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COMPUTATIONAL FLUID DYNAMIC STUDY OF A HIGH-PRESSURE EXTERNAL GEAR PUMP

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Abstract. A study of a high-pressure external gear pump is described in this paper. The pump has been studied with modeling and experimental techniques. Starting from a CAD geometry of the pump, the three-dimensional CFD model has been built up using the commercial code PumpLinx®, developed by Simerics Inc. All leakages have been taken into account in order to estimate the volumetric efficiency of the pump. Then the pump has been tested on a test bench of Casappa S.p.A. Model results like the volumetric efficiency, absorbed torque, outlet pressure ripple have been compared with the experimental data performed by Casappa S.p.A.
Model has demonstrated to predict with good accuracy the experimental data and from now, it represents a useful support to help the design of pump. The model is, in fact, able to run in some conditions (such as at high pressure value) which are very challenging from a modeling and numerical point of view.
This study is the result of a research collaboration between the FPRG (Fluid Power Research Group) of the University of Naples "Federico II", the pump's manufacturer Casappa S.p.A. and the company OMIQ srl, as technical experts and distributors of PumpLinx®.

Keywords: External Gear Pump, 3D CFD Analysis, Experimentation

INTRODUCTION

Ii is well known that one of the most used pumps in fluid power fields are the external gear pumps (EGPs). These pumps are normally adopted in both mobile and fixed applications such as in agricultural, construction machines and hydraulic presses.
EGPs have many advantages such as the compactness and low cost with relatively high efficiency and remarkable reliability, a wide range of operating conditions and a structural simplicity.
The working principle of the EGPs is very simple. There are two gears, one is called driving gear one is the driven gear. The driving gear is connected directly to the pump shaft while the driven one is free. Gears are mashed each other generating chambers. Two plates connect the gears with the pump housing where, usually, ports are located.
The geometry of these machines therefore is relatively simple, however there are nowadays many researches addressed on the improvement of them performance. For example, in literature there are several numerical models. These researches (analytical, experimental and modeling) are focused on the prediction of the performance of these pumps typology.
Vacca et al. [1] analyzed with numerical approach the operation of the spur external gear units. Pellegri et all. [2] studies EGP with a CFD modeling approach.
Borghi et al. [3-4], used a mathematical model to predict the volumetric efficiency of gear pumps. The model has been also validated with experimental data. Mancò at al. [6] analyzed an external gear pump using a lamped parameter modeling approach. Model results have been compared with experimental data showing a good agreement.
However, the improvement on the pump performance can be achieved also studying the internal fluid dynamic of the pump lateral plates. Grooves designed in the plates can have several functions also for reducing the noise inside the pump. These grooves, for this reason, can affect the volumetric efficiency of EGPs. Borghi at al. [7] did a research on the transient pressure in the meshing volume of external gear pumps.
Yoon at al. [9] did a study on EGPs using a three-dimensional approach. The model (with an immersed solid method) includes also the decompression slots. The model has been used to make interesting consideration on

the internal pressure peak, local cavitation, and delivery pressure ripple. Also Castilla et al. [8] built up an entire 3D model of an external gear pump with the OPENFOAM Toolbox. No simulation models have been found for the study of cavitation.
This paper is result of a research collaboration between the Fluid Power Research Group (FPRG) of the University of Naples Federico II and two companies Casappa S.p.A. and OMIQ srl.
It has been studied the flow behavior in the chambers and in the meshing zone using a 3D CFD modeling approach [11 – 15]. The implementation in the numerical model of all the groove and leakages is important to achieve the best accuracy in the prediction of working conditions.
The analysis has been done on an external gear pump manufactured by Casappa SpA studing the internal fluid-dynamic of the pump. In particular, the pump under investigation is the Casappa KP30 and it is shown in figure 1a.

