25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COB-2019-0900
STUDY FOR POWER OPTIMIZATION OF A NEW PNEUMATIC MOTO-COMPRESSOR

Vinícius Gomes Pereira Siston
Guilherme Amaral do Prado Campos
Centro Federal de Educação Tecnológica Celso Suckow da Fonseca campus Nova Iguaçu - Departamento de Engenharia Mecânica, estrada de Adrianópolis, n^{o}1.317, Santa Rita, Nova Iguaçu, RJ, CEP 26041-271
viniciusgpsiston1@gmail.com, guilherme.campos@cefet-rj.br

Abstract. *There is significant commercial interest in projects of motor-compressors or motor-pumps, but before to build this device is necessary to define power and displacement. In this work, the development of the model for power and displacement optimization is carried out for a new vane-compressor, which main characteristic is to keep the torque constant throughout 87% of the cycle. The objective of the optimization is to acquire parameters that allow to improve the efficiency of the moto-compressor, since they are currently obtained in a secondary way. The methodology used is based on numerical optimization techniques (methods deterministic and stochastic) to compare two configurations of the device maintaining the same torque: Maximum Power and displacement; and Minimum power and displacement. The results obtained propose a viable model for the optimization of the power through the adjustment of dimensional parameters.*

Keywords: *Power Optimization, Displacement Optimization, Moto-compressor, Constant torque*

1. INTRODUCTION

The rolling piston conversors (RPC) currently are widely used at refrigeration, because it has some benefits as, simple construction, few pieces, reduced weight and size, insulation between the chambers of input and output, besides as low cost. All theses points that attract attention of industry and researchers since 1970's according to the work of Yanagisawa *et al.* (1982), Ooi (2005) and Kussul *et al.* (2016). However, the mechanism had been invented since 1588, according to Skinner (2014).

According to Colaço and Dulikravich (2009), such minimization procedures require the use of an optimization technique. There are several gradient-based (deterministic) and non-gradient-based (stochastic) techniques, for example, steepest-descent method and conjugate gradient method, deterministic; genetic algorithm and particle swarm, stochastic.

In this work is studied two methods of optimization, namely steepest-descent and genetic algorithm, applied to optimize the power and displacement of a new vane-compressor, which main characteristic is to keep the torque constant throughout 87% of the cycle.

2. FORMULATION

When developing a motor compressor it is necessary to understand its design, for this, in Fig. 1, a schematic with the main components is presented. The operating principle, of this type of equipment, consists of an eccentric axis cylinder that when rotating causes a increased volume in the inlet chamber, suctioning in the inlet port air, and a decrease in the volume of the outlet chamber, compressing the air to the outlet port. This is only possible because of the vane which, sliding on the surface of the eccentric cylinder, separates sealing the inlet chamber from the outlet chamber. The spring serves to maintain the contact between the blade and the piston.

Note that the profile of the reed shown in Fig. 1 is rectangular in shape and only moves in one direction (1 GDL - Degree of Freedom). According to Siston (2018), it is possible to obtain the torque of the device, with rectangular profile and 1 GDL, through the Newton-Euler equations, as shown in Eq. 1. In Figure 2a, the movement scheme and its variables are presented,

$$T = P \cdot (Disp \cdot b) \cdot (Rext - Disp/2) \tag{1}$$

where $Disp$ is the displacement of the blade in the Y axis, $Disp_{max}$ is the maximum vertical displacement of the blade, b is the base of the blade profile and $Rext$ is the radius of the outer cylinder.

It is noted by the Eq. 1 that by varying the displacement ($Disp$) the torque also varies, since all other parameters are constant. Thus, to keep the torque constant, it is necessary to vary a parameter other than the pressure.

