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Using PV Diagram Synchronized With the Valve Functioning to Increase the Efficiency on the Reciprocating Hermetic Compressors

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ABSTRACT

Opening and closing of suction and discharge valves are critical to determine the volumetric efficiency in the reciprocating compressor. The discharge and suction valves open due to the pressure differential and negatives effects, as back flow, may occur decreasing the compressor efficiency. Understanding the power consumption on the refrigerating cycle and its losses can contribute to obtain better compressors. Analyzing the PV diagram it is possible to obtain the work exerted on the gas during the compression cycle and also the losses on the suction and discharge valves. In this work it was measured the PV diagram of reciprocating refrigerating compressor synchronized with its valve functioning. Measuring the PV and the valve functioning, it is possible to get a better understanding of the valves losses and the gas back flow can also be completely verified.

1. INTRODUCTION

To increase the efficiency of refrigerating systems the compressor needs to be optimized to obtain a high performance in all operating conditions. One of the most relevant factors to be considered in the refrigerating 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. The suction and discharge valve works due to the pressure differential generated by the alternate 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 open easily and to close quickly to avoid back flow. They are built with light material, designed to provide fast dynamic response and positioned to minimize the dead volume of the system.

One way to verify the valve efficiency is through the PV diagram. The understanding the power consumption on the refrigerating cycle and its losses can contribute to obtain better compressors. By the PV diagram it is possible to obtain the work exerted on the gas during the compression cycle and also the losses on the suction and discharge valves.

This paper presents a special methodology created to measured the PV diagram of reciprocating refrigerating compressor synchronized with its valve functioning. Measuring the PV and the valve functioning, it is possible to get a better understanding of the valves losses and the gas back flow can also be completely verified. The angular position of crankshaft was used as reference to the data acquisition, allowing to acquire one piece of information for each 0.1 degree of crankshaft angular displacement.

2. EXPERIMENTAL SET-UP

A computer with a data acquisition board and signal conditioner was used to collect all the sensors information. Special software has been developed to manage data acquisition, to show the information in real time and to save data.

Two non-contact sensors were used, one for each valve. The RC171 model was used to the suction valve and the RC100 to the discharge valve. These sensors are reflective devices using bundled glass fibers to transmit light to and receive reflected light 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 (20 KHz). These sensors manufactured by Philtec™ Inc. They are sealed, compact, and accurate allowing measurements inside the mechanisms submerged in fluids and in hostile environments like temperature and pressure.

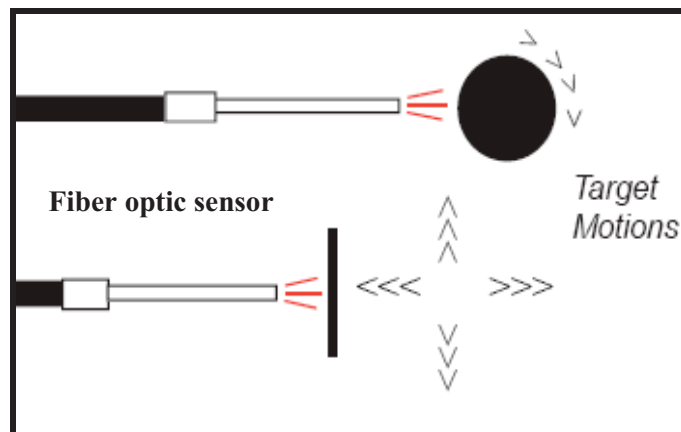


Figure 1 - Fiber optic displacement sensor (Philtec sensors – 2002)

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 and the valve bending. Gauge blocks and depth micrometer were used to calibrate the valves displacement.

It is necessary to execute the fiber-optic sensor alignment before performing the measurements. Figure 2 shows details of this alignment.

