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MUFFLER AND BEARING OPTIMIZATION APPLYING GENETIC ALGORITHM

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ABSTRACT

This study presents a overview of suction mufflers and bearings optimization in a hermetic reciprocating compressors. There are many optimization methods available in literature, however, only the genetic algorithm methodology was used in this study.
Optimization is performed using a certain range for the geometric variable values important for each component and by using computational simulation codes it is possible to obtain the geometric configuration for the best product performance. The lengths and diameters of the suction mufflers were the modified parameters and the optimization goal was to increase energy efficiency. The parameters in the bearing were the diameter, length and bearing clearance and the goal was to reduce the bearing power losses keeping the oil film thickness value (reliability parameter).

1. INTRODUCTION

Hermetic reciprocating compressors are used in various applications, such as commercial and domestic refrigeration and air conditioning, among others. To meet the growing market demands for lower noise levels, greater efficiency and lower costs, the need to develop components optimized for their functions is becoming more pressing.
The project for compressor components generally requires an enormous amount of experimental tests for validating the numerical results and to guarantee product reliability. Therefore, in order to avoid an excessive number of tests, it is advisable to obtain, through numerical simulation, the product configurations that fulfill project requirements in the most possible optimized way. At this time it is crucial to use a reliable and robust optimization tool linked to a simulation program that faithfully represents the physical phenomena involved in compressor operation.
This work studies the optimization of two types of components present in alternative hermetic compressors, the radial bearings and the mufflers, using a specific simulation software for each component and the LMS Optimus commercial software for performing optimization using genetic algorithm.

2. A REVIEW OF OPTIMIZATION ALGORITHM

Ragsdell (1974) states that the definitions of three basic functions are necessary for optimization to be successful in a numerical optimization. The first and most important is the definition of the objective function. This function must represent and contemplate the parameters that have to be optimized in order to reach the project's objectives. The second most important function is the input parameter restrictions. These parameters must be limited to prevent the occurrence of unreal situations and to ensure that the geometric dimensions do not exceed the physical limitations of the component in the end product. The third function also concerns parameter restrictions, however, combinations of other parameters, which should always be kept constant, are used in this function, an example of which is the volume of a box where its dimensions are optimized.

Prins *et al.* (1996) performed the optimization of a valve system using the genetic algorithm. The choice of this optimization methodology is useful to prevent the local maximum and minimum values to the objective function instead the global value. For parameter input, Prins *el al.* used valve thickness, plate orifice diameter and the maximum suction valve displacement allowed. The objective function parameters consist of the isentropic efficiency, the volumetric efficiency, using the impact speed of the valve on the seating as restriction.

The genetic algorithm is a simulation using the survival principle for adaptation. When searching for an optimum situation, a population is first created randomly and the objective function is calculated for each one of the individuals with the most suitable ones being selected. The most suitable individuals are used to create new populations and the process continues until only the most suitable ones have survived.

Sandgren and Ragsdell (1974) emphasize that it is not always possible to obtain the expected value for the objective function, as sometimes the input parameters are unable to satisfy the restrictions and the objective function at the same time. However, the value obtained through optimization will be the closest possible to the desired target.

3. COMPUTATIONAL METHODOLOGY

The authors of this study used the genetic algorithm method, denominated self-adapting. This optimization routine is available in LMS Optimus commercial software. The muffler and bearing simulation codes use the finite volume methodology for solving continuity, momentum and energy equations.

The muffler simulation code considers a one-dimensional, turbulent and periodic flow for simulation inside the muffler. The valve dynamics is modeled using a one degree of freedom mass-spring-damper system. Deschamps *et al*. (2002) describe this methodology in details.

The computational code used for solving the bearing pressure field during the running cycle considers the laminar, incompressible and isothermal flow. The bearing power losses can be estimated through equation (1). Observe the proportionality symbol in this equation and not the equality symbol, as in practice the bearing power losses value is equal to this value multiplied by a constant. Manke (1991) describes the methodology applied in this work in details.

$$\dot{W} \propto \frac{\mu ?^{2} L R^{3}}{c} \cdot f(e) \tag{1}$$

4. RESULTS

The following sections present the results obtained in the muffler and bearing optimizations.

