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CYLINDER DEFORMATION SENSITIVITY STUDY USING FEA

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ABSTRACT

When trying to increase efficiency of a hermetic compressor, one of the critical challenges to solve is the topology of the crankcase in order to have acceptable deviations on the cylinder region. The shape of the cylinder significantly affects the efficiency, performance and reliability of the compressor. The aim of this work is to use finite element analysis to predict cylinder deformation and investigate which factors significantly affect it by using sensitivity analysis. Among the factors evaluated are screws assembly torque, material properties, gasket properties, temperature and stator stiffness. Experimental measurements showed good correlation with the simulation considering cylindricity values and deformed shape. The sensitivity analysis allows to estimate how the cylindricity error is accumulated to the manufacturing errors, resulting in a cylindricity error statistic distribution.

Keywords: Crankcase, Cylinder, Deformation, Cylindricity, Sensitivity

1. INTRODUCTION

When trying to increase efficiency of a hermetic compressor, one of the critical challenges to solve is the topology of the crankcase in order to have acceptable deviations on the cylinder region. The shape of the cylinder significantly affects the efficiency, performance and reliability of the compressor. This topic is largely studied in the compressor industry. Castro (2015, 2016) shows that Finite element analysis (FEA) can be used to predict shape errors in the crankcase cylinder. Castro (2017, 2018) suggest an automated method to minimize shape errors in specific regions of a mechanical component using FEA and topology optimization. Similar effects are also relevant in other industries, like the automotive. Fan (2019) investigated the effect of different piston profiles obtained by a diffent manufacturing process and the interaction with the engine cylinder, including the effect on friction losses. Iftikhar (2019) included the thermal deformation of the piston and liner obtained via CFD model on the dynamic engine simulation. Telsemeyer et al. (2019) also included the thermal deformation and piston profile to check the effect on piston reliability, avoiding fatigue failures. Hay (2019) showed a numerical model including thermal deformation of the piston and liner, assembly induced deformation of the liner, roughness and even the deformation of the piston surface around the rings due to the different shapes of the ring grooves. The aim of that research was to show how friction losses and oil consumption were affected by including or not the piston ring region deformation.

2. FINITE ELEMENT MODEL

A numerical model was used to estimate the deformation of the parts, and finally, provide data to calculate roundness and cylindricity errors in the cylinder of a crankcase. The boundary conditions applied are basically the assembly torque on the screws and the crankcase is fixed to the ground (Figure 1). The numeric model considers the real gasket behavior. The gasket material property is based on the measurements according to the material formulation used in the simulation software (pressure/closure curve).

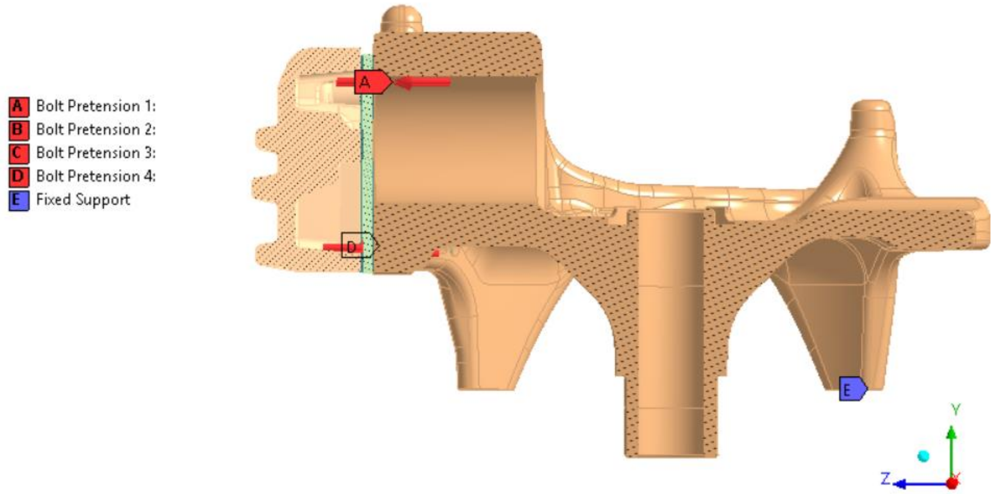

Figure 1: Boundary conditions

The results of interest consist on the node coordinates and displacements in the cylinder region (Figure 2). With this data, it is possible to calculate the roundness of separated sections of the cylinder and the cylindricity of the complete region (Figure 3).

