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Correlation Between the Fluid Structure Interaction Method and Experimental Analysis of Bending Stress of a Variable Capacity Compressor Suction Valve

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ABSTRACT

The valves are responsible for controlling the suction and discharge systems of reciprocating compressors, therefore they are considered the principal components of the manifold subsystem. Although usually the valves present a simple geometry, these components are difficult to design, because they involve a nonlinear analysis, and stochastic events need to be considered to succeed in their project. Among other care that the engineer should take, the bending stress levels developed during operation of the compressor is of paramount importance. The purpose of this paper is to show the correlation between the application of the numerical method known as FSI (fluid structure interaction) and the experimental strain gage method, for the mechanical stresses analysis in the suction valve of a reciprocate compressor with variable capacity. During the experimental phase, the conditions that represent the compressor application envelope are mapped by varying the suction and discharge line pressures and the mechanical stresses in the suction valve are measured. The same pressure variations are imposed on the FSI numerical model and then the results for mechanical stress are compared to the ones obtained through the experimental method.

1. INTRODUCTION

The new environmental policy, the green marketing and the need to create even more attractive products for the refrigeration market has are factors that boosted the development and optimization of hermetic compressors worldwide. The aim for more efficient compressors and the speed required for new products market launches, require a minimization of the design time for these equipments. Deliver a robust design to ensure large-scale production with high quality becomes the reality of development engineers in this sector. The design of hermetic compressors congregates several areas of engineering, and to overcome the challenges and ensure the robustness of the designed component, design refinement strategies are necessary. The proposal of this work is to present the correlation obtained through the mechanical stresses analysis of a variable speed compressor suction valve, employing the strain gauge experimental method and the fluid structure interaction (FSI) numerical simulation techniques. The numerical approach does not require that the suction valve is manufactured, which reduces costs and complexity of valve design for variable speed compressors, when compared with experimental approaches only.

2. WHAT IS AND WHAT IS THE FUNCTION OF THE SUCTION VALVE?

The suction valve is located in the manifold subassembly, which also includes the discharge valve, valve plate, gaskets and so on. Figure 1 shows an exploded view of a manifold construction, listing its basic components.

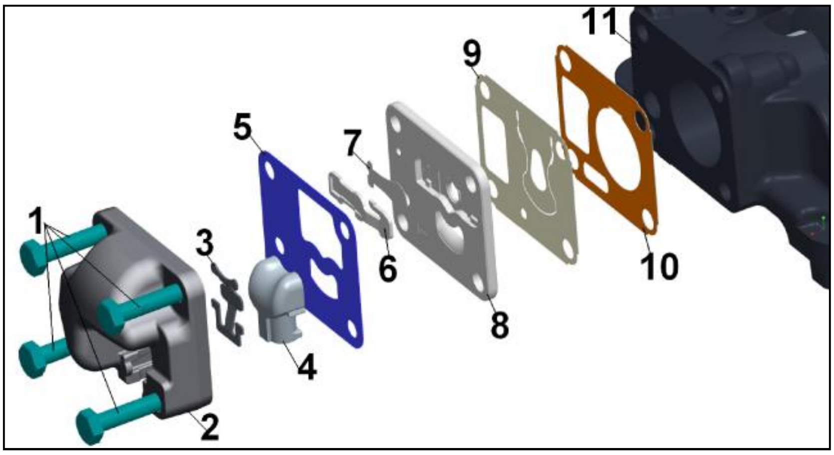

Figure 1- Basic components of a reciprocating compressor manifold

1. Screws - (Steel);
2. Cylinder Cover - (Aluminum);
3. Muffler Spring - (Steel);
4. Muffler nozzle - (PBT and glass fiber);
5. Cylinder cover Gasket - (hydraulic Cardboard);
6. Discharge valve delimiter- (Steel);
7. Discharge valve - (Steel);
8. Valve plate - (sintered iron);
9. Suction valve - (Steel);
10. Cylinder Gasket - (hydraulic Cardboard);
11. Crankcase (cast iron);

The suction valve (Component 9 in figure 1) is the component responsible for preventing the refrigerant fluid backflow to the suction line during the compression process, and allows the flow of refrigerant fluid into the compression chamber during the suction process, as can be seen in figure 02, which depicts the valve opening at the suction cycle.