4.1. Bearing optimization

For the purpose of conducting the optimization, a bearing was selected which had undergone parametric modifications to its clearance, length and shaft diameter. The optimization goal was to reduce the bearing power losses and the limitation was to guarantee that the lowest instantaneous oil film thickness does not fall below the value considered safe for bearing reliability in relation to fatigue forces at any time throughout bearing operation. Figure 1 presents a diagram showing the contribution of each one of the parameters in bearing power losses.

In figure 1 the parameters with negative contribution indicate that according to the value the bearing power losses are reduced and the parameters that appear with a positive contribution bring an increase in mechanical power when its values lean to the highest limit stipulated for optimization. In figure 1 it is further possible to perceive that the only important interaction occurs between the s haft radius and the bearing clearance.

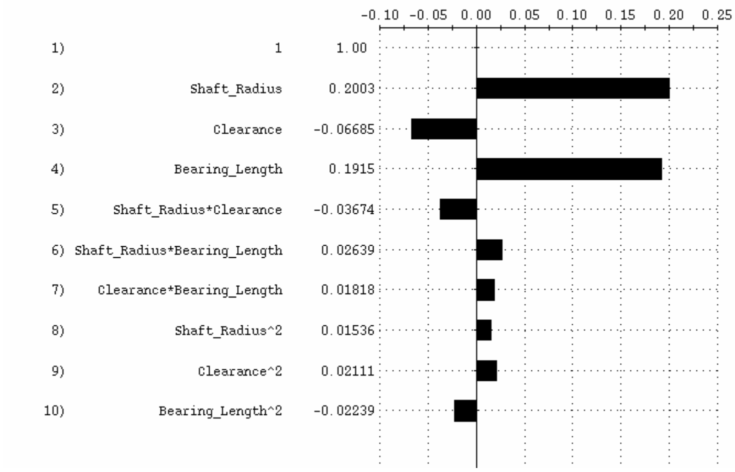

Figure 1 – Contribution diagram showing bearing power losses

Another important point that should be analyzed is the behavior of the bearing power losses curve in relation to the parameters used in the simulation. As three control parameters were used in this optimization, the response curves cannot be presented in one single curve, being necessary to fix one of the parameters and analyze the variation of the other two. As the contribution diagram showed that the most important interaction occurs between the shaft radius and the bearing clearance the parameter that will have to be kept fixed will be the bearing length. Figure 2 presents the bearing power losses curve in relation to the parameters used in the optimization.

In figure 2 it is possible to verify that as the bearing clearance increases, the power losses are assimptotically reduced. Concerning the small clearances, a rapid increase to values below 1.00 is perceived. The shaft radius also plays a very influential role in the power losses. Increases to the order of 50% (fifty percent) are obtained when there is a single bearing clearance with the shaft radius varying 22% (twenty-two percent)

Figure 3 presents the lowest oil film thickness for the same situations described in 2. Thus, it is possible to locate the best relation between reliability and power losses.

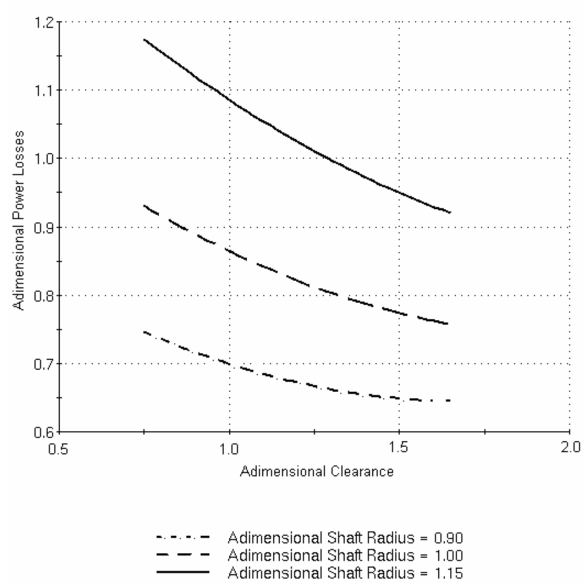

Figure 2 – Power losses in relation to bearing clearance

Figure 3 shows the bearing reliability parameter in relation to the various bearing clearances. Take the adimensional oil film thickness equal to 1 (one) as the minimum parameter for guaranteeing a bearing that will operate without excessive wear. Thus, the great reduction in bearing power losses end up being restricted by reliability aspects.
Figure 4 presents the power losses in relation to bearing length. As expected according to the physical phenomenon description there is a linear variation with the bearing length. Thus, the bearing length is not an attractive variable to be modified for the reduction of mechanical loss.

