2014

Experimental Pressure-Volume diagrams of scroll compressors

Alain Picavet
Danfoss Commercial Compressors, France, a.picavet@danfoss.com

Pierre Ginies
Danfoss Commercial Compressors, France, p.ginies@danfoss.com

Pressure-volume diagrams of scroll compressors at various operating points

Alain PICAVET, Pierre GINIES*

Danfoss Commercial Compressors, 01600 Trevoux ; France
a.picavet@danfoss.com ; p.ginies@danfoss.com

* Corresponding Author

ABSTRACT

This paper presents the results of scroll compressor tests conducted in order to establish pressure-volume diagrams. Two compressors were thinly instrumented with pressure and displacement sensors so as to follow the whole compression process, from suction to exhaust. A gear coder was set to record the opening of gas pockets, and to study the speed variations occurring during a single rotation.
These tests help understanding the various phenomena encountered in a compressor, such as back-flow, overshoot, leakages, at the different operating points. Comparing an ideal pressure-volume diagram to the experimental one enables identification of improvement possibilities.
One of the compressors was equipped with Intermediate Discharge Valves (IDVs) that could be deactivated. Comparative tests for points at low pressure ratio showed precisely the influence of these devices on the distribution of pressure inside the machine.

1 INTRODUCTION

In order to acquire detailed knowledge of the compression process, two scroll compressors of the Danfoss SH family were thinly instrumented with thermocouples, unsteady pressure sensors and displacement sensors. They were run on a calorimeter and the installed sensors were used to establish pressure-volume diagrams. Such tests were already performed near the design operating point (Mahfouz et al., Wang et al.). In this paper, we also present the results of measurements made at low and high pressure ratio. Similar results were previously presented only for piston expanders (Zeng et al.).

The post-processing of the unsteady measurements, coupled with the performance measurements made on the calorimeter, allow a precise analysis of indicated efficiencies, suction and exhaust flows, backflow, overshoot, leakages, and differences in behavior between the direct and indirect pockets. The comparison with diagrams based on isentropic pressure evolution gives us indications on the losses, their nature, where they occur and the possibilities of improvements.

Two intermediate discharge valves were set on one of the machines and could be activated or blocked. The way they work and the gain in performance they bring could then be described, as well as some improvement opportunities.

2 EXPERIMENTAL SETUP

The aim of these experiments is to study precisely the compression process. If we consider a particle of gas crossing the compressor, we must be able to follow it from the inlet to the outlet. It is thus necessary to set enough pressure sensors to ensure that at any time a sensor is active in the same pocket as the particle. The distribution of sensors inside the scrolls is depicted in Figure 1. One set of sensors is put in the direct pocket (P_{d1}, P_{d2} and P_{d3}), the other one in the indirect pocket (P_{i1}, P_{i2}, P_{i3}). Thus we can distinguish the evolution of gas pressure and see if there are some differences. A sensor P_{ex} is placed in the discharge port area, so as to permanently track the exhaust pressure level. The sensors use piezo-resistive technology, which allows sampling frequencies high enough to follow all the unsteady phenomena.