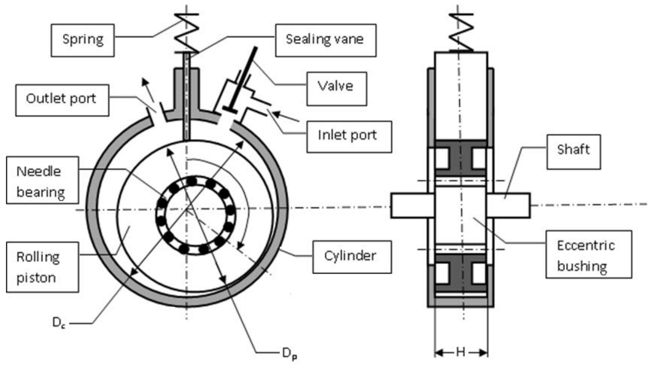
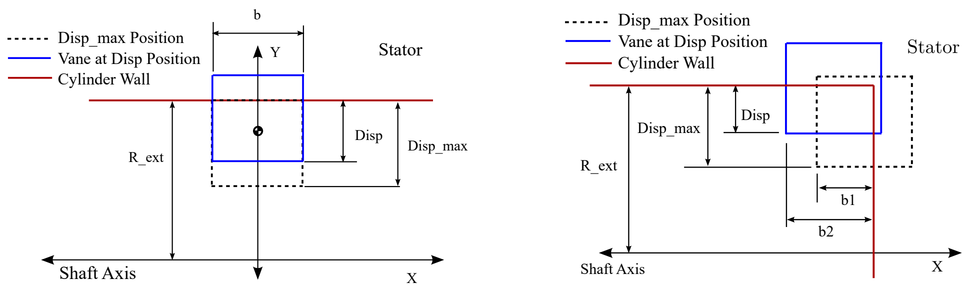


Figure 1: Schematic of motor compressor (Fonte: Kussul *et al.* (2016)).



(a) Rectangular profile.

(b) Profile proposed by Siston (2018).

Figure 2: Geometric schemes of reed profiles.

As was initially proposed by Siston and Campos (2017) and further developed by Siston (2018), to maintain constant torque the profile of the vane becomes variable, as shown in Fig. 2b since the parameter b will also vary according to Eq. 2.

$$b = \frac{T/P}{Disp \cdot (Rext - Disp/2)} \tag{2}$$

The variable profile adopted is a function of the displacement ($Disp$) given by the rotation of the eccentric axis cylinder. In Figure 3 is presented a geometric scheme that relates the displacement ($Disp$) to the angle of rotation of the axis (u).

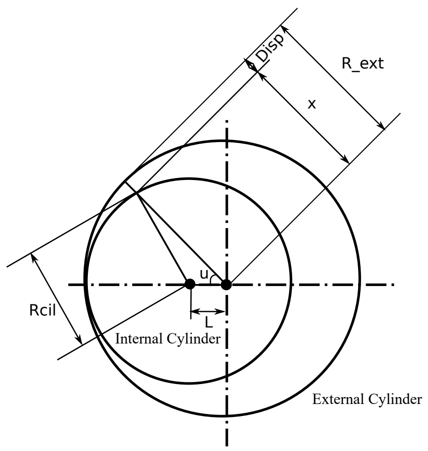


Figure 3: Geometric schemes of the vertical came.

To obtain the displacement $Disp$ parameterized by the angle we must solve the Eq. 3 and Eq.4.

$$Rcil^2 = x^2 + L^2 - 2 \cdot x \cdot L \cdot cos(u) \tag{3}$$

$$x' = \frac{-(2 \cdot L \cdot cos(u)) + \sqrt{(2 \cdot L \cdot cos(u))^2 - 4 \cdot L^2 - Rcil^2}}{2} \quad (4)$$

In Equation 5, the relation to get the value of $Disp$ is displayed.

$$Disp = Rext - x' \quad (5)$$

To put the horizontal cam curve in function of the angle u, simply replace the equation 5 in Equation 2. For very small values of $Disp$ (10 times less than its maximum value $Disp_{max}$), the value of b becomes too large, this would make the construction unfeasible. Thus, it is assumed that for very small values of $Disp$, the reed is approximately completely retracted.