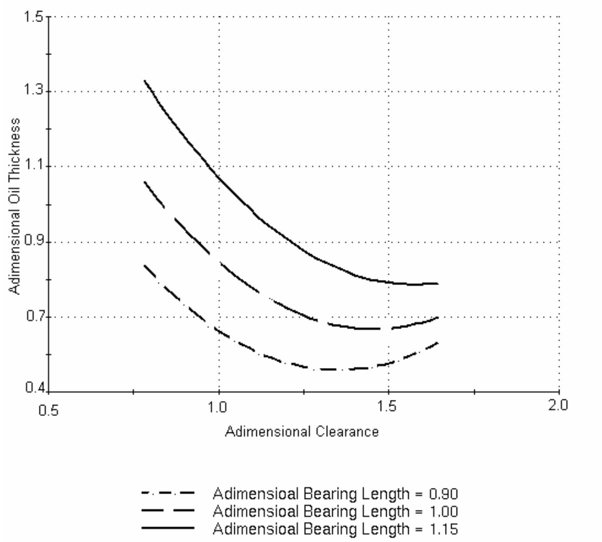

Figure 3 – Oil film thickness in relation to bearing clearance

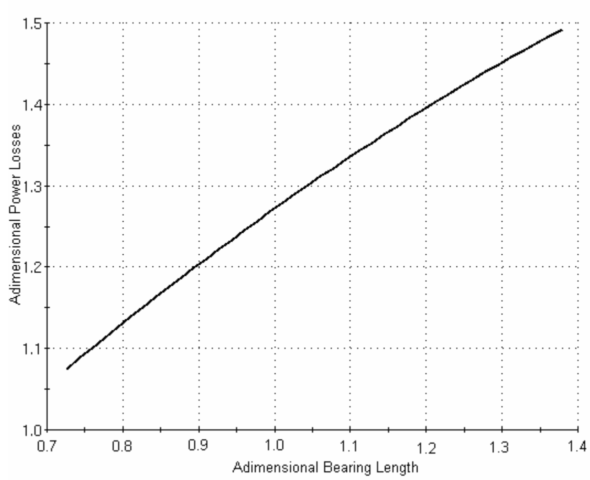

Figure 4 –Power losses in relation to bearing length

4.2. Muffler optimization

Suction mufflers are essential for compressor performance, both in relation to noise levels as well as to energy efficiency. A muffler with 1 (one) volume and two cylindrical tubes was used in the present study. Figure 5 presents a muffler schematic model used for the simulations. The best configuration for a muffler is that which, with the lowest possible head loss, maintains the valve with sufficiently stable dynamics and the mass flow at the values designated in the project. Parameters for the optimization of the diameters and the two suction muffler tubes were considered in the present study. The optimization goal was to increase compressor energy efficiency value without significantly reducing compressor capacity. Figure 6 presents the contribution diagram showing the performed optimization.