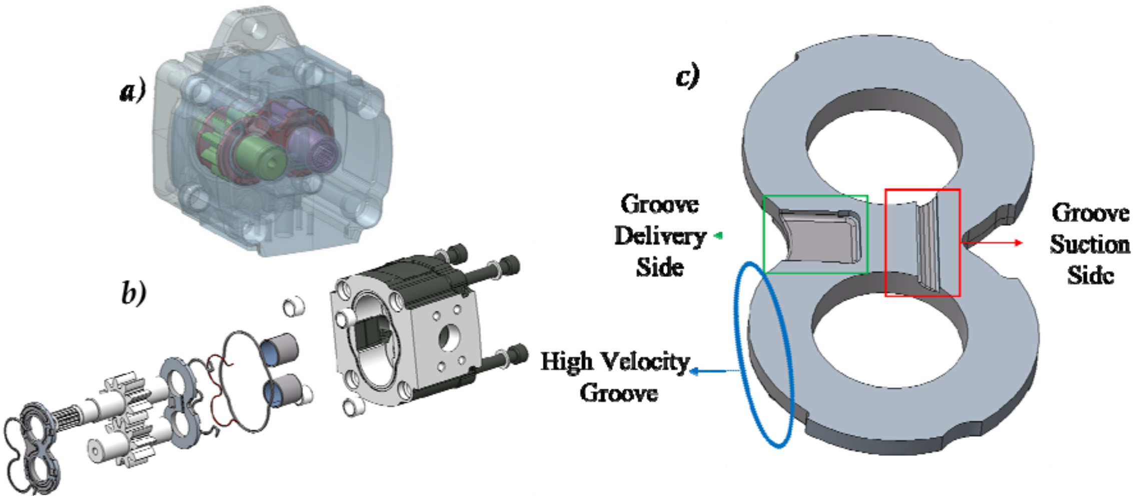

FIGURE 1. (a) Casappa KP30, (b) Exploded vision of the pump drawing, (c) Grooves inside the lateral plates

The pump main features are listed in table 1.

TABLE 1: Pump main features – Casappa KP30

Nominal Displacement	44 cm^3
Inlet Pressure Range	0.7 ÷ 3 [bar]
Max. Continuous Pressure	P1 - 250 [bar]
Max. Intermitted Pressure	P2 - 270 [bar]
Max. Peak Pressure	P3 - 290 [bar]
Rotational Speed	Min. 350 [min^-1] Max. 3000 [min^-1]

CFD MODEL OF THE HIGH-PRESSURE EXTERNAL GEAR PUMP

The Casappa External Gear pump has been studied using an accurate CFD model built up with the commercial code PumpLinx®. The entire model of the pump has been validated with experimental data performed by the pump manufacturer. All the comparisons have been done at three different delivery pressure and oil temperature varying the pump speeds with an accuracy always below the 2% for all the analyzed working conditions.
The validation of the model has been also done also on the pressure ripples. Particular attention has been reserved to the connection plates interposed between ports and gear. Figure 1c presents the geometry of one plates. As said, the design phase of plates is important and a CFD modeling approach can help design to optimize those geometries achieving the best solution. The groove created at the delivery side (underlined with the green rectangle in figure 1c, preventing the trapping of the fluid in the high-pressure volume reducing, as consequence, the pressure spike in mashing area. On the other side, the groove instead allows the filling of the chambers from the suction port. In this way, the pressure drop is reduced limiting the cavitation occurs. Those grooves have also the function to reduce the noisiness of the pump during the operation.
The design of groove, however, is important because they prevent also a loss of flow-rate and, as consequence, of the pump efficiency.
Other grooves have been designed on the plates. These volumes are called high velocity grooves (underlined with the ellipse in blue in figure 1c and connect a defined number of chambers with the high pressure side. This solution affects on the forces acting on gears.

Starting from the pump design in figure 1a the fluid volume has been extracted and then meshed. The extracted fluid volume of the entire pump is presented in figure 2a. Figure 2b presents the fluid volumes inside grooves while in figure 2c there are the chambers fluid volumes. Ports are shown in figure 2d.
The fluid volume has been meshed using a body-fitted binary tree approach. The grid generated with a body-fitted binary tree approach is accurate and efficient because the parent-child tree architecture allows for an expandable data structure with reduced memory storage.
In this architecture of the grid, the binary refinement is optimal for transitioning between different length scales and resolutions within the model. The majority of cells are cubes, which is the optimum cell type in terms of orthogonally, aspect ratio, and skew ness thereby reducing the influence of numerical errors and improving speed and accuracy. The grid can also tolerate inaccurate CAD surfaces with small gaps and overlaps.
The entire mesh of the pump is shonw in figure 3a while in figure 3b the realized interfaces are presented.

