic sensor, but applied in a VIP compressor (Valve-in-Piston ™). The measurements were done in natural gas**,** in a single stage, double acting, VIP compressor, installed in a closed loop compressor test rig.

2 Experimental Assembly

The experimental set up was assembled in a hermetic compressor (600BTU/h) widely used in household refrigerators. Figure 1a illustrates the suction valve and Figure 1b the discharge valve system for compressor used in this application.

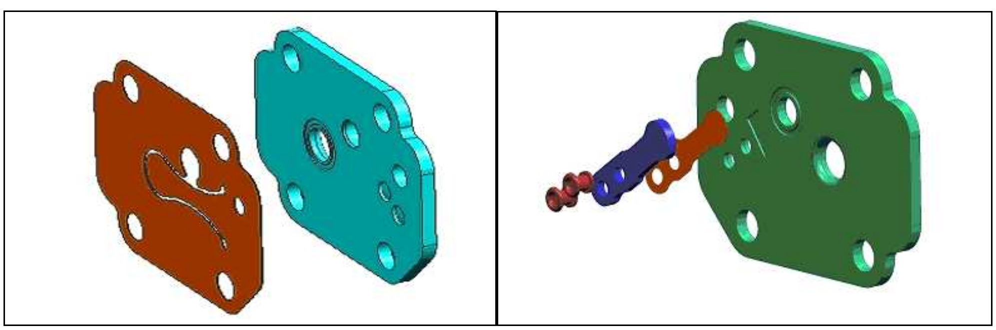

Figure 1a – Suction valve leaf and valve plate   Figure 1b – Discharge valve and retainer

Two non-contact sensors were used, one for each valve. These sensors are reflective devices using bundled glass fibers to transmit light to and receive light reflected from target surfaces. The intensity of the reflected light is proportional to the distance between the sensor tip and the target object. They have high resolution and high-speed response (20KHz). These sensors are sealed, compact, and accurate allowing measurements inside the mechanisms submerged in fluids and in hostile environments like temperature and pressure.

The sensor tips were aligned with the valves with the maximum distance allowed by the sensor range to minimize the effect over the flow. The sensors were threaded in adapters that were fixed in the cylinder head. This arrangement is illustrated in Figure 2.

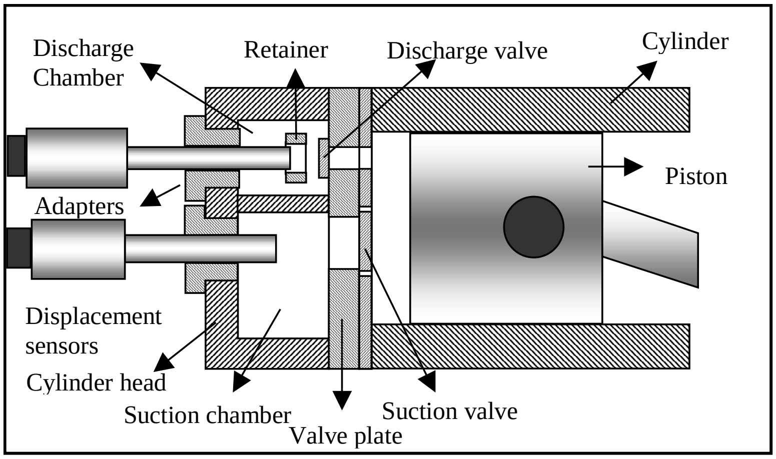

Figure 2 - Fiberoptic sensor assembled in the cylinder head

Due to the optical characteristics of sensors, several aspects were considered during the calibration, as follows: the surface texture, the light presence over the tip, oil droplet presence and the valve bending. To get better results the calibration was done *in situ*. Gauge blocks and depth micrometer were used to calibrate the valves displacement as shown in Figure 3.