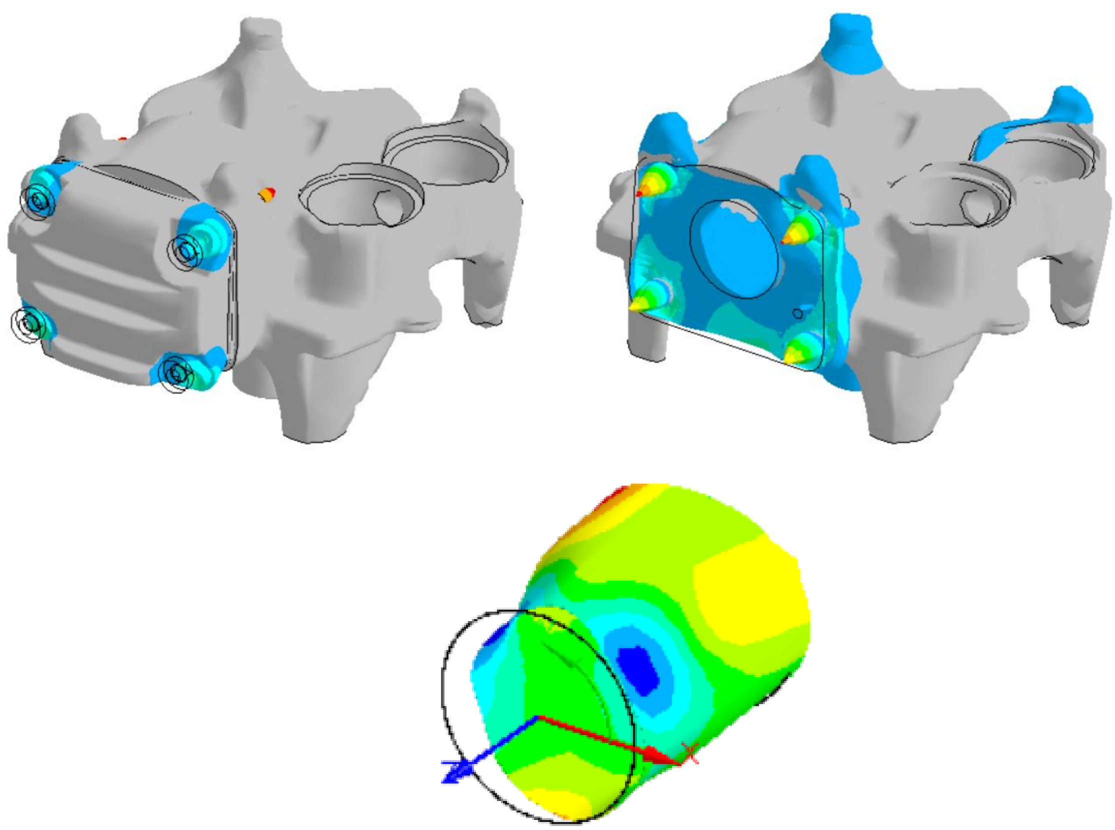

Figure 2: Deformation

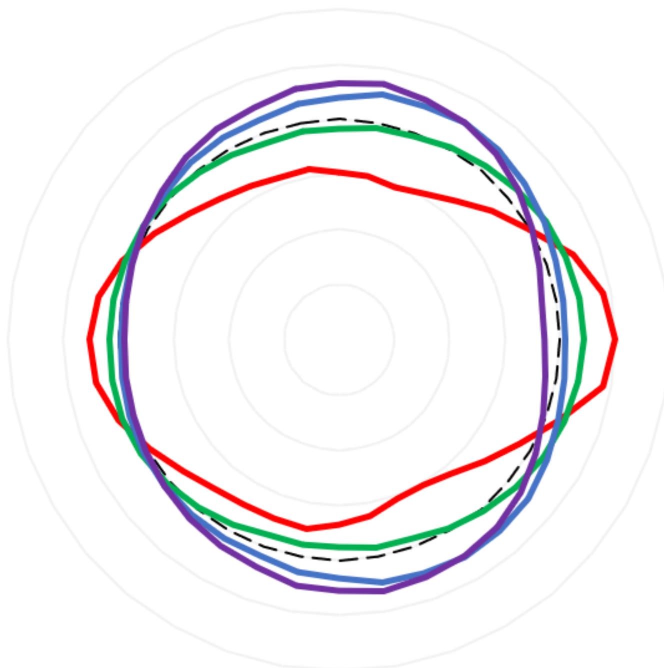

Figure 3: Cylindricity plot

3. RESULTS

3.1. Experimental setup

Experimental measurements showed good correlation with the simulation considering cylindricity values and deformed shape. In order to compare results, both numerical and experimental cylinder deformations were exported, making the comparison possible for each angular section of the cylinder, and for any section along the cylinder length (Figure 4). To exclude the initial shape errors on the real part caused by manufacturing, the measured roundness is calculated as the difference of the shape deviations before and after the bolt pretension.

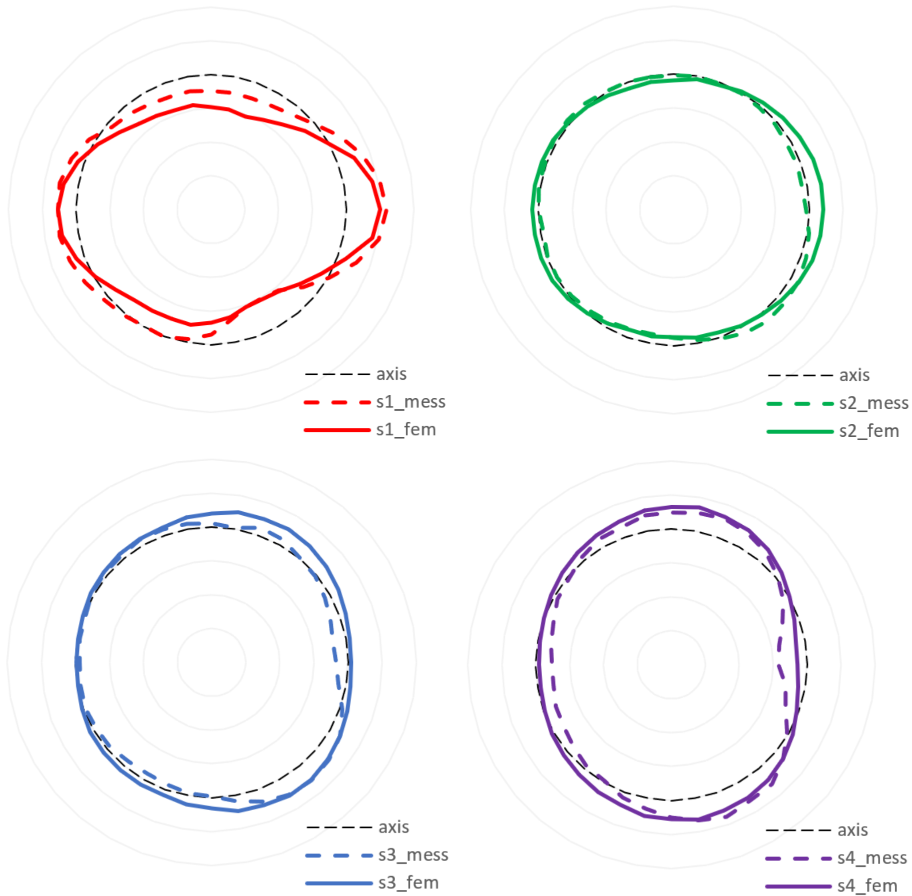

Figure 4: Roundness plot comparing experimental measurements and numerical results by sections

3.2. Sensitivity analysis

In order to evaluate how shape errors (i.e. roundness or cylindricity) are affected by several factors (Figure 5 and Figure 6), a sensitivity analysis was performed. The factors include cylinder cover assembly torque, material properties, gasket properties and temperature. It was identified that for this compressor model, the stator stiffness was not affecting results, thus, it was removed from the factors. All those are real parameters than can physically affect deformation (Figure 7). In this paper, it is also evaluated how deviations of those factors could influence the precision of the numerical results. Other purely numerical factors, like the method used to model the screw threads were already evaluated by Castro (2015).