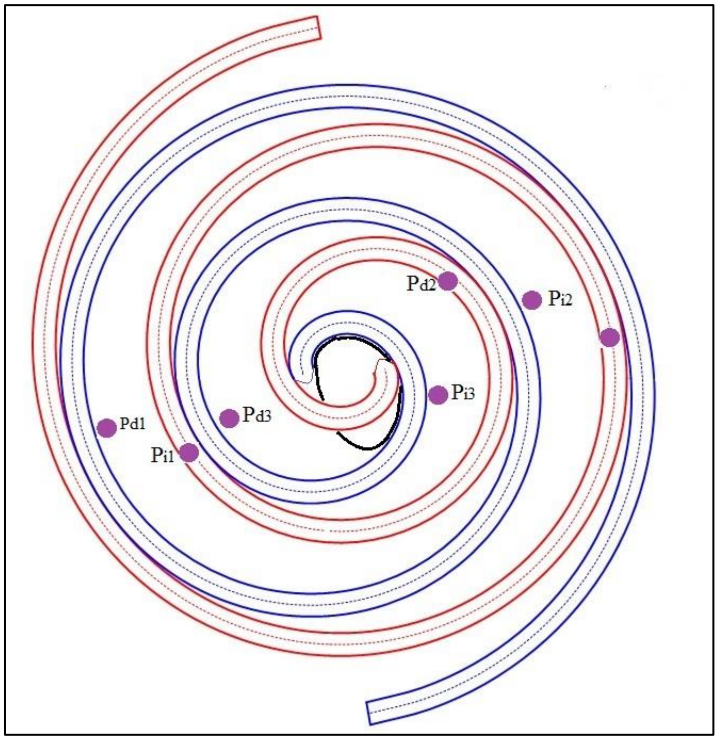

Figure 1: Location of the pressure sensors inside the scrolls

A gear is mounted on the upper counterweight of the crankshaft, and a proximity sensor is positioned in order to generate a signal allowing the shaft velocity calculation. One of the gear teeth is larger, so as to generate a specific pulse when the pockets are closing at the end of the suction process.

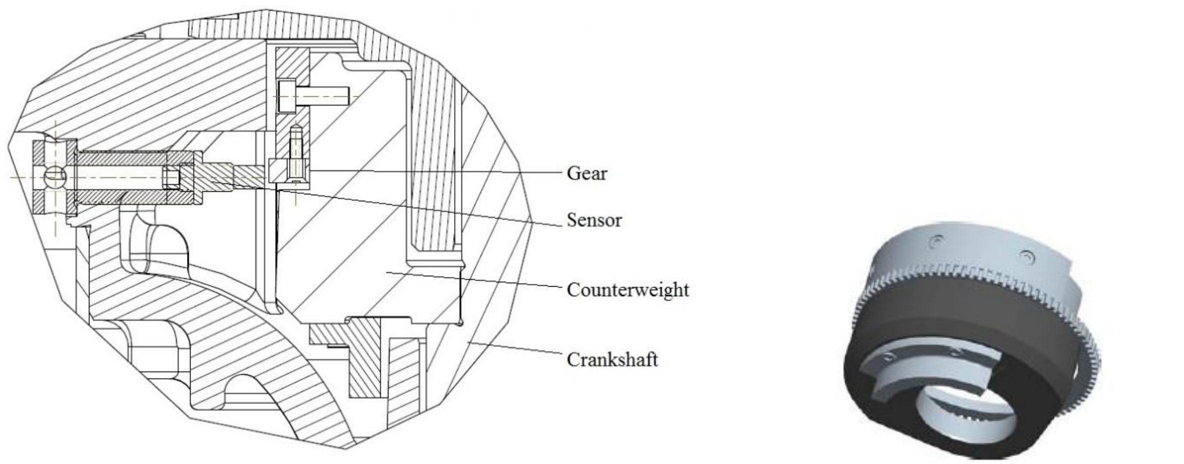

Figure 2: Gear coder

On the second compressor, a proximity sensor is set above one of the IDVs so as to detect the valve opening and compare it to the evolution of pressure in the scrolls. We choose an eddy-current sensor, which is the best solution in this difficult environment (capacitive or optical ones cannot be used because of the presence of oil droplets).

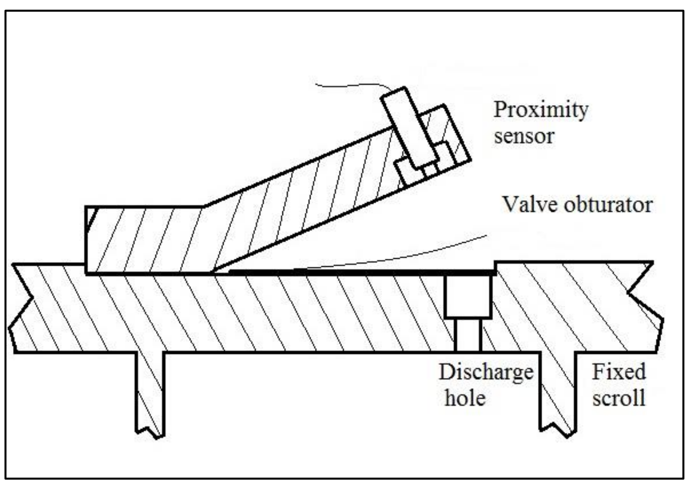

Figure 3: Instrumentation of an IDV

All the measurements are done with a LMS recorder (device of the Belgian company Leuven Measurement Systems) driven by a laptop. The post-processing of the data is done with the software Matlab. Some additional data are recorded by the calorimeter (inlet and outlet pressures and temperatures, mass flow rate, electric power, frigorific power).