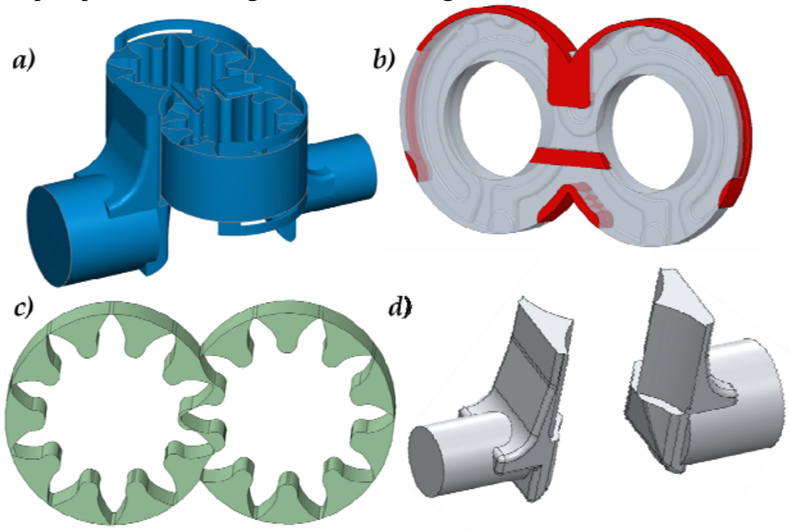

FIGURE 2. Extracted fluid volume of the external gear pump, a) Entire fluid volume, b) Fluid volume of the plate, c) Fluid volume in rotation, d) Fluid volume of the ports

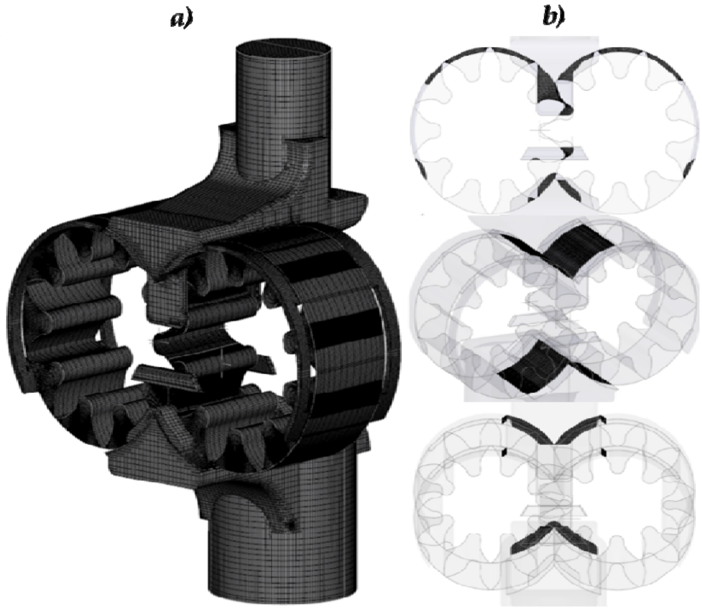

FIGURE 3 (a) Binary Tree Mesh, (b) Mismatched Grid Interface (MGI) between volumes

The code allows for the simultaneous treatment of moving (gear chambers) and stationary (like suction and delivery ports and grooves in the plates geometry) fluid volumes. Each volumes have been connected to the others via an implicit interface called Mismatched Grid Interface (MGI). Each MGI, due to deformations and motion, is updated at each time-step. MGI are shown in figure 3b.
Different techniques are available for the treatment of a moving mesh. For positive displacement pumps, it is necessary to use a moving/sliding methodology whereby the stationary and moving volumes are meshed separately.

Due to the complexity of the geometry in the boundary layer, the grid density on the surface have been increased without excessively increasing the total cell count. In the regions of high curvature and small details the mesh been subdivided and cut to conform it to the surface.
A maximum cell size has been chosen for the grid. This parameter define the maximum cell size in all the fluid volume. At the same way, a minimum cell size has been fixed to limit minimum dimension of all cells. Fixing this parameter means that no cell side can be smaller than the minimum cell size. Another important parameter must to be set; it defined the size of cells on surfaces.