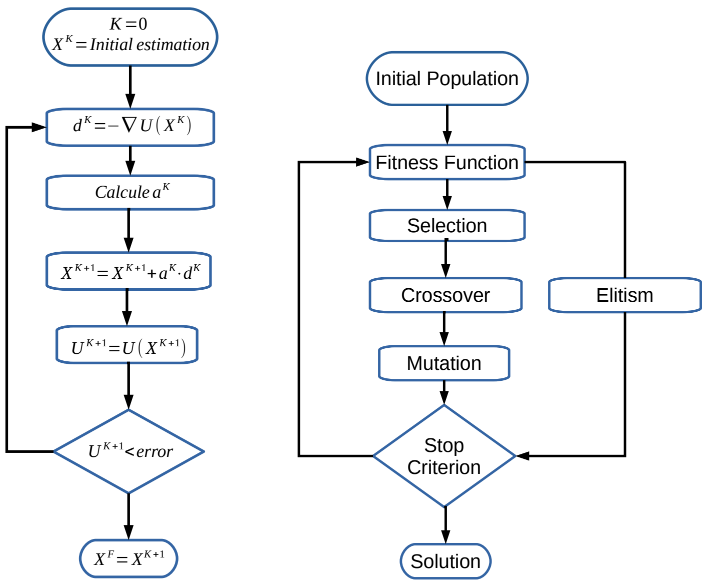
To determine the volume of the displacement, we use Eq. 6. Note that the area A is a function of the angle of rotation (u) and is defined as $A(u) = Disp(u) \cdot b(u)$. The radius of the area centroid is determined by $r(u) = Rext - Disp(u)/2$, and is also a function of u,

$$\phi = \int_{u_i}^{u_f} A(u) \cdot r(u)\, du \quad (6)$$

where ϕ is the volume of the displacement, A is the exposing area of the vane, r is the radius of the centroid of area, u_i is initial angle and u_f is final angle.

3. METHODOLOGY

The methodology consists in using two numerical methods of optimization, Steepest Descent and genetic algorithm, to compare the efficiency of each one and to verify which is the best method for the present application. The flowcharts of each optimization method employed can be seen in Fig. 4.The objective function of optimization is the displacement function ϕ. In this approach, velocity and inlet pressure are maintained constant and power is changed only by the displaced volume.



(a) Steepest Descent Method. (b) Genetic Algorithms.

Figure 4: Optimization Methods.

4. RESULTS AND DISCUSSIONS

To obtain the results of both optimization methods it is necessary to establish a desired configuration for the device in Tab. 1 . The parameters to be adjusted are the external radius of the chamber ($Rext$) and the radius of the eccentric cylinder ($Rcil$).

Table 1: Standard parameters

Parameter	**Value**	**Unit**
Pressure (inlet)	$6 \cdot 10^5$	Pa
Torque (shaft)	50	N· m

The computer used has the following characteristics: Intel(R) Core(TM) I5-3230M CPU @ 2.60GHz 2.60GHz 64 bits, 4.00GB(RAM) and Windows 10 operating system. The software used to run the algorithms was Matlab-2016a(R).