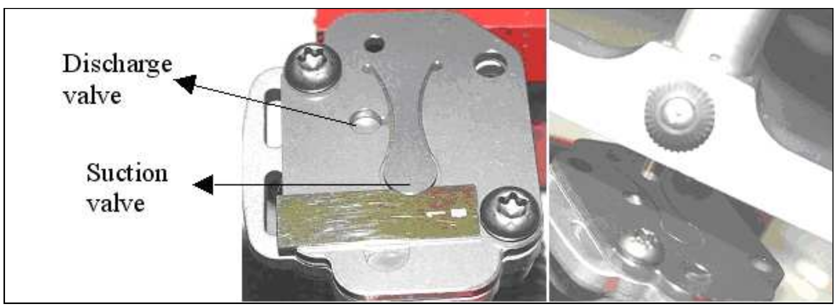

Figure 3 – Calibration of fiberotic displacement sensor

Pressure transducers were used to measure the suction, discharge and cylinder pressure. The selected sensors are one of the smallest amplified transducers currently available and can be used in harsh environments. The microprocessor in the transducer offers high accuracy with a total error band of ±0.25% FSO, including all errors over a wide temperature range of -40ºF to +250ºF. The sensors were calibrated in an ambient at 77°F and 212ºF and their sensitivity did not changed. This verification was made due to the high temperatures during the compression and discharge process of compressor work cycle.

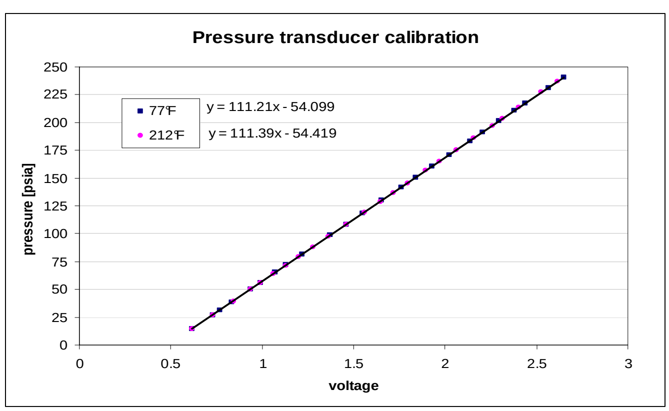

Figure 4 – Calibration of pressure transducer as a function of the temperature

The sensors were arranged to keep the sensor tip on the same plane of the cylinder head wall to avoid reducing the suction and discharge chamber volumes. The volume reduction was just due to the displacement sensor tip assembly.

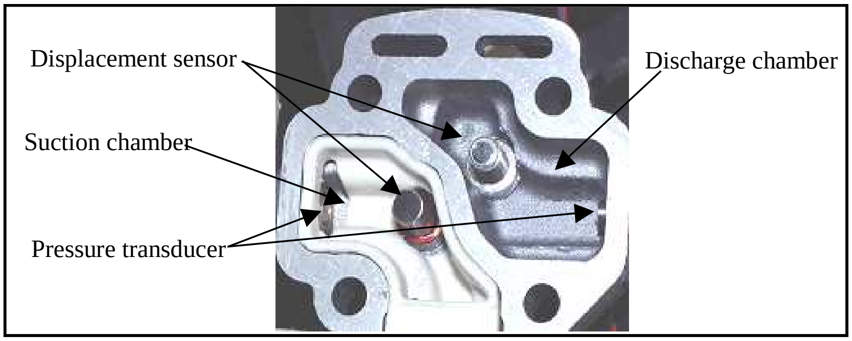

Figure 5 – Sensors positioned in the cylinder head

One way to verify the influence of the sensor tip in the suction and discharge chamber is measuring the pressure behavior to discharge chamber with and without the volume of the sensor tip. For this verification a cylinder head was prepared with a pressure sensor positioned in the discharge chamber and a variable extra volume (probe) that takes 1.6 and 3.2% of the total volume of chamber. The results are listed in Figure 6.