MODEL VALIDATION

The pump has been tested, as already said, on a dedicated test bench of Casappa SpA.
Simulations have been run in the same conditions tested in the lab. These operating condition are listed below:

- Pump speed of 1500 rpm and 2500 rpm,
- Oil temperature of 50°C and 80°C,
- Delivery pressure of: 50bar, 150bar and 250bar.

In figure 4 a), b) and c), the first comparison between model and experimental data is shown for three different pump speeds: 1000rpm, 1500rpm, and 2500rpm. In the graph, the continuous line are the experimental data while the dashed one are the simulation results.
Simulations and test, as said, have been done for three delivery pressure conditions: 50bar, 150bar and 250bar. The comparisons have been done on the torque requested on the driving gear.

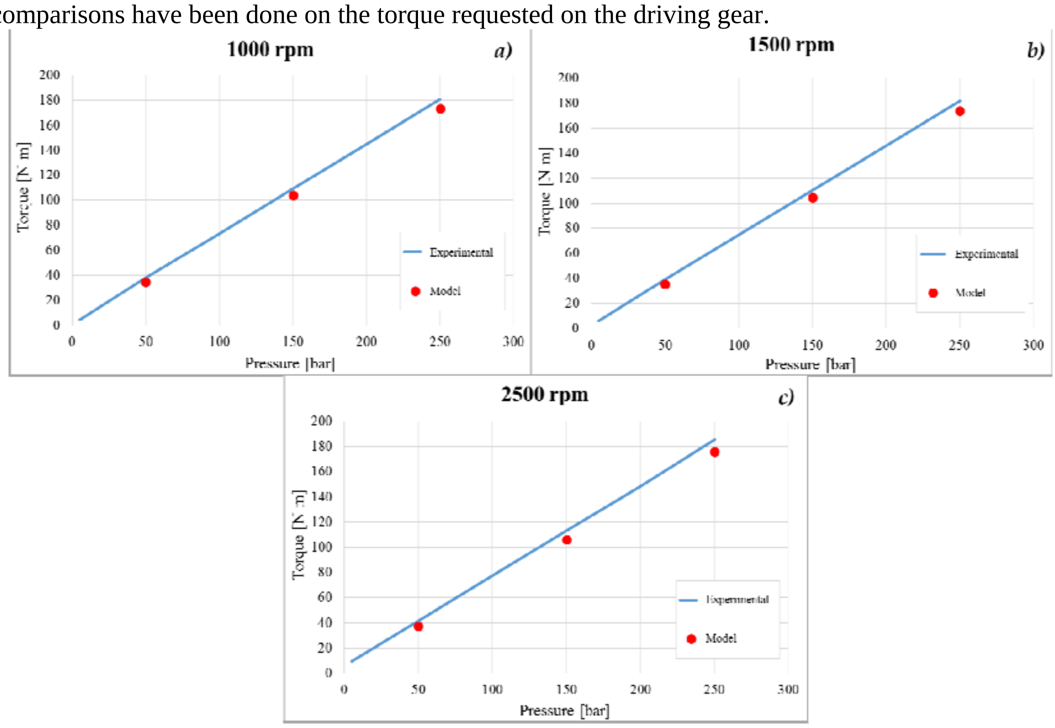

FIGURE 4. Absorbed torque – Comparison between model and experimental data. (a) 1000rpm, (b) 1500rpm and (c) 2500rpm

By analyzing figure 4, it is possible to appreciate that the model results are really close to the experimental data. The percentage errors are, in fact, always below 2%.
The little gaps between model and experimental data depend also by the fact that the model does not consider torque due to mechanical friction.
Model validation has been done also comparing at the delivery flow-rate varying the delivery pressure (see figure 5).
This comparison is shown in figure 5 at the oil temperature of 50°C and 80°C and at the pump speed of 1500rpm and 2500rpm. It can be noticed that delivery flow rate decreases by increasing the delivery pressure for both model and experimental data; the error percentage between model and experimental data is always below 2%.
Of extreme interest, it is the comparison of pictures at the same delivery pressure, changing only the oil temperature. All images at 50°C present a velocity lower than the same at 80°C. This depends by change of the fluid properties with the temperature.
With the validated model other considerations on results have been done.