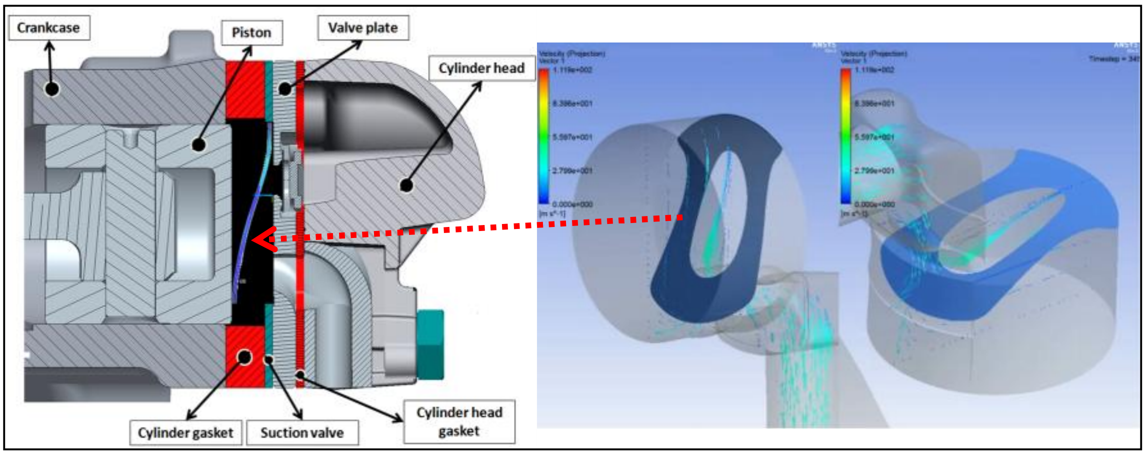

Figure 2 - Suction valve opening during the suction process

3. MOTIVATION FOR USE OF NUMERICAL TOOLS IN THE PROJECT OF SUCTION VALVES

The range of existing cooling systems in the market is very large and consequently, the operating range (pressure and rotational speeds) that the compressor will work varies according to the characteristic curve of each system. Therefore, the refrigeration compressors are typically subject to approval within LBP (low back pressure) and MBP (medium back pressure) envelope conditions, as seen in Figure 3.

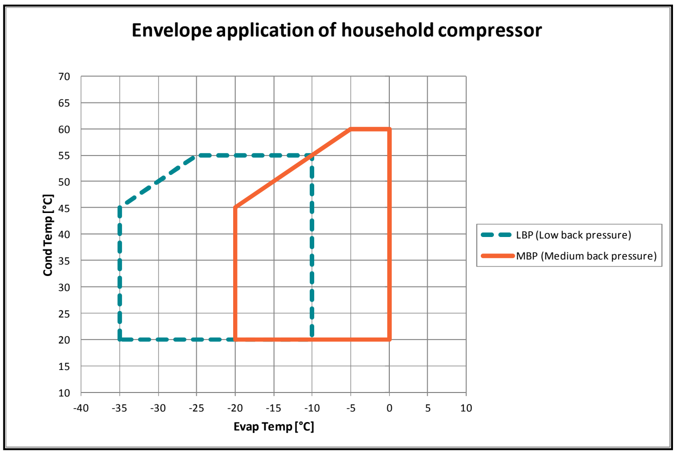

Figure 3 - Envelope application

The dynamics of the valve during the suction process is a function of the operating conditions (figure 3), of the refrigerant and the rotational speeds of the compressor, consequently the mechanical stress developed in this component is also a function of these factors.
As this paper compares the results obtained by the experimental method and the numerical method FSI, all mechanical stress refer to stress in the strain gage region, see figure 4 where the highlighted region is the moment of the suction valve reaches the maximum opening.
In this work all graphs of mechanical stress, were normalized using as denominator the value of stress found by strain gauge technique, with the compressor in the condition 0°C evaporation and 20°C condensation at 4000 RPM.
Figure 5 show the normalized peak of mechanical stress (this peak represent the highlighted region of the picture 4), measured by the strain gage technique for sweeping the LBP and MBP envelopes, using the refrigerant R134a, where it is possible to identify the influence of rotational speed on the mechanical stress on the valve.