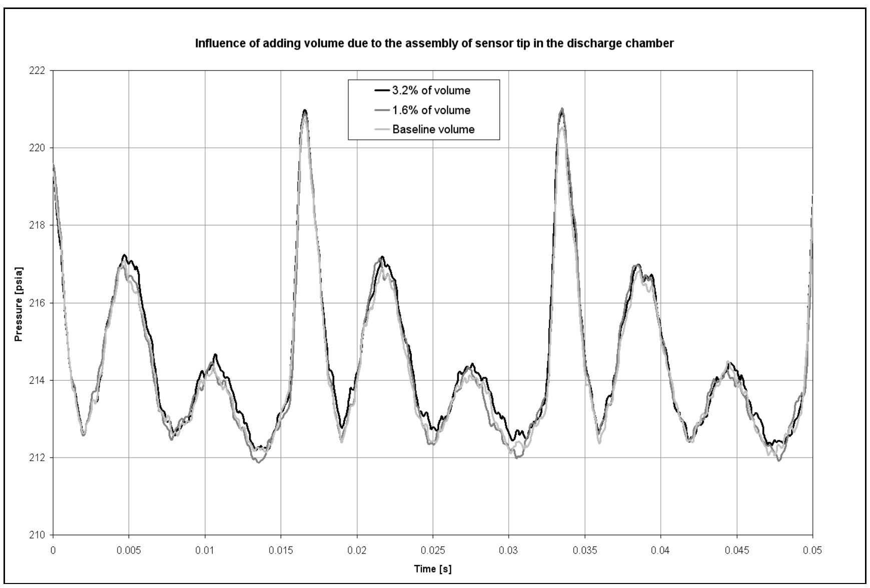

Figure 6 – Influence of the sensor tip in the discharge chamber volume.

Figure 6 shows the discharge pressure of two cycles of hermetic compressor where no important changes were verified in the pressure behavior due to the probe volume.

The information of crankshaft angular position was obtained by angular displacement sensor (encoder) coupled in the shaft. The reference pulse of encoder was synchronized with the TDC. The top dead center (TDC) was found using a dial indicator and the reference pulse of angular displacement sensor by oscilloscope. The angular displacement sensor has 2000 pulses per revolution that was used as triggering to DAQ board, acquiring the valve displacement and pressure. Hence, it was possible to get the information for each 0.18° crankshaft rotation.

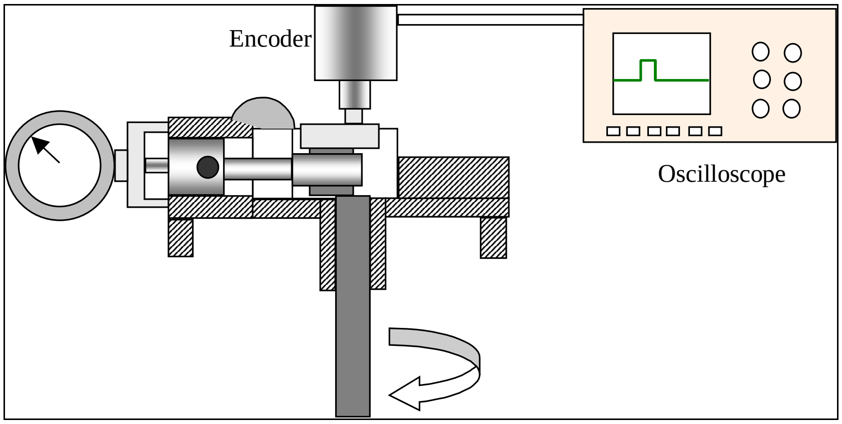

Figure 7 – Angular displacement sensor assembly

With the connecting rod length and the eccentricity of the shaft it is also possible to get the piston position using equation (1):

$$X(\Theta) = B + E - E\cos(\Theta) - \sqrt{B^2 - (E \cdot sen(\Theta))^2} \qquad (1)$$