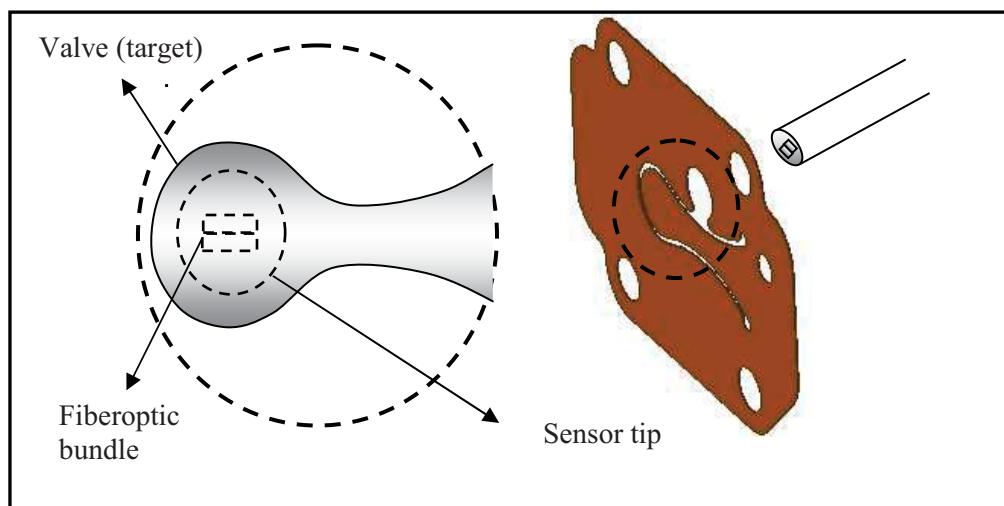


Figure 2 - Alignment of sensor tip to measure the valve displacement.

The sensor tips were aligned with the valves with the maximum distance allowed by the sensor range. The sensors were threaded in adapters that were fixed to the cylinder head.

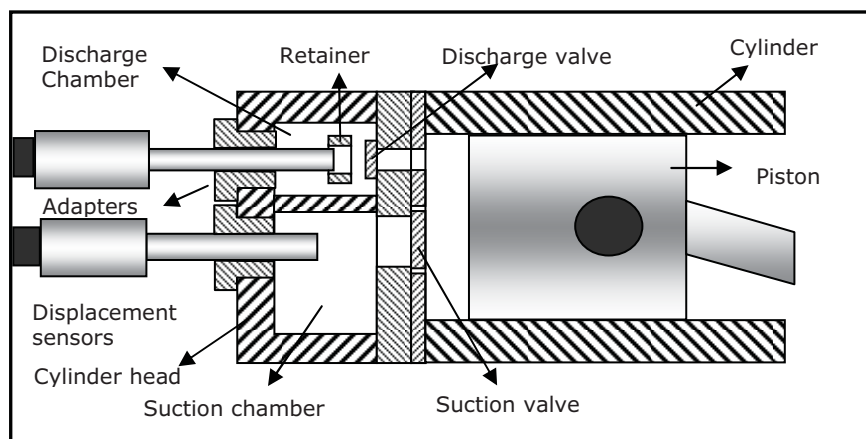


Figure 3 - Fiber-optic sensor assembled in the cylinder head.

Kulite™ ETL76M190 absolute pressure sensors were used to measure the suction, discharge and cylinder pressure. The selected sensors are small and amplified and can be applied in harsh environments. The microprocessor in the transducer offers high accuracy with a total error band of $\pm 0.25\%$ FSO, including all errors over a wide temperature range of -40°C to $+125^{\circ}\text{C}$. The sensors were arranged flush with the plane of the cylinder head wall to not reduce the volume of suction and discharge chamber. The volume reduction was just due to the displacement sensor tip assembly.

Due to the assembly of the displacement sensors in the cylinder head there was not enough room to assemble the pressure transducer in the cylinder bore. It was necessary to create a probe to assemble the pressure sensor in the crankcase, as shown in the figure 4.

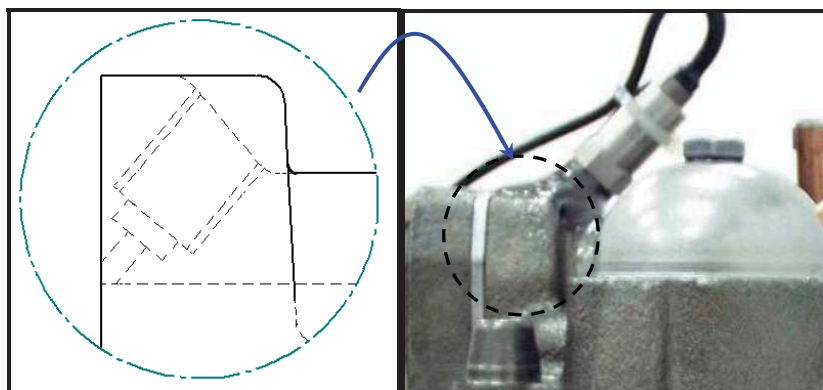


Figure 4 – Probe to assemble the cylinder pressure sensor.