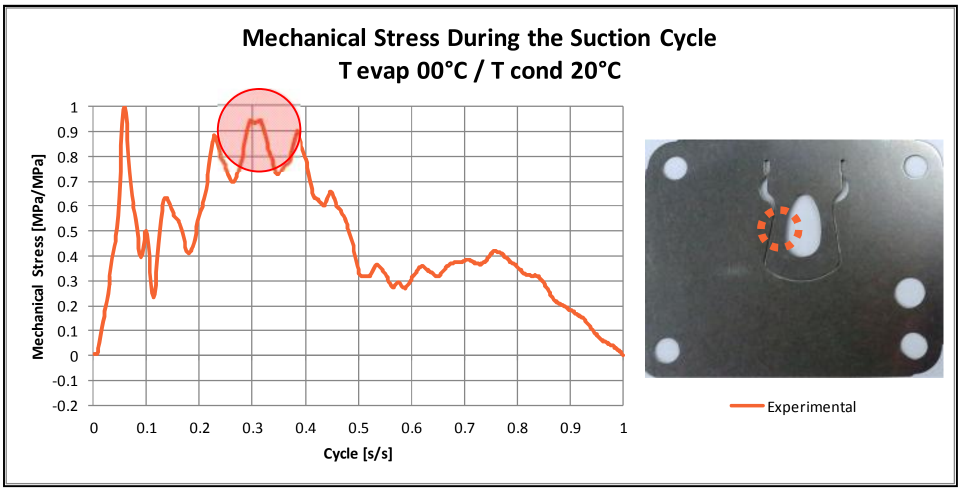

Figure 4 - Suction valve instrumentation (all mechanical stresses discussed here refer to strain gauge region)

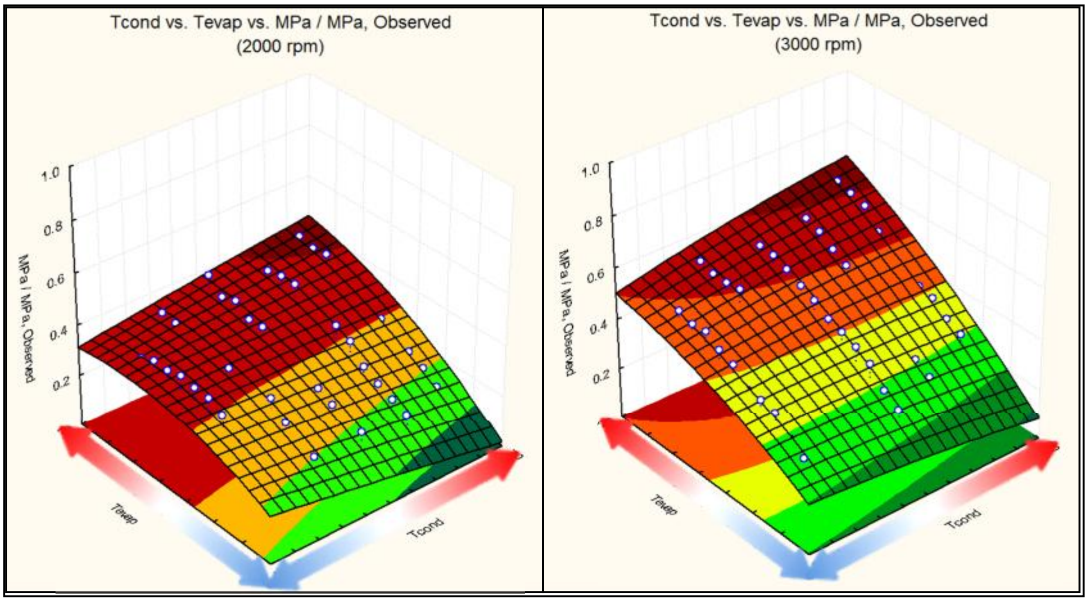

Figure 5 - LBP, MBP envelope application and speed variation (2000 and 3000 rpm)