Table1. Sensitivity analysis factors variation range

Factor	min	max
Screw assembly torque	-20%	+20%
Crankcase Young modulus (E)	-20%	+20%
Gasket pressure/closure curve	-20%	+20%
Temperature	-20%	+20%

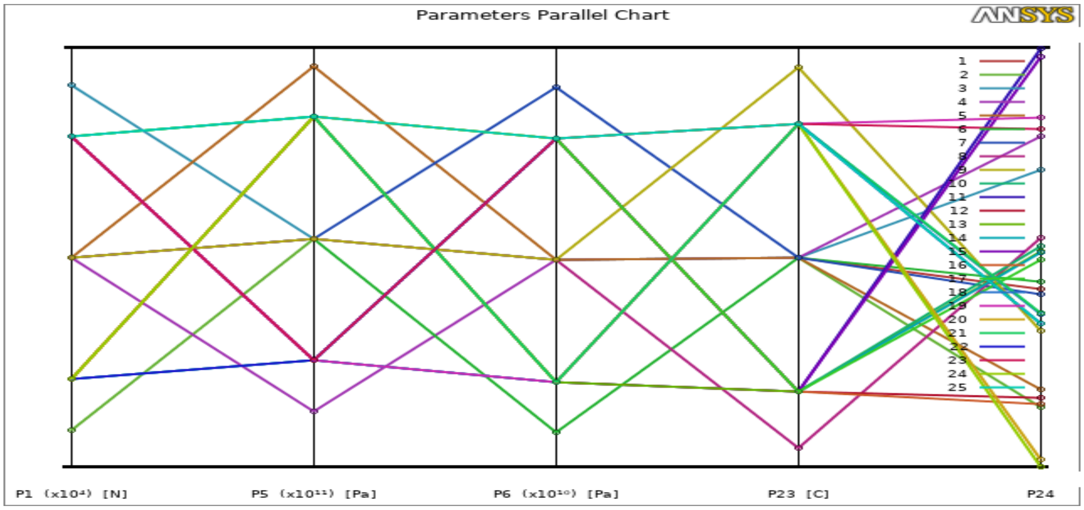

Figure 5: Parallel chart showing the variation of 4 factors and the output variation of roundness

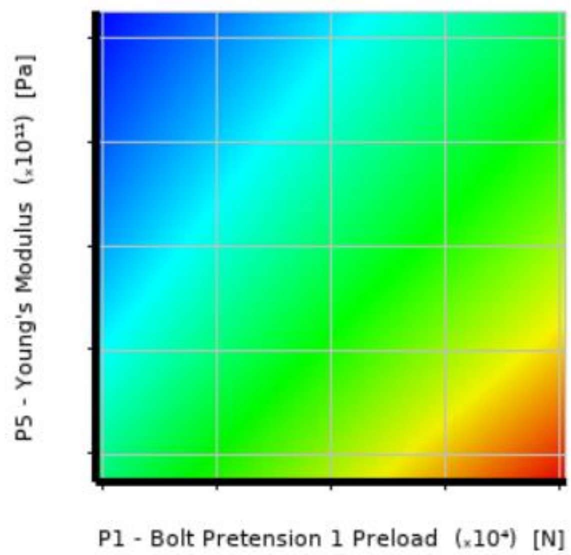

Figure 6: 2d countour plot of roundness vs. bolt pretension and crankcase Young modulus