3 RESULTS AND DISCUSSION

The first results presented here are obtained with a Danfoss SH compressor running at 50Hz with R410A. Two sets of results obtained with this machine are presented: the first one is for the ARI point; the second one is for an operating point at high pressure ratio. A second SH compressor, working with Intermediate Discharge Valves which can be activated or not, is tested at low pressure ratio. The machine is run twice at these operating points: with the IDVs working; then with the IDVs blocked.

ARI point: the Figures 4 and 5 show the evolution of the pressure inside the scrolls. The system allows a complete measurement of the pressure form the inlet to the discharge port.

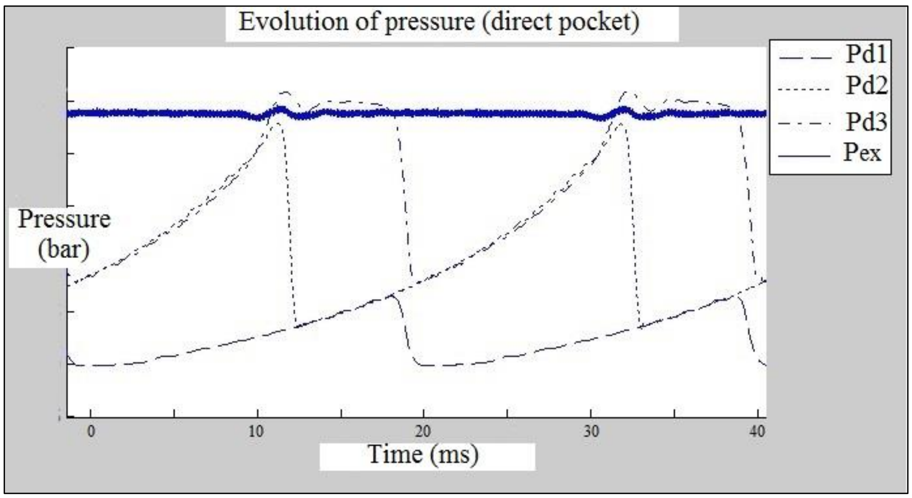

Figure 4: Distribution of pressure in the direct pocket

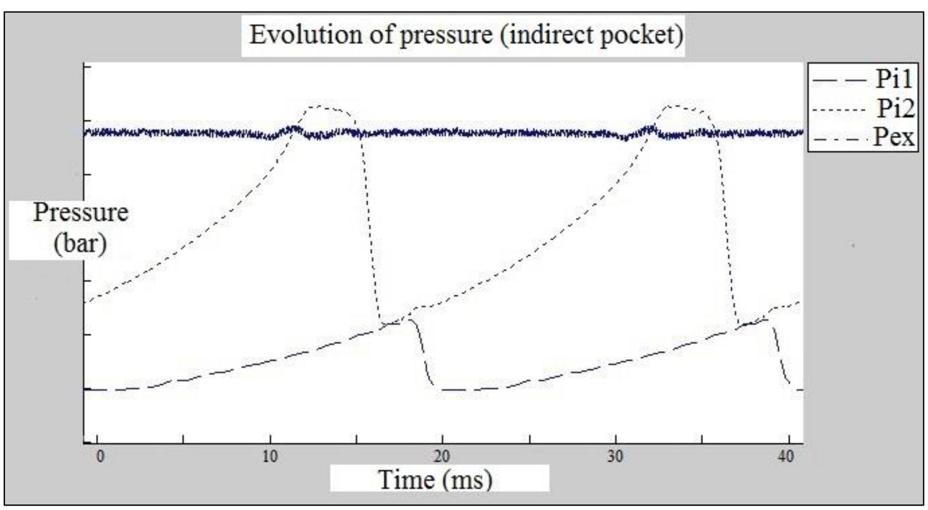

Figure 5: Pressure in the indirect pocket

The pressures are then recombined with the volume to give the pressure volume diagram (Figure 6). The over-compression appears clearly at the beginning of the discharge, as well as differences between the direct and the

indirect pocket. The experimental diagram is compared to an ideal one, computed with an assumption of isentropic compression.
We used two assumptions to compute the variation of volume with respect to time: one is based on the velocity computed with the signal from the encoder; the other one considers constant crankshaft velocity. We obtain, for the various quantities measured (provided work, power, efficiencies), differences inferior to one percent.