4.1 STEEPEST DESCENT OPTIMIZATION

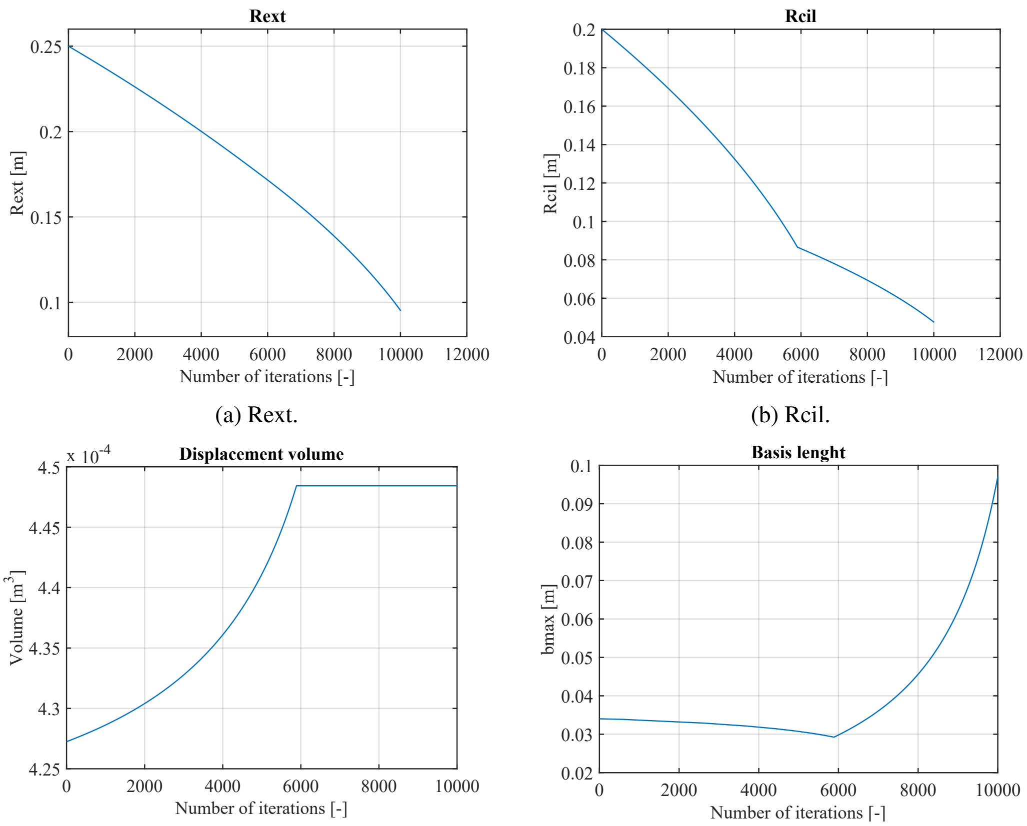
The Steepest Descent is a basic numerical method of gradient and needs an initial estimation, that estimation is $0.25\,m$ for $Rext$ and $0.20\,m$ for $Rcil$. The step between iterations is 0.00001.

In Figures 5a and 5b, the evolution of each parameter is displayed. The total duration of iterations in this method was 136.20 seconds.

It is observed that to maximize the volume the parameters tend to reduce, but the variable $Rcil$ has its decay rate changed from the iteration 5,900, because it reaches the proposed restriction. This restriction implies the viability of the mechanism, in case $Rext$ is smaller the axis of rotation is compromised.

It is noted in Fig. 5c that the volume growth rate increases until an asymptote begins at the iteration of 5,900, just when $Rcil$ is limited to half of $Rext$. The assymet occurs because there is no change from $Rext$ to $Rcil$, and preliminary results indicate that the volume increases when that variation is positive.

It is important to note in Fig. 5d the variable $bmax$, because, although secondary, it influences the geometry of the device. The evolution occurs with decay, contributing to the space savings used, up to the point of restriction of $Rcil$, when its growth rate increases rapidly, hampering the efficient use of space.



(a) Rext. (b) Rcil.

(c) volume. (d) bmax.

Figure 5: Target function and bmax.

4.2 GENETIC ALGORITHM OPTIMIZATION

From the same configuration of Tab. 1, the Genetic Algorithm method was used in four different tests. The same conditions and algorithm were maintained in all tests, only individuals from the initial population changed from one test to another and in a random manner.