The introduction of the probe could in some cases introduce little distortions at the pressure signal. Then, to check an eventual disturbance, the cylinder pressure was acquired with two different ways: one measuring directly at the piston top (figure 5) using a cylinder head without the displacement sensors and the other by the probe shown in figure 4. The pressure measurements were made simultaneously based on the shaft angular position and in the same condition of the test.

With the small difference between the sensors data it was created a vector that was used by the acquisition software to correct automatically the value read using the probe, point by point.

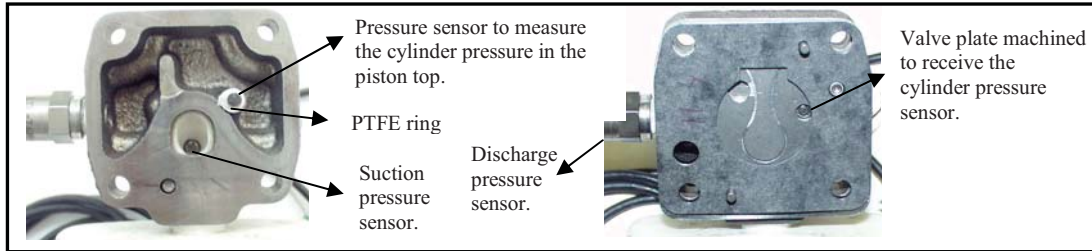


Figure 5 – Pressure sensor assembled to measure the cylinder pressure in piston top.

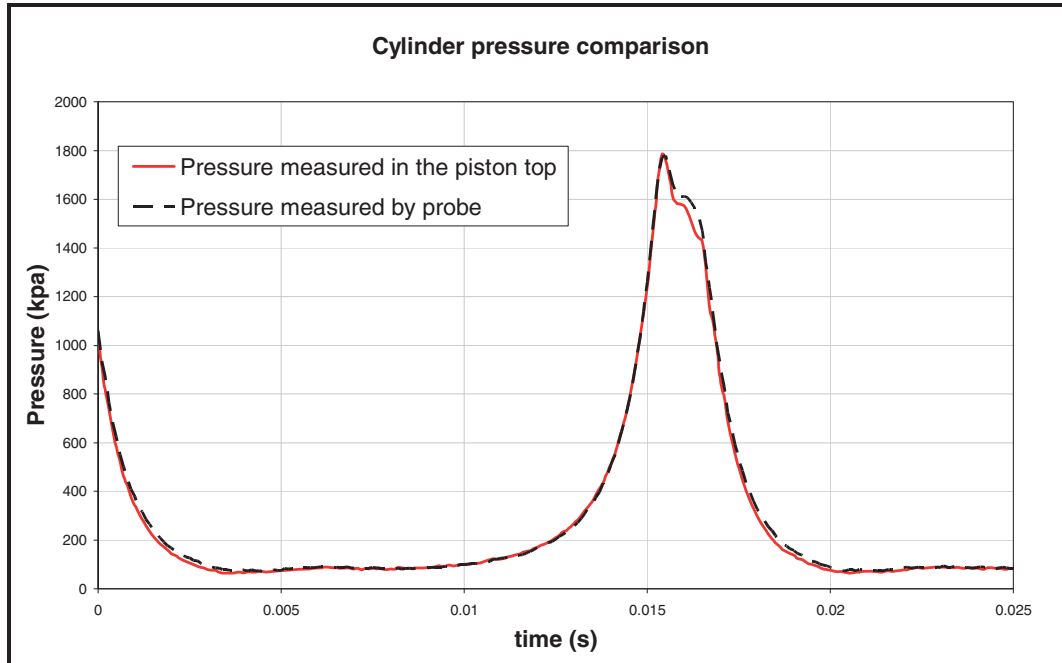


Figure 6 – Pressure in the cylinder measured in piston top and by probe

The crankshaft angular position information was also used in this instrumentation. The 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. A 3600 pulses per revolution angular displacement sensor was used to trigger the DAQ board, acquiring the valves displacements and pressures. So, it was possible to get information at each 0.10° crankshaft rotation.