Using the areas of the ideal and the measured diagrams, and the volumetric efficiency, we can compute the indicated efficiency.
Here, $\boldsymbol{\eta_i}$**=0.9.**

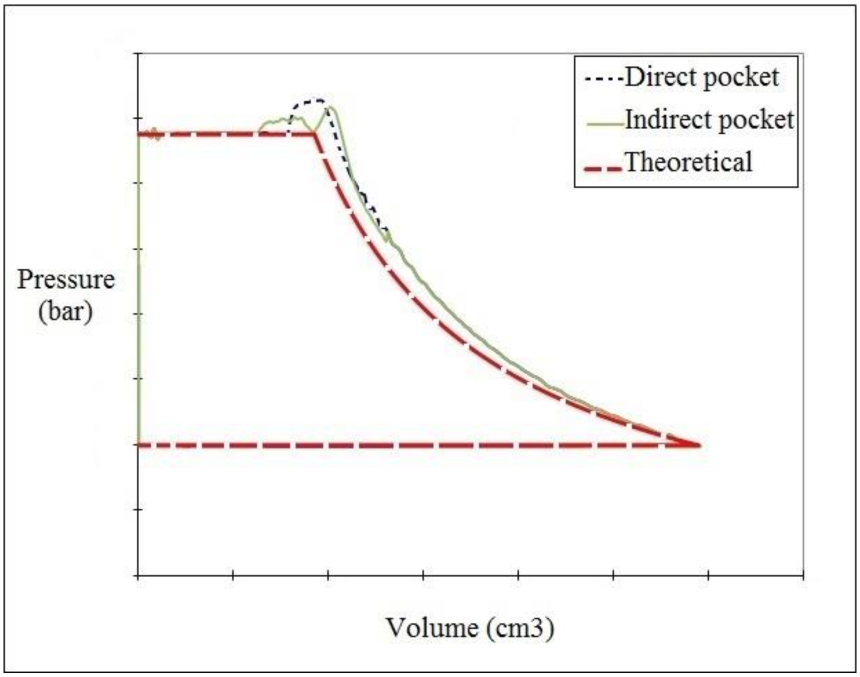

Figure 6: Experimental and ideal Pressure-Volume diagrams of the compressor

High pressure-ratio point:
The compressor is run at 50Hz at a point at much higher pressure ratio. On the Figure 7, we can see the distribution of pressure along the direct pocket. The change of slope when the discharge port opens is clearly visible; at that time, the compression in the pocket is partly due to the backflow coming from the upper shell volume which is at higher pressure. At the end, we can also see a slight over-compression at the beginning of the discharge process.

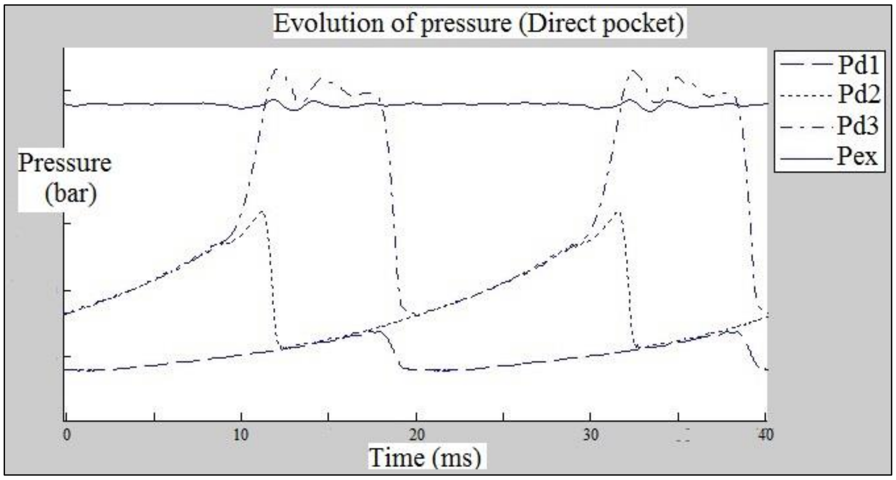

Figure 7: High pressure-ratio - pressure in the direct pocket

In the same manner, we establish the pressure volume diagram. Once again, we see the difference between both pockets, the direct one opening and receiving the backflow before the indirect one.