Table 2: Genetic algorithm configuration

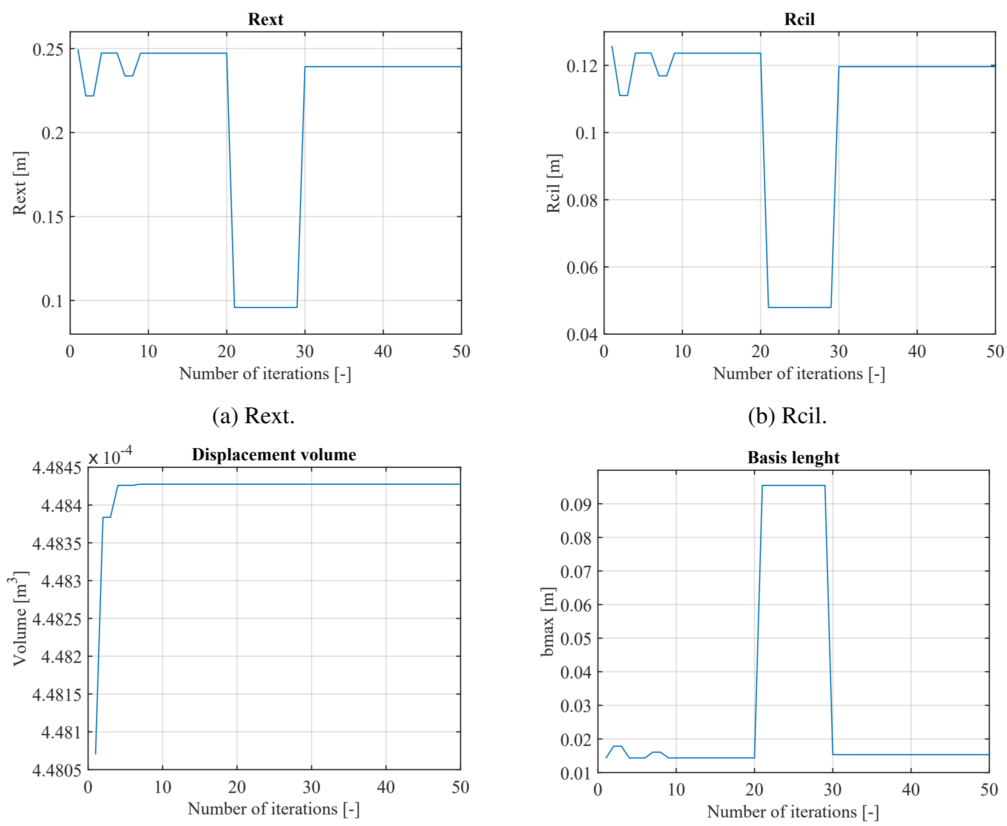
Parameter	**Value**
Population individuals	50,000
Number of iterations	50
Crossover point	1 (in the middle)
Elitism individuals	25,000
Mutation potential points	3

The geometric constraint of $Rcil \leq Rext/2$ has been applied since the initial population was created and verified with each new generation.

In the Figure 6 is possible to see the evolution of Test 1. In this Test the lapsed time was 236.2794 seconds. However the last one result was reached at thirtieth iteration. It is important to note that at the beginning the volume is already close to the optimized value. The geometric constraint has more significant influence in this method, because every time an individual is substituted, the parameter $Rcil$ is nearly half of $Rext$, and it indicate that the optimal parameters are nearly the boundary constraint.

Between the iterations 20 and 30 the parameters values are approximately the optimal result on Steepest Descent method in its iteration 1000. But is then replaced by a better option in which the parameters $Rext$ and $Rcil$ are larger. It demonstrate that the faster the Steepest descent method reaches the limit of the restriction (on larger values for $Rext$ and $Rcil$), the faster you will also find the best result.

The secondary parameter Basis lenght ($bmax$) also reaches best values in this test, as can be seen in Fig. 6d, because lower values of $bmax$ means less space occupied by the device.



(a) Rext.

(b) Rcil.

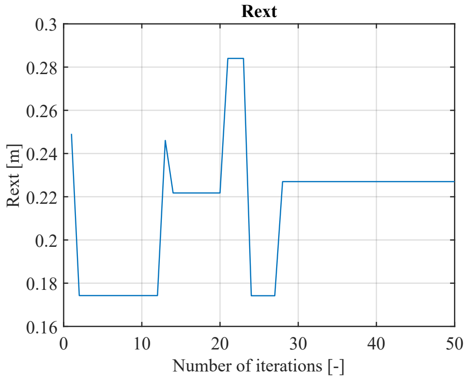
(c) volume.