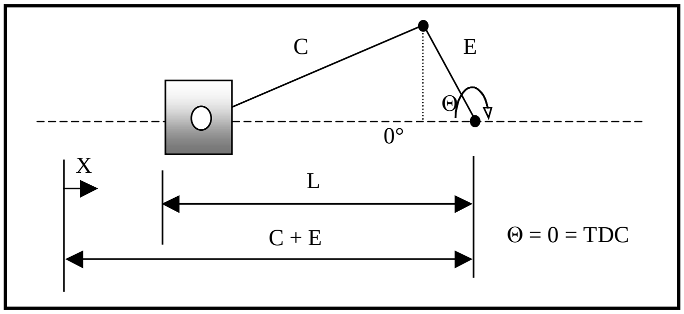

Figure 8- crank train geometry.

Where:
X = Piston displacement
C = Connecting rod length;
E = Eccentricity.

For this instrumentation, it was used a special housing, slightly longer than the usual, with bolts and rubber ring to assure the inner hermetic ambient. Also it was used rubber rings to avoid gas leakage between the fiber optic cable and the housing.

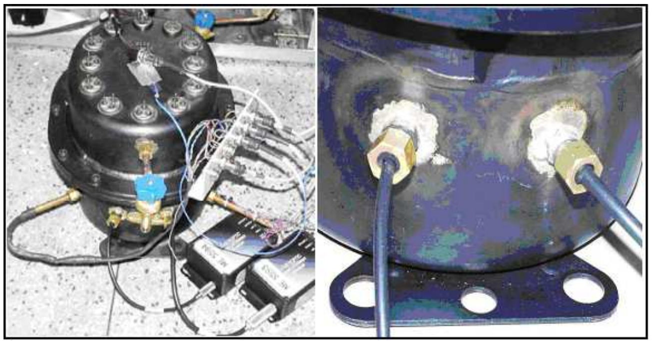

Figure 9 - Special housing and detail of fiberoptic cable in the housing.

3 Results and comments

In order to keep the conditions during the measurements, the compressor was applied in a calorimeter to provide constant boundary conditions for the test.

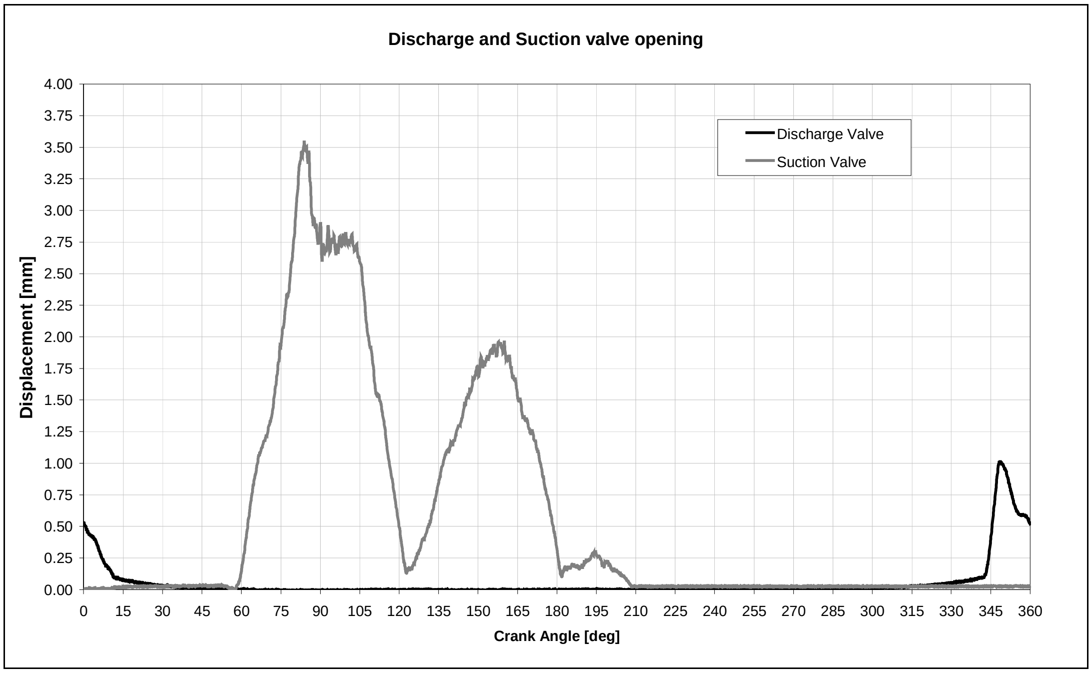

Figure 10 – Discharge and suction valve behavior.