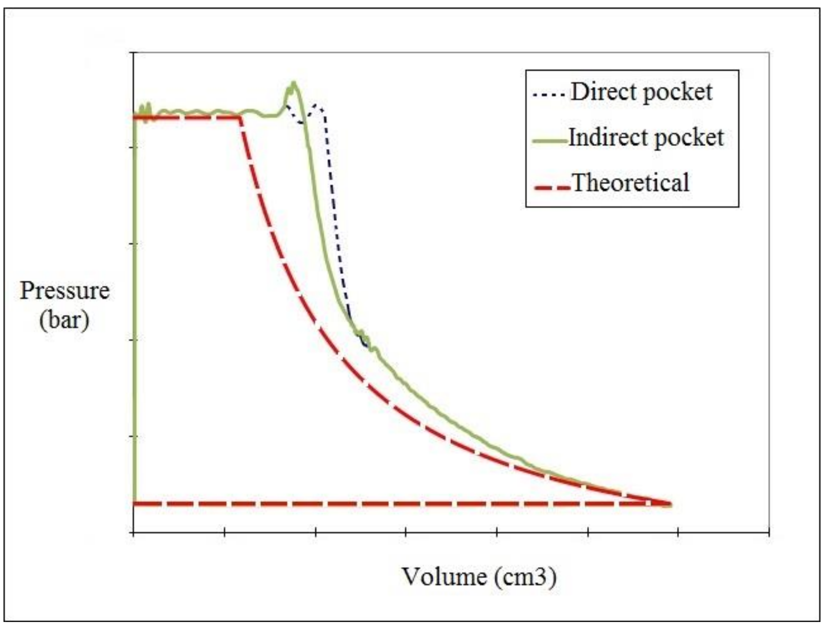

Figure 8: Pressure-volume diagram at high pressure ratio

The indicated efficiency is in this case η_i =0.824.

Low pressure-ratio point:

On the second machine, as mentioned before, there are some IDVs which can be enabled or disabled (blocked). The same refrigerant is used (R410A), and the frequency is 50Hz. There are fewer pressure sensors inside the scrolls because we kept only the sensors necessary to distinguish the pressures in the direct and indirect pockets at the end of the compression (see Figure 9).

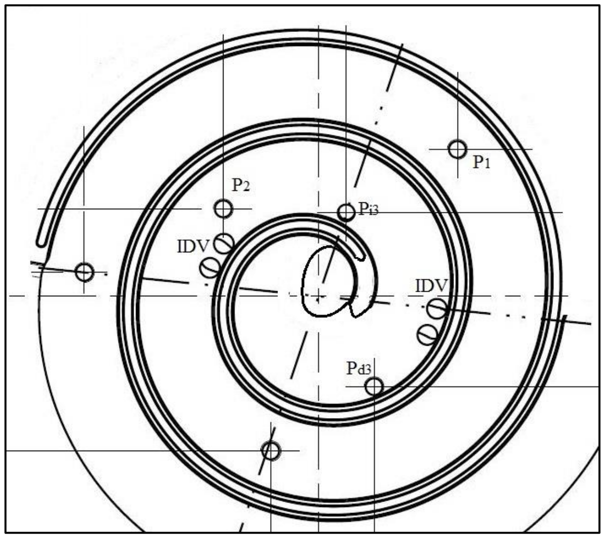

Figure 9: Location of the IDVs and of the pressure sensors

A first series of tests is made with the IDVs enabled. Then, the points at pressure ratio inferior to the design point pressure ratio are re-tested, with the IDVs disabled. We give the results obtained for one of them.

Similarly to the other results previously presented, we can see on the Figure 10 the distribution of pressure along the compression path in the pockets. The IDVs do not prevent a certain overpressure at discharge. We can also notice that the maximum pressure obtained with the sensors P_{i3} and P_{d3} (the sensors located at the extremities of the indirect and the direct pockets) are lower than the pressure recorded by P_2. This is due to the flow rate crossing the IDVs before the discharge process starts.
The comparison between the sensor tracking valve position and the pressure shows that a certain difference of pressure is necessary before the opening. This gives us indications to improve the device, tweaking the valve stiffness and mass.