(d) bmax.

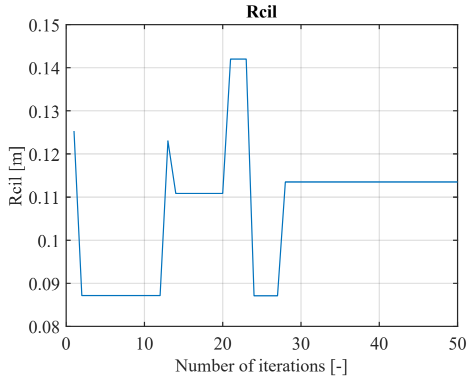
Figure 6: Test 1 evolution.

The results of Test 2 are shown in Fig. 7, over a time period of 236.4027 sec. In comparison with test 1 the tendency of $Rcil$ to be half of $Rext$ is maintained as the graph format of Fig. 7a and 7b shows. The final results are similar but in the second test the input parameters values are lower and $bmax$ value is lower too.

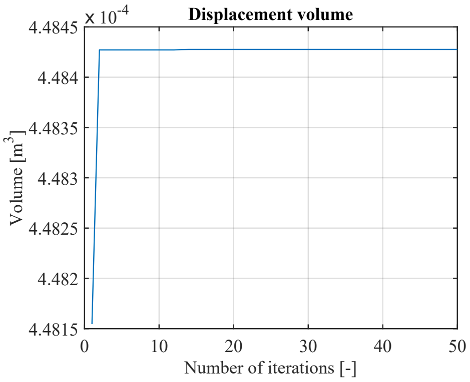
The number of times the best individual has been replaced keeps same (6 times) between test 1 and 2. However the sensitivity about the target function is very low after the first substitution.



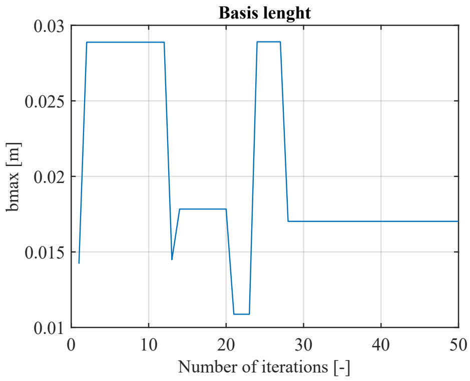
(a) Rext.



(b) Rcil.

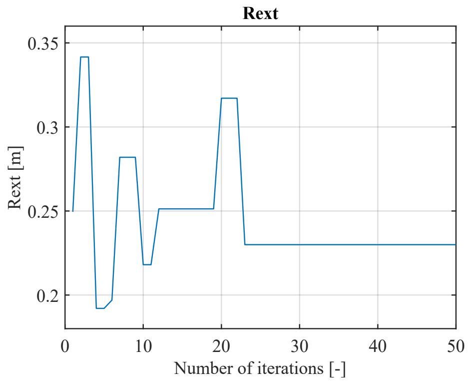


(c) volume.

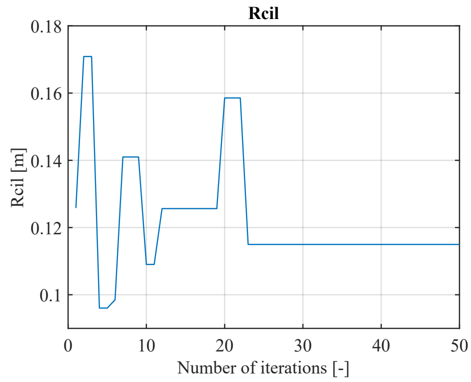


(d) bmax.