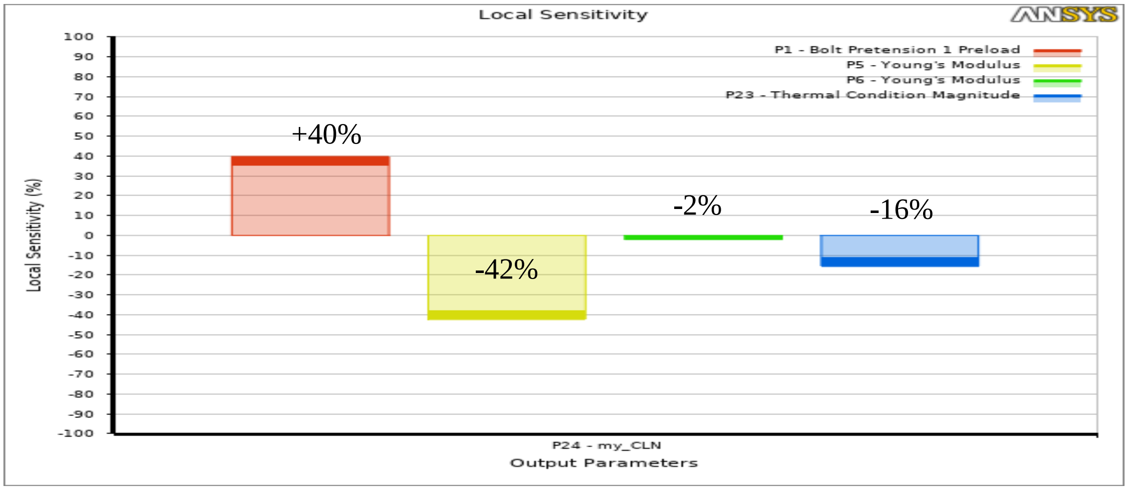

Figure 7: Sensitivity results

All factors were defined having a normal distribution with standard deviation of 6.66% of the nominal value. The roundness response is also normal, like seen in the Figure 8, and its variation is around ±39%.

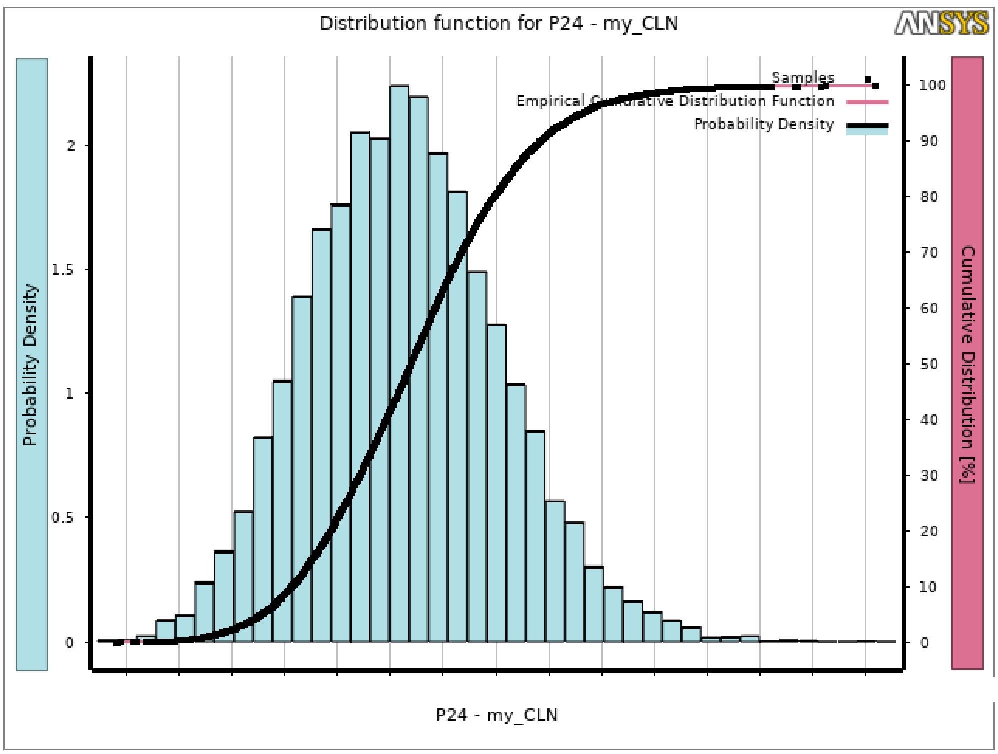

Figure 8: Roundness statistical distribution for 4 factors

4. CONCLUSIONS

The sensitivity analysis allows to estimate how the cylindricity error is accumulated to the manufacturing errors, resulting in a cylindricity error statistic distribution. The highest contribution to induce shape errors in the crankcase cylinder are the bolt pretension and the crankcase Young modulus (82% together). Using a realistic variation range for each parameter, it is demonstrated that the experimental results fit inside this range, thus, the numerical model can capture shape erros with acceptable precision. For the given variation range, the roundness can vary within a range of ±41%, including manufacturing errors.

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