In figure 6, the velocity magnitude evaluated by the code inside the chambers at different pressure and oil temperature.

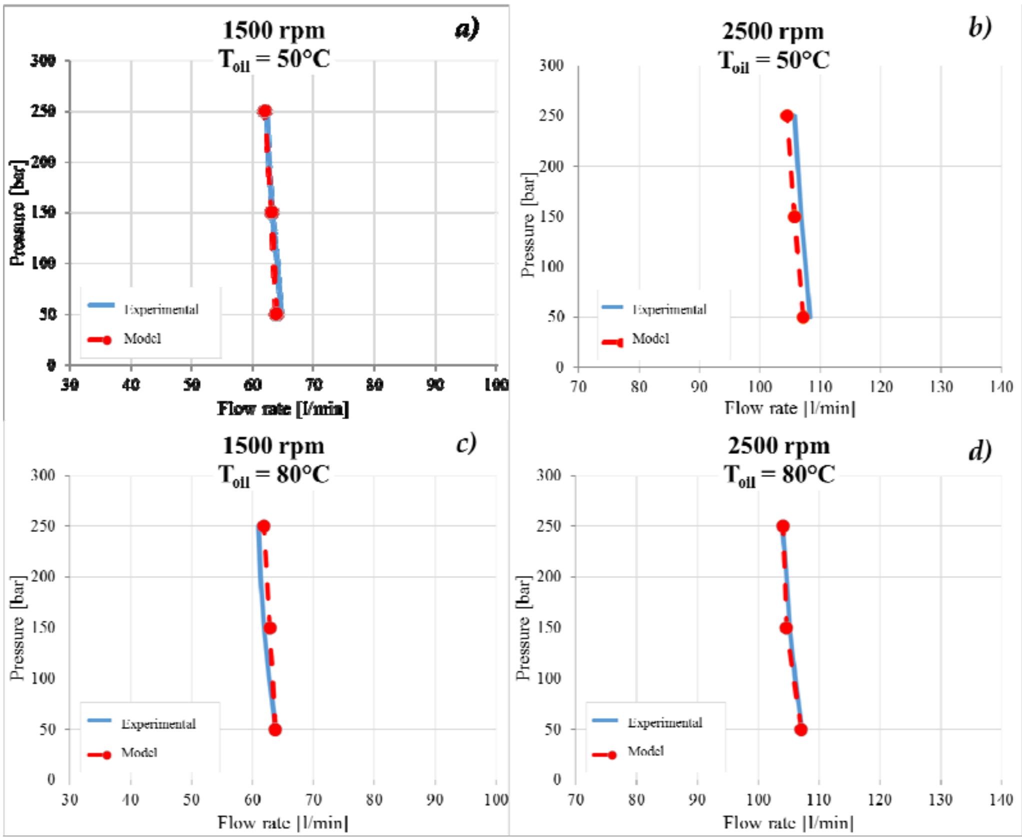

FIGURE 5. Pressure vs delivery flow-rate comparison, (a) 1500rpm and Toil of 50°C, (b) 2500rpm and Toil of 50°C, (c) 1500rpm and Toil of 80°C, (d) 2500rpm and Toil of 80°C