The method used to estimate the mechanical stress developed in the suction valve shown in the figures above is essentially experimental, which requires all the components of manifold subsystem being prototyped. The same experimental procedure is repeated several times to cover the rotational speed at which the compressor will work. In other words, the valve design relies heavily on the accumulated knowledge of the engineering team, so that no loop occurs in the final phase of the project.

Apart from the technological advances in numerical computing, facilities and possibilities that this tool brings, its use is arguably necessary for a reliable design with lower cost and shorter development time. In other words, employing numerical simulation iteration between fluid and structure techniques, reduce the risk of loops in prototyping phase, the number of experimental tests and increases the likelihood of success in the design of this type of component.

4. CORRELATION BETWEEN THE EXPERIMENTAL METHOD AND NUMERICAL METHOD BY FLUID STRUCTURE INTERACTION - FSI

During construction of the numerical model, a series of recommendations should be followed in terms of dead volume, fluid volume mesh, structural region mesh, discretization in time to capture the valve resonances and others. These recommendations ensures to obtain a satisfactorily reproduction of the dynamics of the suction valve in regard to the experimental results.

The numerical model was created using ANSYS Mechanical software to solve the solid mesh, and the ANSYS CFX software to solve the fluid mesh, the coupling between the two solvers was done through the pressure field.

Prior to the comparison of the results, it is necessary to understand how mechanical stress varies over the cycle in the suction valve surface.

4.1 Mechanical stress developed during the suction stage.

Throughout the suction process the valve is subject to various levels of mechanical stress, varying strongly with speed and temperature conditions imposed to the compressor. Figure 6 shows the complete cycle of valve opening for 0°C evaporation and 20°C condensation temperatures, obtained by FSI simulation. In this figure it is also possible to observe that the valve region where the maximum stress occurs varies throughout the cycle (This region is indicated by the arrow in figure 6). This observation is important for estimating the fatigue life of the component, since this movement is repeated a number of times equal to the operating frequency of the compressor during time the life span.

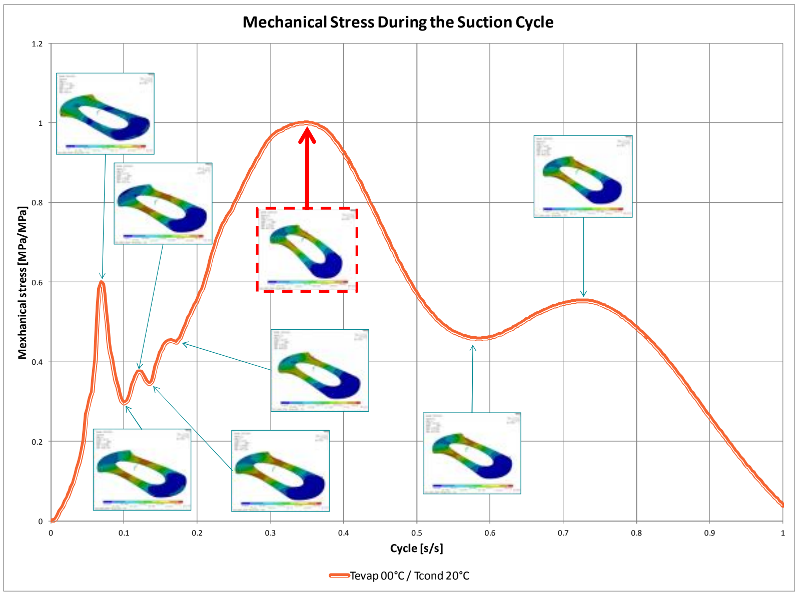

Figure 6 - Variation of stress region on the valve during the suction process

Understanding the region where mechanical stress occurs throughout the cycle is of utmost importance for the analysis of the results obtained by numerical simulation, allowing that the acceptance criteria for a good correlation between numerical and experimental results is high for some regions, but not high for complete cycle.