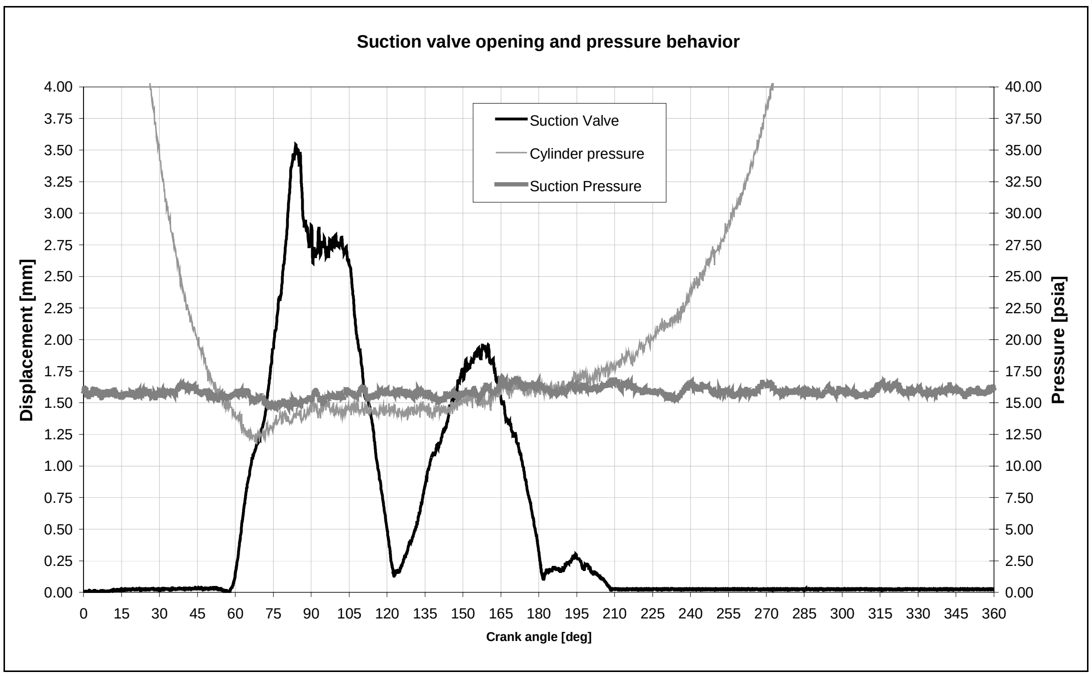

Figure 11 – Suction valve and pressure behavior.