Figure 11 shows the same results when the IDVs are not working. The differences are striking and show how efficiently the IDVs limit the overpressure. The indicated efficiency decreases from 0.88 to 0.72, and the isentropic efficiency of the machine loses 0.12 point when the IDVs are blocked. This shows that a machine with IDVs preserves good operating efficiency at pressure ratios very different from the design ones.

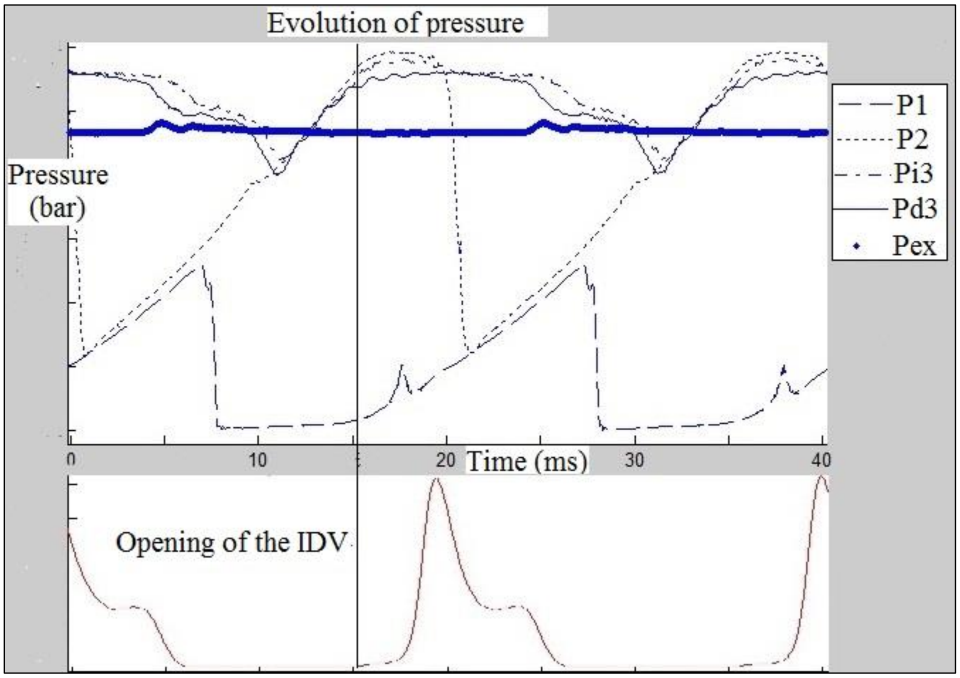

Figure 10: Distribution of pressure with IDVs working

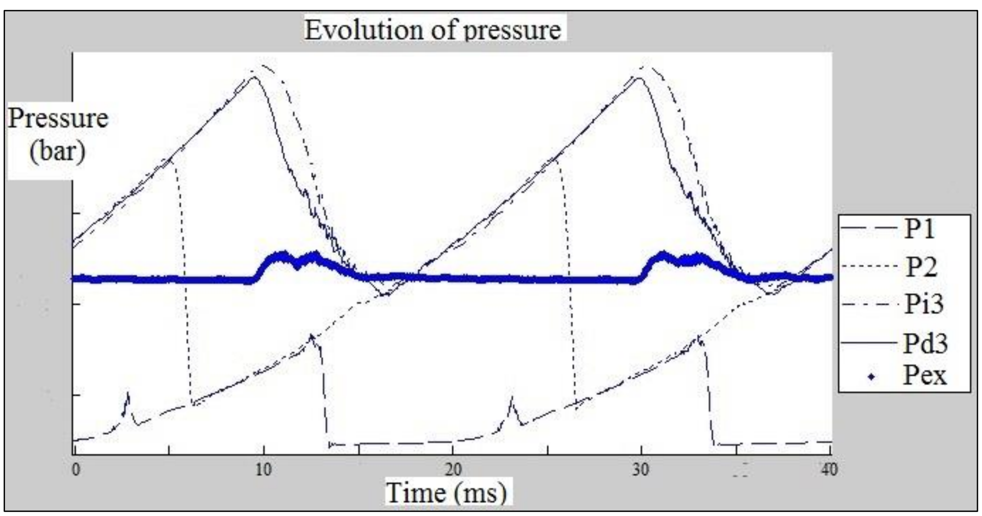

Figure 11: Distribution of pressure without IDVs

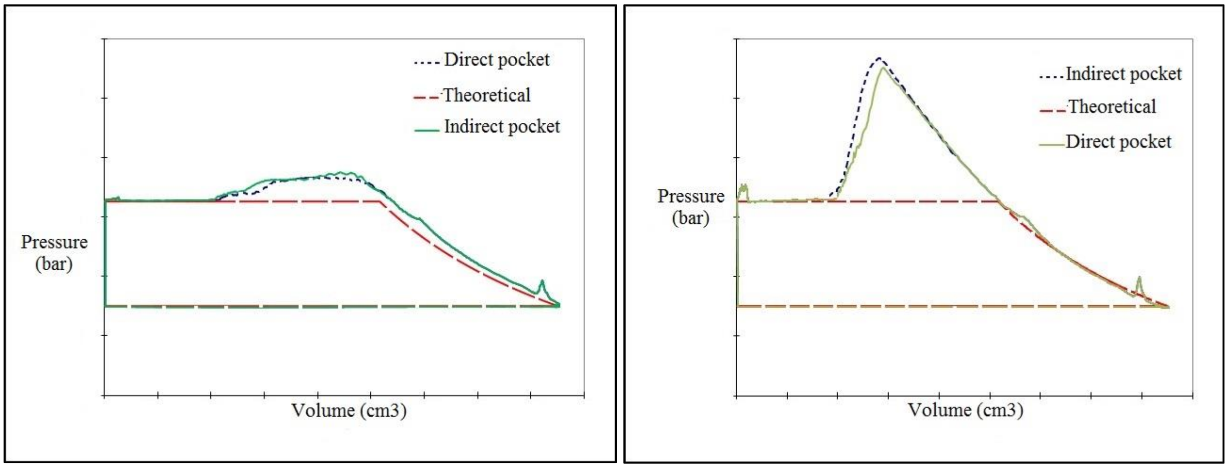

Figure 12: Compared pressure-volume diagrams with and without IDV

4 CONCLUSION

All these experiments provide a significant amount of very detailed information about the pressure distribution inside the machine, the losses, the efficiencies, the velocity fluctuations, at various operating points. They also allow a precise estimation of the gain that can be expected by using Intermediate Discharge Valves. In addition, they provide a large database of experimental results, unsteady and steady, local and global, which will allow further detailed comparisons between computation models and measurements. This is an essential step to qualify and tune software for the design and the prediction of performances.

NOMENCLATURE

P_{i1} : 1st pressure sensor in the indirect pocket following the flowpath of the 1st compressor tested (see Figure 1).