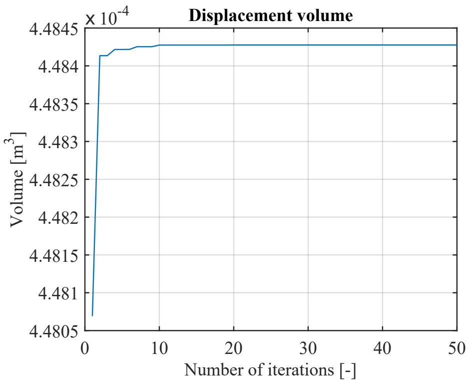
Figure 7: Test 2 evolution.



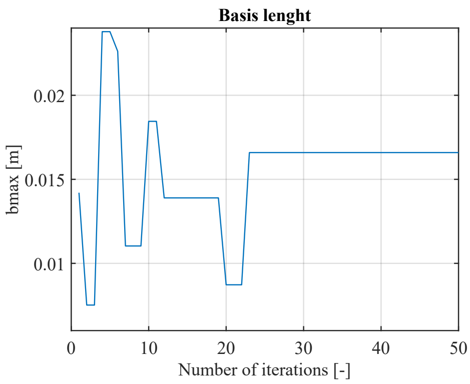
(a) Rext.



(b) Rcil.



(c) volume.

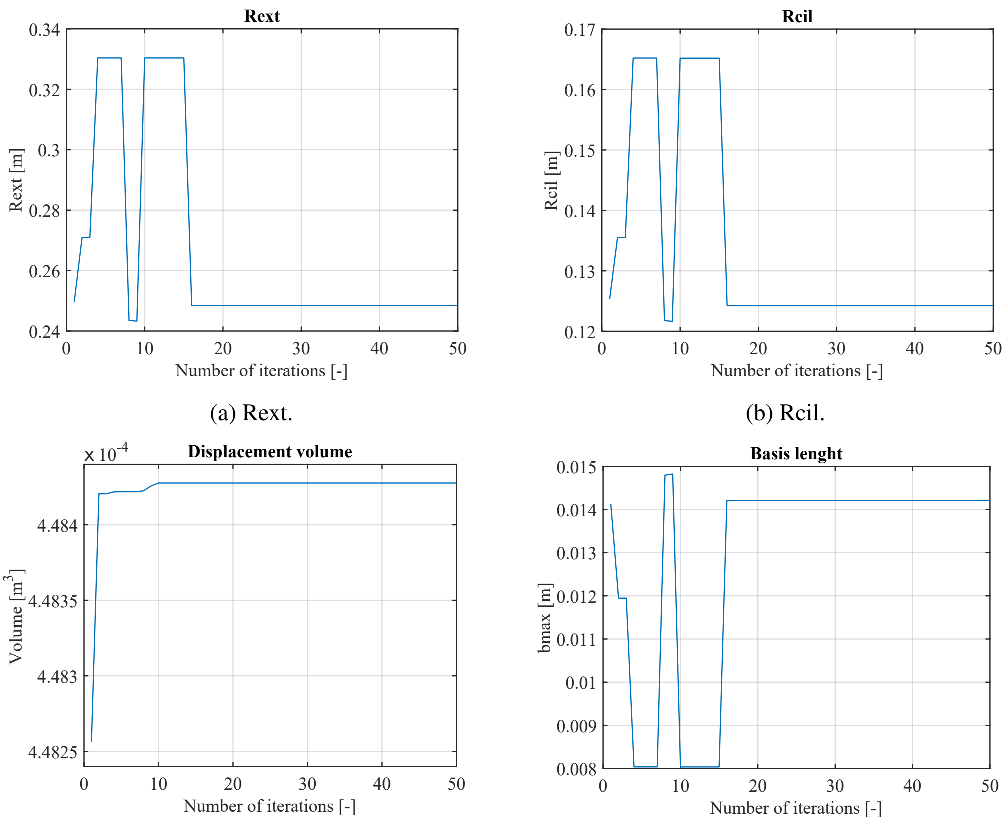


(d) bmax.

Figure 8: Test 3 evolution.