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4.2 Comparison between experimental and numerical results

The dots shown in figure 7 represent the conditions numerically simulated using the FSI method. Figures 8, 9, 10 and 11 show the results obtained by experimental method and numerical FSI method, and the point to point difference, between the two methods for conditions depicted in figure 7.

The three conditions on the right side of Figure 7, where the evaporation temperatures is higher than -15 °C result the pressure in the suction line being relatively high and causes an early opening of the suction valve. This phenomenon causes the valve touching the top of the piston. When this event occurs, higher frequencies in the valve signal take place and a mechanical stress peak early in the opening, figures 8, 9 and 10 depict this condition.

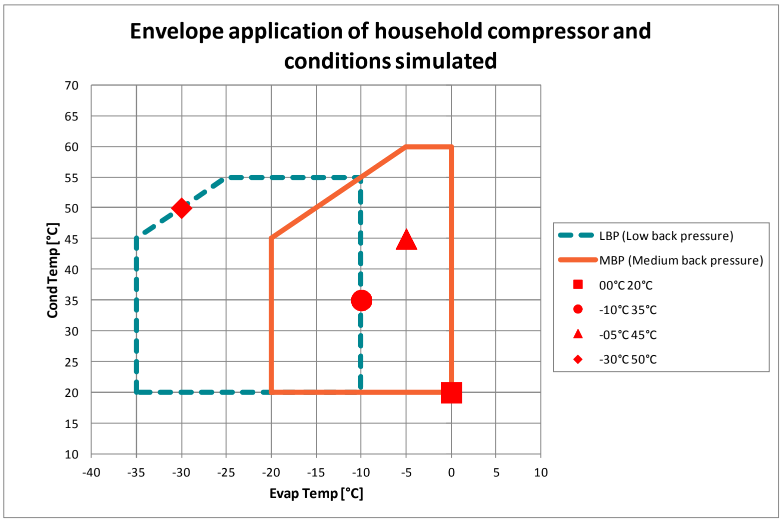

Figure 7 - Conditions simulated numerically

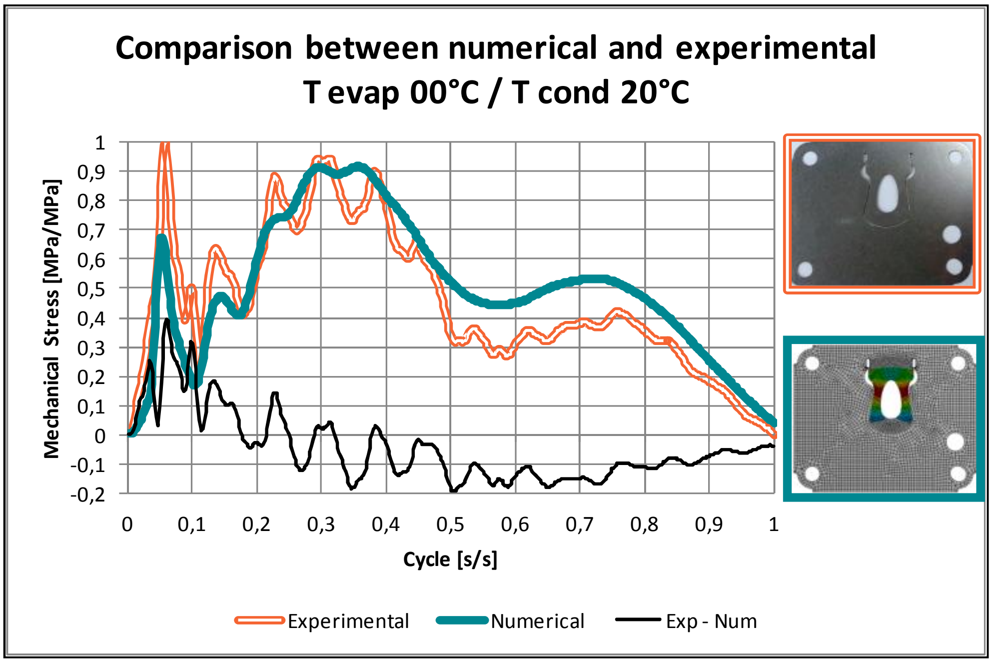

Figure 8 - Comparison between experimental and numerical data for condition 00°C evap. and 20°C cond.