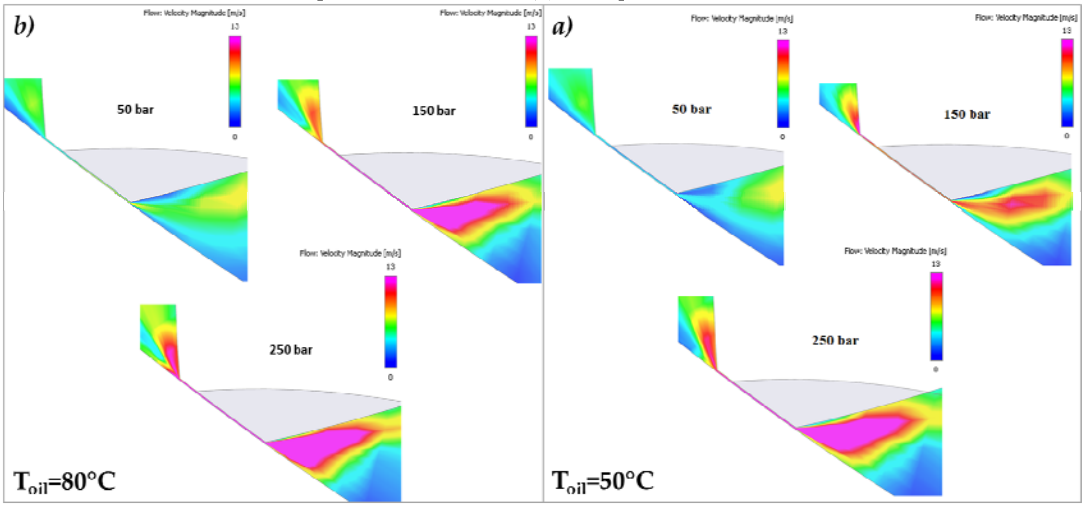

FIGURE 6. Velocity magnitude at (a) 50°C and (b) 80°C

As well known, by using a three-dimensional CFD modeling technique it is also possible to obtain results difficult to be obtained experimentally. Data shown in graph of figure 7 can allow to evaluate the pressure spikes inside the chamber of volumes in rotation for each gear. As expected, when the chamber is connected to the delivery port, it has an oscillating pressure around the delivery value (in this case 50bar and 250bar). Pressure are smoother around the mean value with a lower pump speed (1500rpm) and increases at 2500rpm. This has been observed for both volume chamber of drive and driven gear the delivery pressure. The pressure spikes inside the chambers are clear for both gears fluid volume. Those investigations, especially the evaluation of the spikes values, are really important to design or optimize a pump.

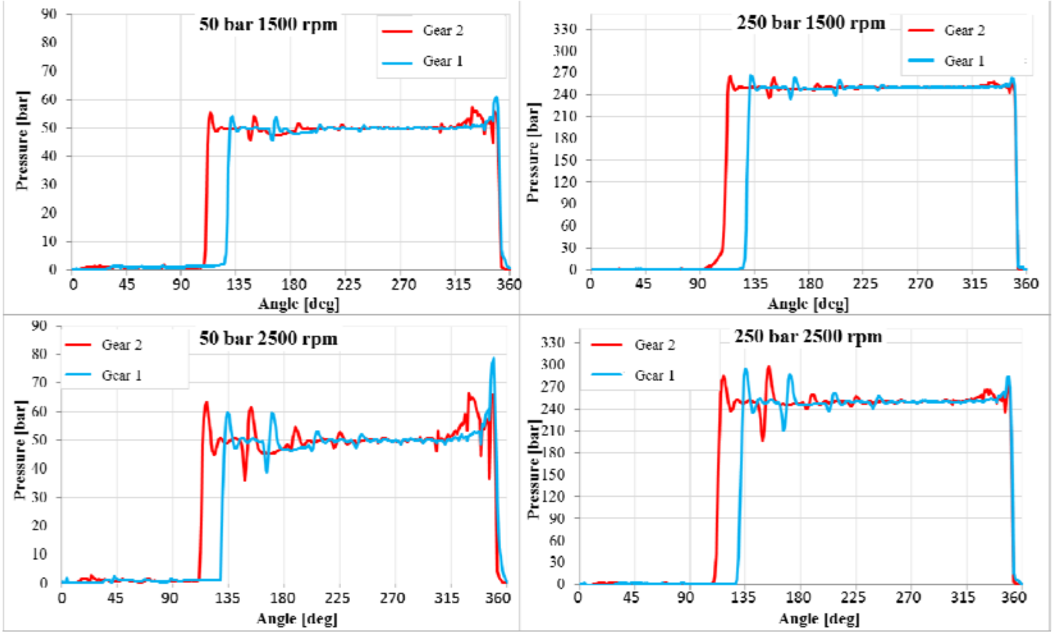

FIGURE 7. Pressure evolutions for two pressure levels at Toil of 50°C

During the tests, a valve has been located close to the pump delivery in order to amplify the pressure ripples at the delivery port. As consequence, the model has been implemented adding a calibrated orifice. The additional fluid volume has been inserted to reply the real experimental setup.