The lapsed time of Test 3 was 234.3094 seconds and its results can be seen in Fig. 8. In comparison with Test 1 and 2 the Test 3 has more changes (8 times) about the best individual population trough the iterations. The final results are similar with the others which demonstrate the robustness of the method.

The Test 4 is shown in Fig.9 and the lapsed time was 234.2321 seconds. The times of substitutions for the best individual was 6 times like as Test 1 and 2.



(a) Rext. (b) Rcil.

(c) volume. (d) bmax.

Figure 9: Test 4 evolution.

The final results about Steepest Descent method and all tests of Genetic Algorithm are put together on Tab. 3. It is possible to observe that all results of displacement volume converge to $4.4843 \cdot 10^{-4}\, m^3$ and the smaller value for $bmax$ is obtained on test 4.

Table 3: Final Results

Parameter	Steepest descent	Test 1	Test 2	Test 3	Test 4	Unit
$Rext$	0.1730	0.2392	0.2270	0.2300	0.2485	[m]
$Rcil$	0.0865	0.1196	0.1135	0.1150	0.1242	[m]
$Volume$	$4.4843 \cdot 10^{-4}$	$4.4843 \cdot 10^{-4}$	$4.4843 \cdot 10^{-4}$	$4.4843 \cdot 10^{-4}$	$4.4843 \cdot 10^{-4}$	$[m^3]$
$bmax$	0.0293	0.0153	0.0170	0.0166	0.0142	[m]

5. CONCLUSION

The proposed work chose to use optimization as a tool to obtain the maximum power of a motor compressor. By adopting a strategy with two distinct optimization models, one deterministic and one heuristic, it was possible to evaluate which method has a better answer to the problem in question.

Because of the characteristics of target function, when the displacement volume ϕ is maximum, the power is maximum as well, as developed in Eq. 6.

Both methods have converged to the same optimal displacement volume value: $4.4843 \cdot 10^{-4}\, m^3$ as can be seen in Tab. 3. The relation between $Rext$ and $Rcil$ in optimal volume condition is the constraint border $Rcil = Rext/2$ for all results. When the secondary parameter $bmax$ is considered, the best result was obtained on test 4 from Genetic Algorithm because it minimizes the space occupied by the device.

Then, even that both methods reached the objective of power optimization, the most suitable is the Genetic Algorithm because of the secondary parameter $bmax$. For future works is possible to compare to others optimization methods and get the one which is better among them.

6. REFERENCES

Colaço, M.J. and Dulikravich, G.S., 2009. "A survey of basic deterministic, heuristic and hybrid methods for single-objective optimization and response surface generation". *Thermal Measurements and Inverse Techniques*, Vol. 1, pp. 355–405.

Kussul, E., Baidyk, T. and Tapia, O.O., 2016. "Quasi isothermal heat engine for concentrating solar power systems". Vol. 4, pp. 16–26. ISSN 2328-7330. doi:10.12691/ajer-4-1-3. URL http://pubs.sciepub.com/ajer/4/1/3.

Ooi, K., 2005. "Design optimization of a rolling piston compressor for refrigerators". *Applied thermal engineering*, Vol. 25, No. 5-6, pp. 813–829.

Siston, V.G.P., 2018. "ESTUDO E DESENVOLVIMENTO DA PALHETA PARA UM NOVO MOTO-COMPRESSOR PNEUMÁTICO". Monografia (Bacharel em Engenharia de Controle e Automação), Cefet-Rj (Centro Federal de Educação Tecnológia Celso Suckow da Fonseca, UnED Nova Iguaçu), Rio de Janeiro, Brazil.

Siston, V.G.P. and Campos, G.A.P., 2017. "Study and development of the vane for a new pneumatic motor-compressor". doi:10.26678/ABCM.COBEM2017.COB17-1943.

Skinner, S., 2014. *Hydraulic Fluid Power-A Historical Timeline*. Lulu. com.

Yanagisawa, T., Shimizu, T., Chu, I. and Ishijima, K., 1982. "Motion analysis of rolling piston in rotary compressor".

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.