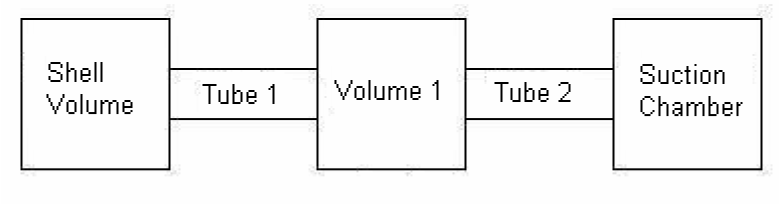

Figure 5 – Muffler schematic model

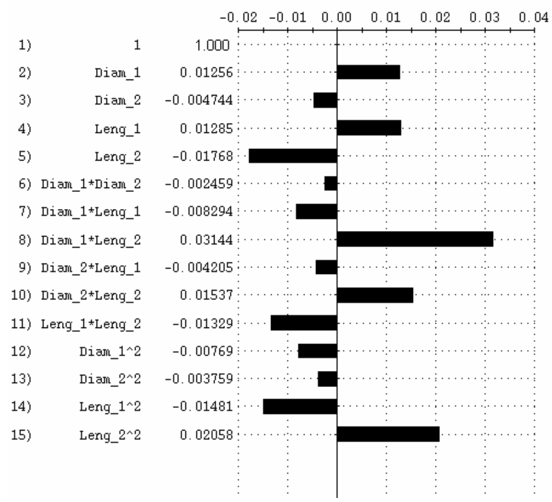

Figure 6 – Contribution diagram showing compressor energy efficiency

As expected, the interactions between the geometric parameters are shown as more important than the individual values of each parameter. For a better understanding how the geometric parameters of the tube next to the suction valve , denominated tube 2 in this study, influences on compressor performance, figure 7 shows the energy efficiency curve in relation to the geometric parameters of tube 2. The geometric parameters of tube 1 were taken as constants in this graph.

By analyzing figure 7 it is possible to verify a coherency in the results with the physics of the problem, as when tube diameter is increased and the length is decreased an increase in energy efficiency occurs. It is important to emphasize that the combination of parameters is essential for good compressor performance, as tube 2 is fundamental in guaranteeing adequate suction valve operation.

5. CONCLUSIONS

The results of optimization using genetic algorithm proved to be very efficient and robust. One important observation is that the good optimization performance is directly linked to the precision with which the computational code is used for simulating the phenomena involved inside the suction muffler and the bearing lubrication phenomena. If the simulation tooling does not accurately present the behavior of the physical model the optimization results will be incoherent with the experimental data. However, more complex models will require greater computational time, thus, the optimization will require a higher computational cost.

Optimization tooling is very useful for the development of new products and enabling the full potential to be extracted from the bearing and muffler simulation code.

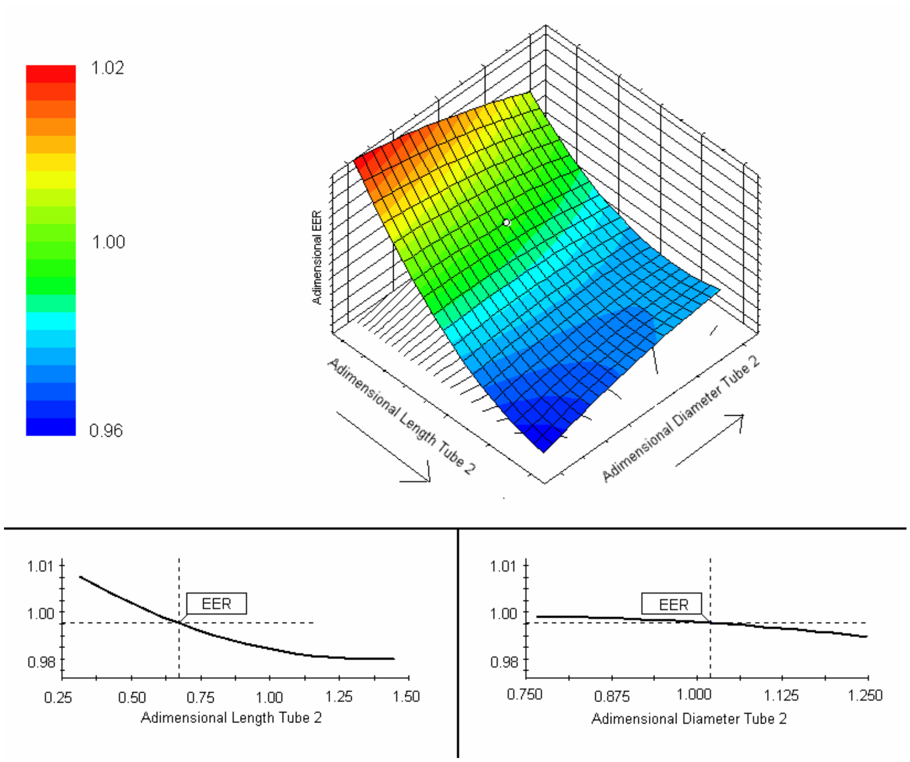

Figure 7 – Energy efficiency curves versus tube 2 geometry

NOMENCLATURE

W	bearing power losses	(W)
μ	oil absolute viscosity	(Pa.s)
?	shaft angular speed	(rad/s)
L	bearing length	(m)
R	shaft radius	(m)
c	bearing clearance	(m)
$f(e)$	adimensional eccentricity function	(-)

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