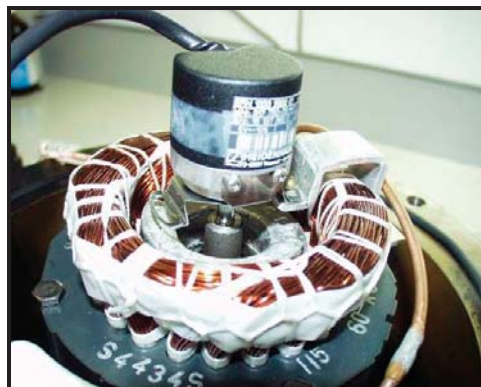


Figure 7 – Angular displacement sensor assembly

With the connecting rod length and the eccentricity of the shaft it is possible to get the piston position using the equation (1) that will be used in the cylinder volume calculation:

$$X(\Theta) = C + E - E \cos(\Theta) - \sqrt{C^2 - (E \cdot \sin(\Theta))^2} \quad (1)$$

Where:

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

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

3. RESULTS

In order to keep the conditions during the measurements, the compressor was placed in a calorimeter to provide constant boundary conditions for the test. The figure 8 shows the general information extracted in the tests. Pressures in the suction, discharge and cylinder were collected and also the valves displacements as a function of the crank angle position.

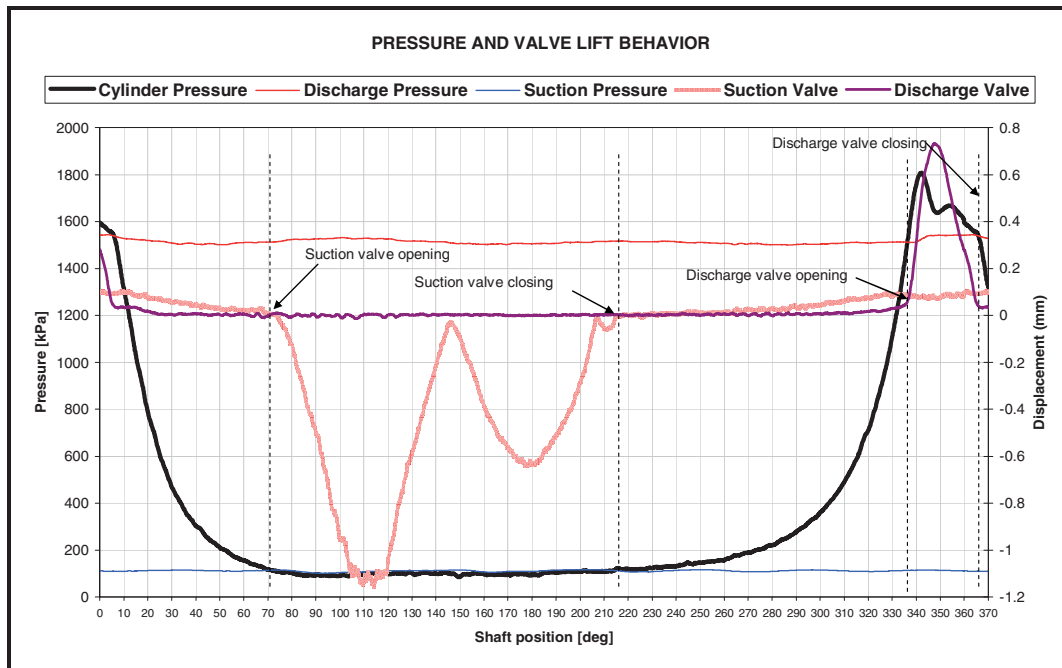


Figure 8- General overview of one cycle of refrigerating compressor behavior.

Through Equation 1, the volume variation in the cycle was obtained and consequently the PV diagram was determined. With the PV diagram it is possible to obtain the work exerted on the gas during the compression cycle and also the losses on the suction and discharge valves. The created program executes this calculation and saves the values. The table 1 shows the values extract from the PV diagram shown in the figure 9.