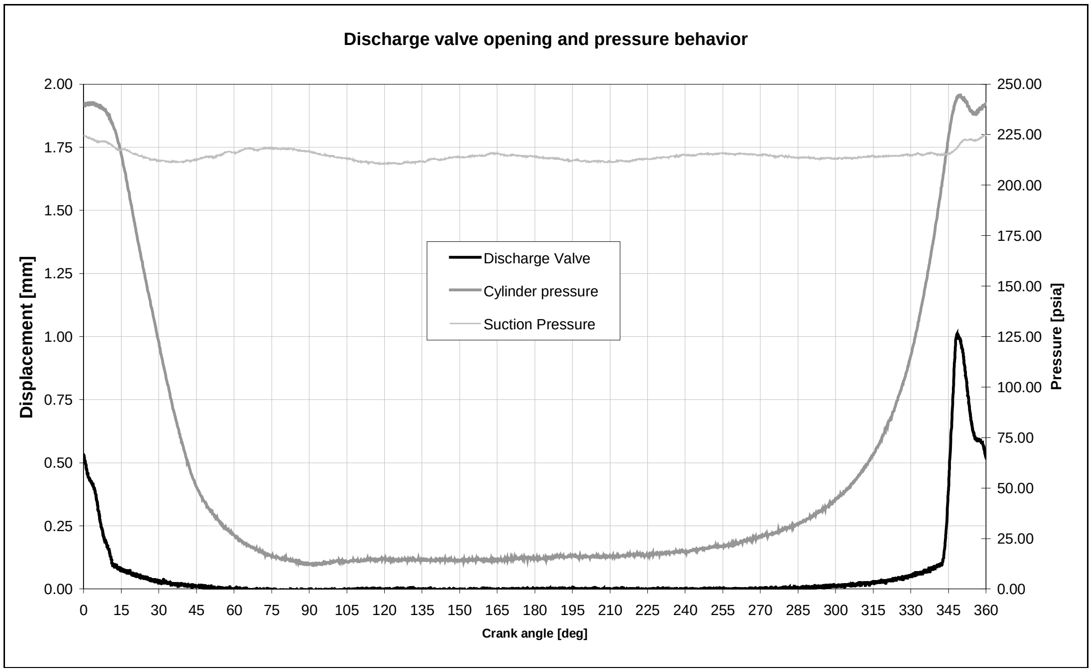

Figure 12 – Discharge valve and pressure behavior.

The suction valve opens for long time in the cycle, nearly 40%, and usually bounces three times in the cycle. The discharge valve opens for shorter time, nearly 9%, and does not have a pronounced bouncing behavior (figure 10).

Using the pressure information it is possible to determine the pressure differential required for valve operation (figure 11 and 12).

Additional information, like as PV diagram and speed variation can also be collected using this instrumentation.

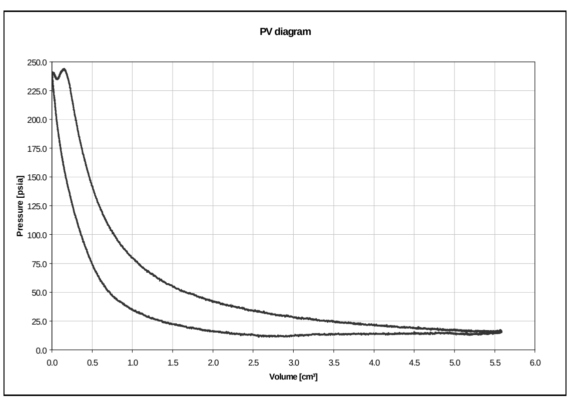

Figure 13a – PV diagram

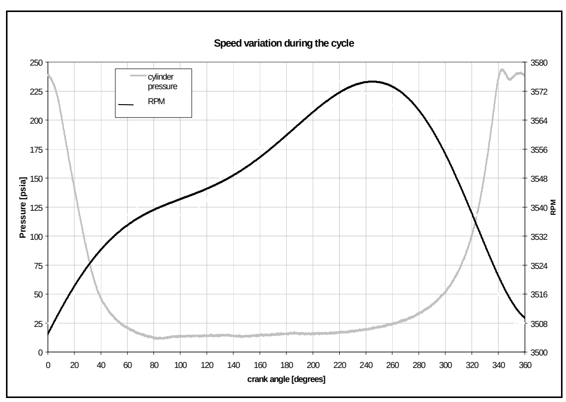

Figure 13b – Speed varition in the cycle

The above analyses are examples of several studies that can be done using the data acquired by this instrumentation. Further pieces of information were extracted from the collected data and used to validate simulation models.

4 Conclusions

The present work shows that the valve displacement used in small-sized hermetic compressors can be measured using fiberoptic displacement sensor. The pressure behavior of the discharge chamber was verified due to the additional volume of displacement sensor and the results did not show significant changes. The technique allowed measuring the valve lift of hermetic compressor widely used in household applications

5 References and Bibliography

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