Simulations have been run with the model and the model results have been compared with the experimental data (see figure 8) [16]. The monitoring point for the simulation has been located in the same position of the pressure transducer installed on the test bench. In that, point the pressure ripple has been both measured and calculated. Comparisons have been done at two rotational speeds and three pressure level at 50°C (see figure 8). Diagrams in figure 8 have been normalized to a reference pressure.

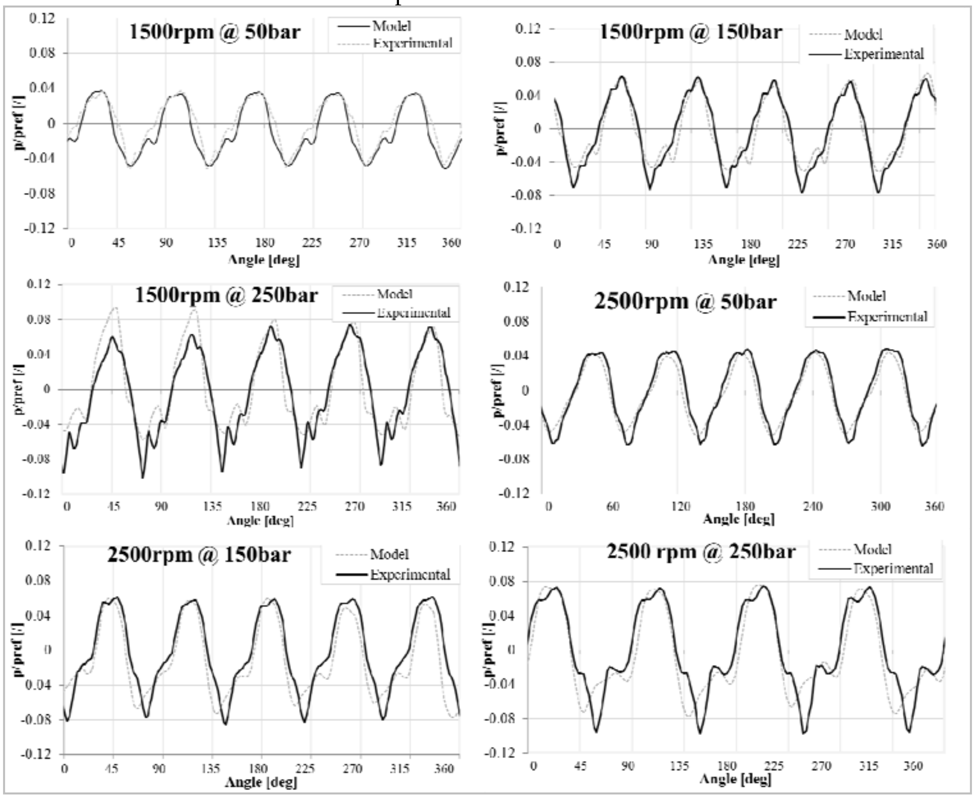

FIGURE 8. Pressure ripple comparison at 50°C, (a) 1500 rpm, (b) 2500rpm at 50°C

CONCLUSION

A three-dimensional CFD study a high-pressure external gear pump has been fully described in this paper. The model has been realized on a geometry of a pump manufactured by Casappa SpA.
The model has been build up using the commercial code PumpLinx® including accurate tools to predict the flow turbulence and cavitation. Leakages have been taken into account in order to correctly estimate the volumetric efficiency of the pump. The final model has demonstrated to achieve an accuracy close to 2%.
Model results have been compared with experimental data performed on a dedicated test bench of the pump manufacturer.
Thanks to the good agreement of data the model has been run in some conditions (such as at high pressure value) which are very challenging from a modeling and numerical point of view.
This study summarized a methodology able to completely describe the operation pumps such as the external gear pump. All the working parameter have been analyzed and, where possible, compared with experimental data.
This research has confirmed the importance of the three-dimensional CFD modeling approach that can be a valuable instrument for engineers in the development of new prodocts.

ACKNOWLEDGMENTS

This research is a result of a research collaboration between the FPRG (Fluid Power Research Group) of the Department of Industrial Engineering of the University of Naples “Federico II” and two companies: Casappa S.p.A. and OMIQ srl.

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