Table 1 – Values extracted from PV diagram

Suction Loss (%)	Discharge Loss (%)	PV Power (%)
2.8	5.6	91,6

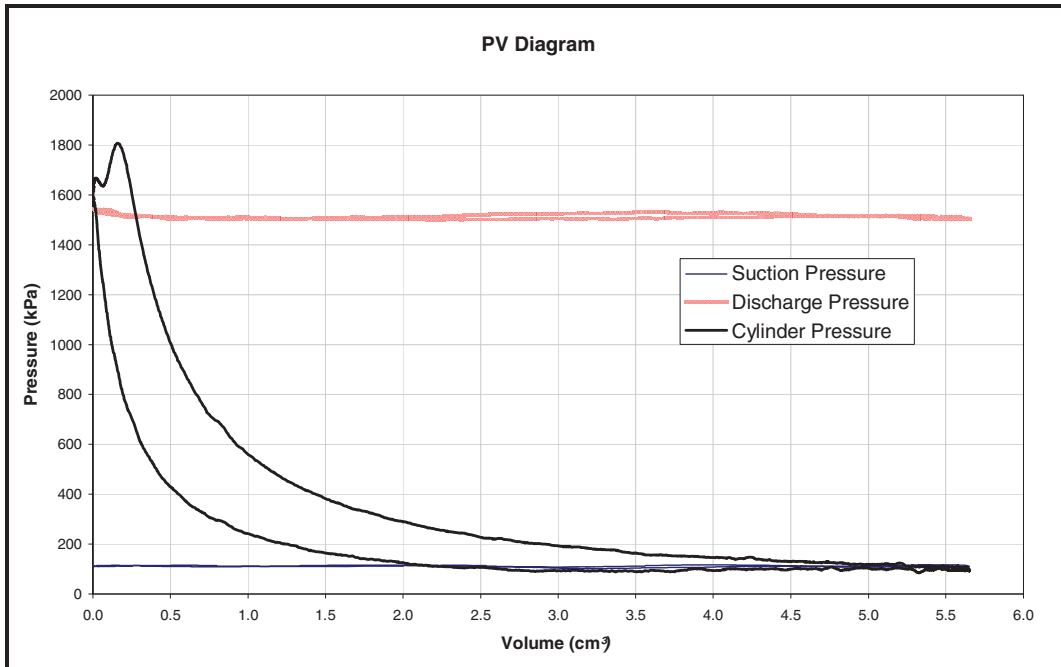


Figure 9 - PV diagram measured.

Using the information of valves and pressures, effects as backflow can be analyzed. Backflow is a phenomenon that can occur in the suction and discharge valves. Backflow occurs when the valve closes too late and allows that part of the refrigerant fluid returns into the cylinder in the suction process and for the suction manifold during the fluid compression. Applying this instrumentation it is possible to verify whether the backflow occurs to both valves or not.

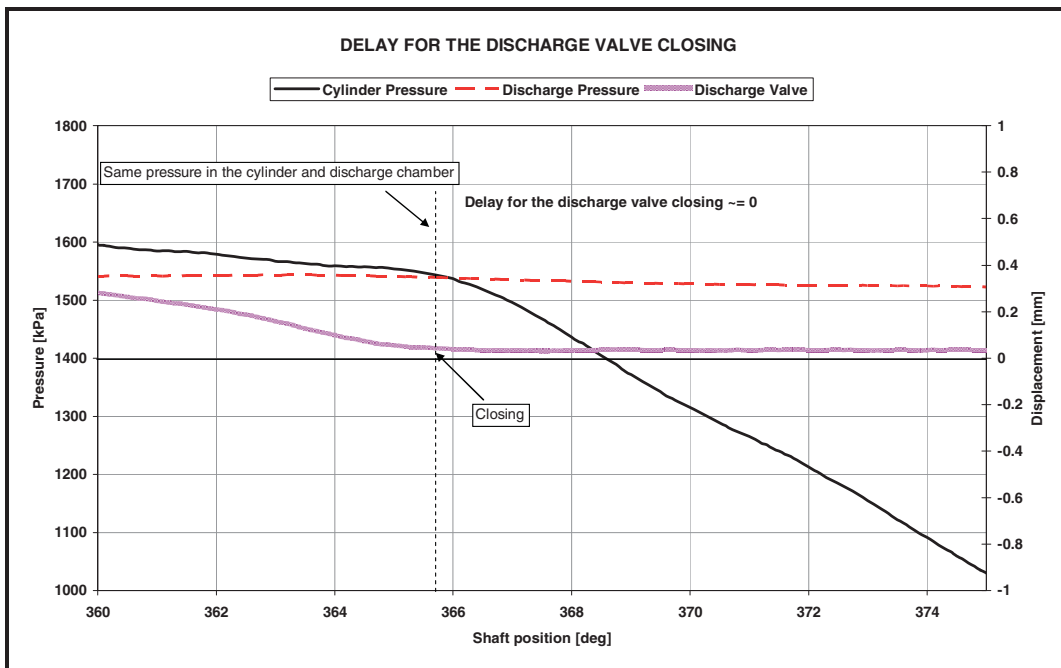


Figure 10 - Delay for the discharge valve closing.