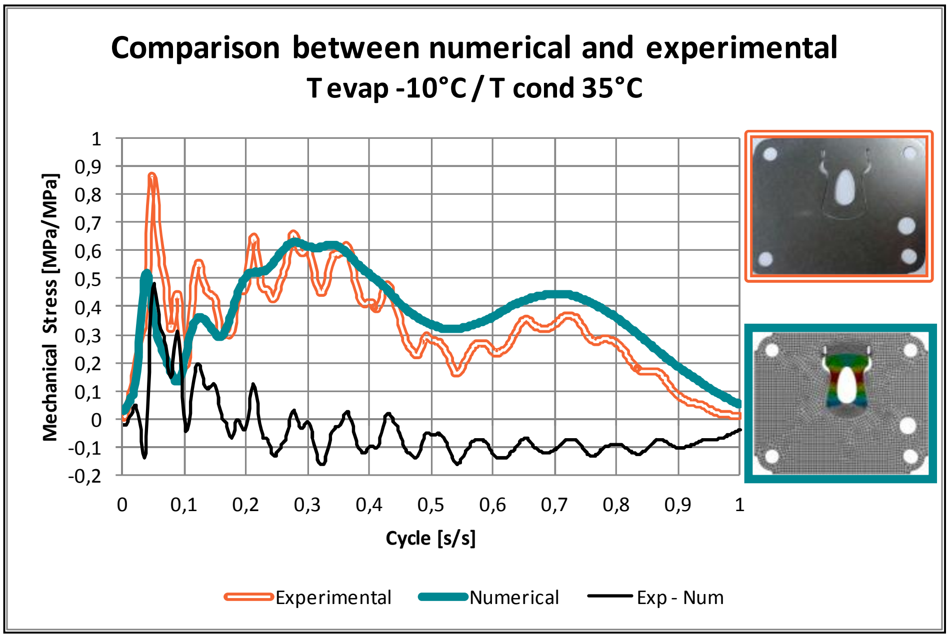

Figure 9 - Comparison between experimental and numerical data for condition -10°C evap. and 35°C cond.