P_{i2} : 2nd sensor.
P_{i3} : 3rd sensor.
P_{d1} : 1st pressure sensor in the direct pocket following the flowpath.
P_{d2} : 2nd sensor.
P_{d3} : 3rd sensor.
P_{ex} : pressure sensor in the discharge port.
P_1 : 1st pressure sensor following the flowpath of the 2nd compressor tested (see Figure 9).
P_2 : 2nd sensor.
P_{i3} : 3rd sensor, located in the indirect pocket.
P_{d3} : 3rd sensor, located in the direct pocket.
P_{ex} : pressure sensor in the discharge port.
η_i : indicated efficiency.
IDV : Intermediate Discharge Valve.
LMS : Leuven Measurement Systems.

REFERENCES

Hamdy. A. Gouda Mahfouz, Mat Nawi Bin Wan Hassan, Md Nor Musa : Analytical and Experimental Study on a Scroll Compressor. *International Engineering Conference at Purdue*, July 12-15, 2004, C072.

Baolong Wang, Xianting Li, Wenxing Shi, Qisen yan : Design of experimental bench and internal pressure measurement of scroll compressor with refrigerant injection. *International Journal of Refrigeration 30 (2007*), 179-186.

Xianyang ZENG, Yitai MA, Shengchun Liu, Hongli WANG : Testing and analyzing on P-V diagram of CO2 rolling piston expander. *International Congress of Refrigeration, 2007, Beijing*. B2-431.

ACKNOWLEDGEMENT

It would not have been possible to lead this study without the contribution of Denis Violette, Alexis Delorme and Xiao Xiao Wang, from Danfoss Commercial Compressors, to whom I am very grateful.