Observing figure 10, the backflow to the discharge valve closing practically does not exist. The discharge valve closes when the cylinder pressure crosses the discharge pressure.

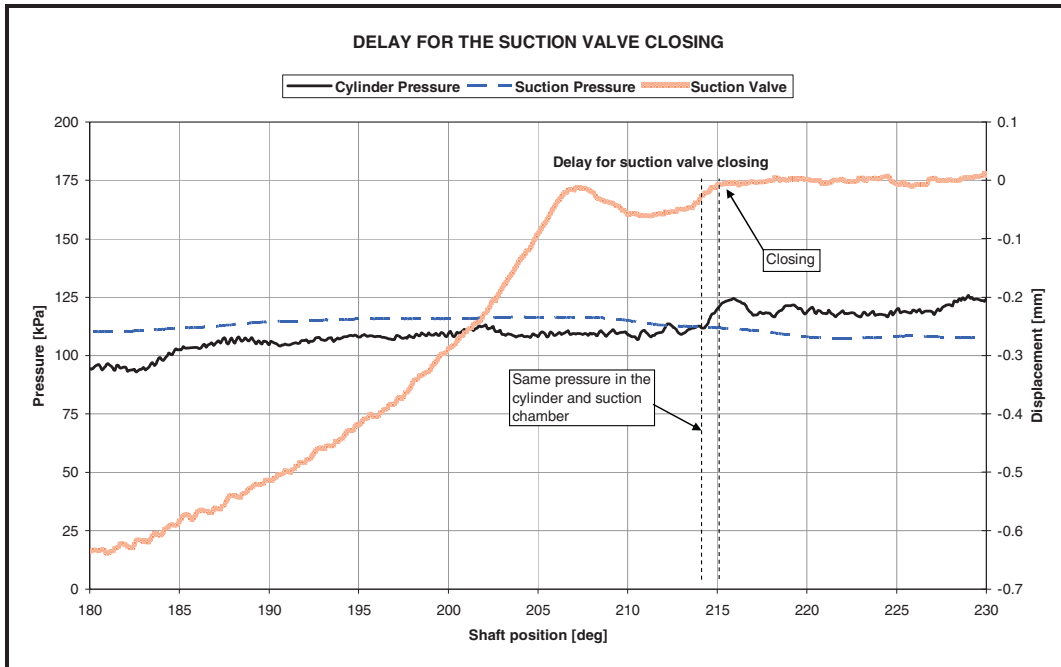


Figure 11 - Delay for the suction valve closing.

In figure 11, the backflow to the suction valve may occur. The suction valve closes almost one crank degree after the cylinder pressure crosses the suction pressure. This loss is very small because the displacement of the suction valve is very small, consequently the flow effective area is very small too.

The figures 12 and 13 show the delay for the suction and discharge valve opening. The time lag can be explained due to the sticky force.