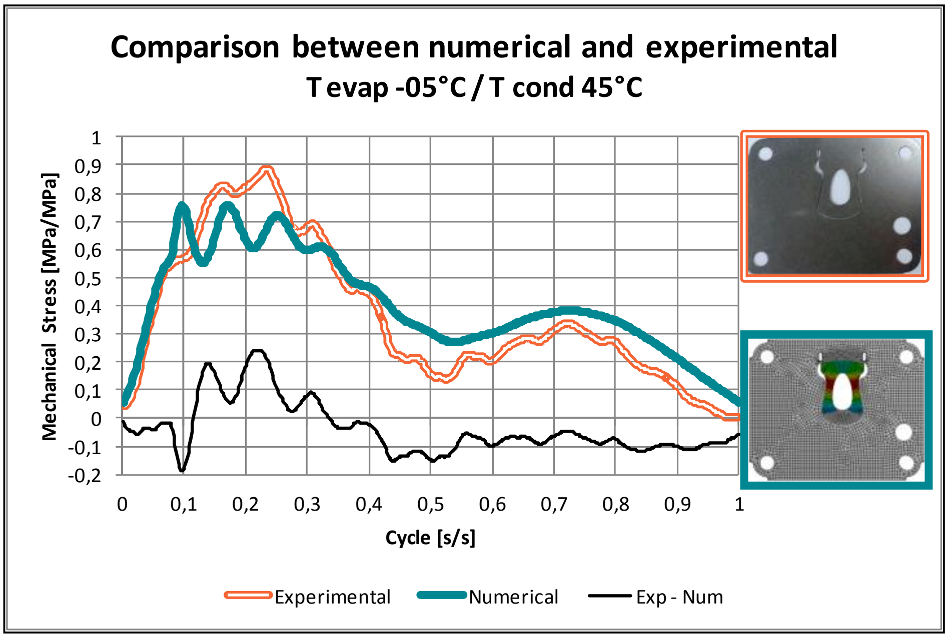

Figure 10 - Comparison between experimental and numerical data for condition -05°C evap. and 45°C cond.

Figure 11 shows a case where the pressure in the suction line is relatively low, and allows that the piston move down enough so that the valve does not touch the piston top, however, as might be expected, this causes a lower mass flow in discharge.
The largest error comparing simulated and experimental data occurs at the instant the valve touches the piston top, when other phenomena that influence the fidelity of the simulation results, these will be addressed in future works. However, understanding that the region of the valve where the mechanical stresses occur suffers variation of position along the suction cycle as shown in figure 6, makes the demand of a good correlation less stringent. Generally speaking, at the moment of maximum suction valve opening, the numerical model shows good correlation with experimental results, making the numerical simulation FSI a very useful tool in valves design.

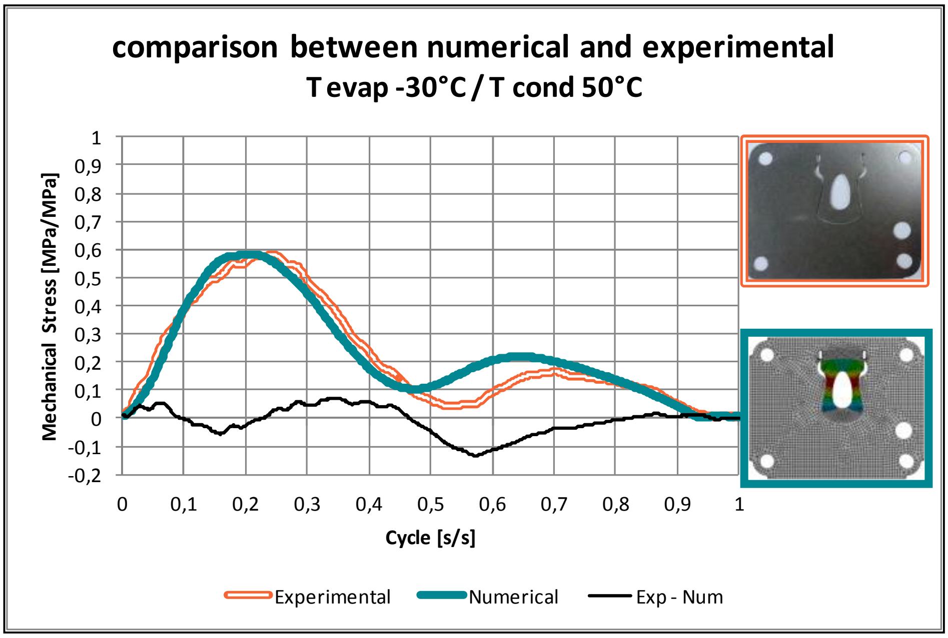

Figure 11 - Comparison between experimental and numerical data for condition -30°C evap. and 50°C cond.

8. CONCLUSIONS

- Mistakes in the manifold design can be very costly due to the number of components involved and the direct impact on efficiency and reliability that a change may cause. Thus, all possible analyzes should be made beforehand, still in the design phase, aiming to avoid any kind of design loop.
- The numerical model is robust to identify under what conditions occur the suction valve touch, on the top of the piston.
- At the moment of maximum suction valve opening, the numerical model shows excellent correlation with the experimental data, making it a reliable tool, enabling a reduction in design time and increasing the robustness of the final component.

REFERENCES

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ACKNOWLEDGEMENT

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