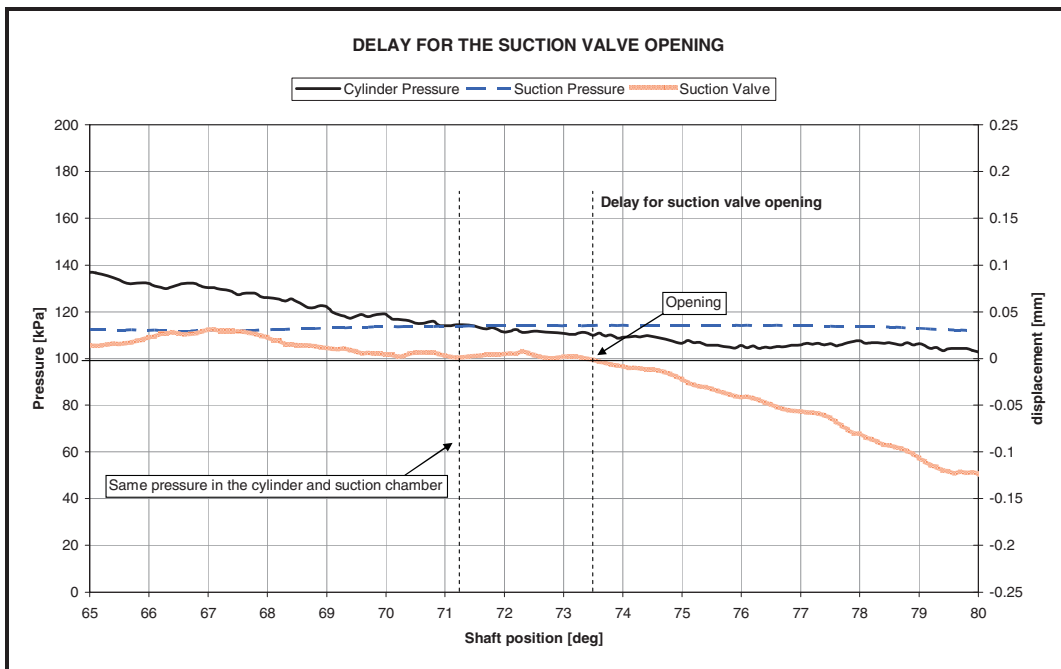


Figure 12 - Delay for the suction valve opening.

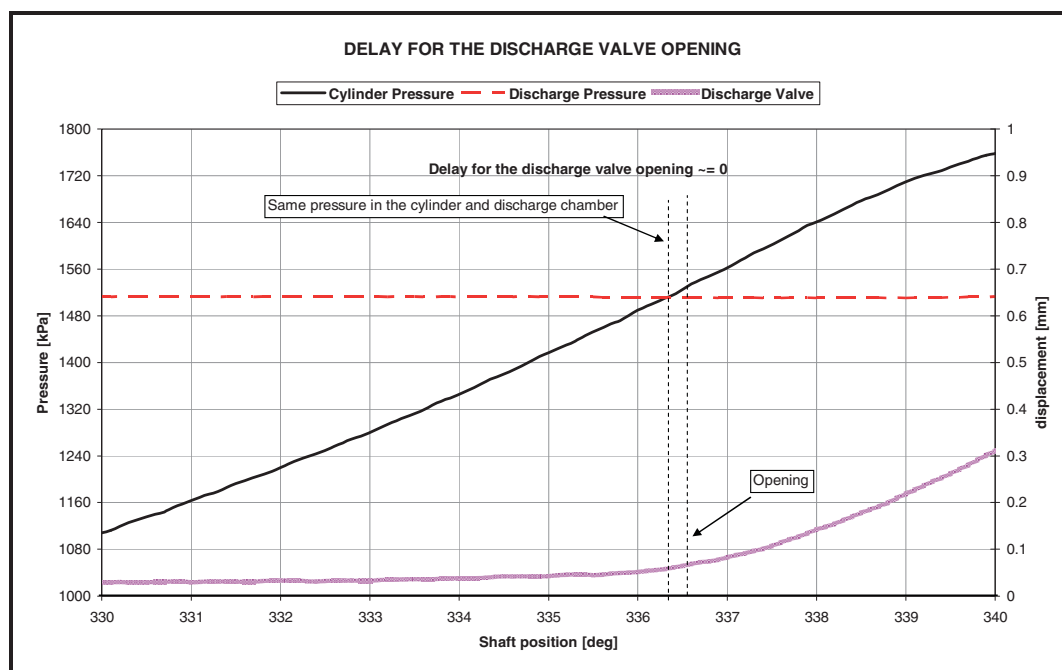


Figure 13 - Delay for the discharge valve opening.

4. CONCLUSIONS

The behavior of the suction and discharge valves was completely characterized. Using the PV diagram it was possible to get the work exerted on the gas during the compression cycle and also the losses on the suction and discharge valves. A special methodology was created to measure the PV diagram of reciprocating refrigerating compressor synchronized with its valve functioning where back flow effects were verified. This information is very important to validate mathematical models and to improve the compressor efficiency.

NOMENCLATURE

X = Piston displacement;
 C = Connecting rod length;
 E = Crankshaft eccentricity.

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