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Linear Compressor Discharge Manifold Design for High Thermal Efficiency

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ABSTRACT

In the design of hermetic compressors for household refrigeration, one important part of the overall efficiency of the machine comes from an optimized thermal efficiency of the discharge manifold. It is aimed that the heat generated during the compression process and heats up gas in the discharge chamber does not return to the compression chamber walls. Heating up the pump implies reducing the volumetric efficiency. Current technologies, like on/off and variable speed compressors, normally make use of metallic parts in the discharge chamber, such parts having high thermal conductivity coefficients, jeopardizing the compressor efficiency. Linear compressor technology, together with the absence of oil, allows the improvement of the discharge manifold system, increasing the thermal insulation of the heat from discharge chamber to the compression chamber, improving overall efficiency. This article aims to show the development of this improved discharge system, tests performed, and results obtained.

1. INTRODUCTION

The development of efficient machines requires from researchers a lot of work, creativity and use of computational and experimental techniques, aiming the achievement of engineering solutions proper to each application. Puff (2008) reported a new solution for a regular hermetic reciprocating compressor that improved thermal efficiency. In the industry of hermetic compressors for household and commercial refrigeration, recent advances lead to the development of new compressors, with lower size and that does not require the use of lubricating oil. The following three points are certainly the ones with major effort spent in this industry field, every time aiming to increase energy efficiency of the compressors used.

- Increase in the electrical motor’s efficiency;
- Friction and wear reduction;
- Increase in the thermal efficiency;
- Reduce pressure loss in the valves.

Going a little bit more deeply in the third one, it is well known that one of the greatest heat generation points takes place inside the cylinder, during the compression. One part of the generated heat is transmitted to the discharge chamber wall (*Wb*), and the other part is carried out by the discharge gas (*Wa*). A fraction of the heat that the gas transmits to the discharge chamber wall is transmitted to the internal compressor environment by a convection phenomenon, and the other part to the cylinder wall (*Wc*), by conduction, increasing the cylinder wall temperature and reducing the compression efficiency.

These heat fluxes can be seen in the Figure 1, for linear compressor technology with suction through the piston.

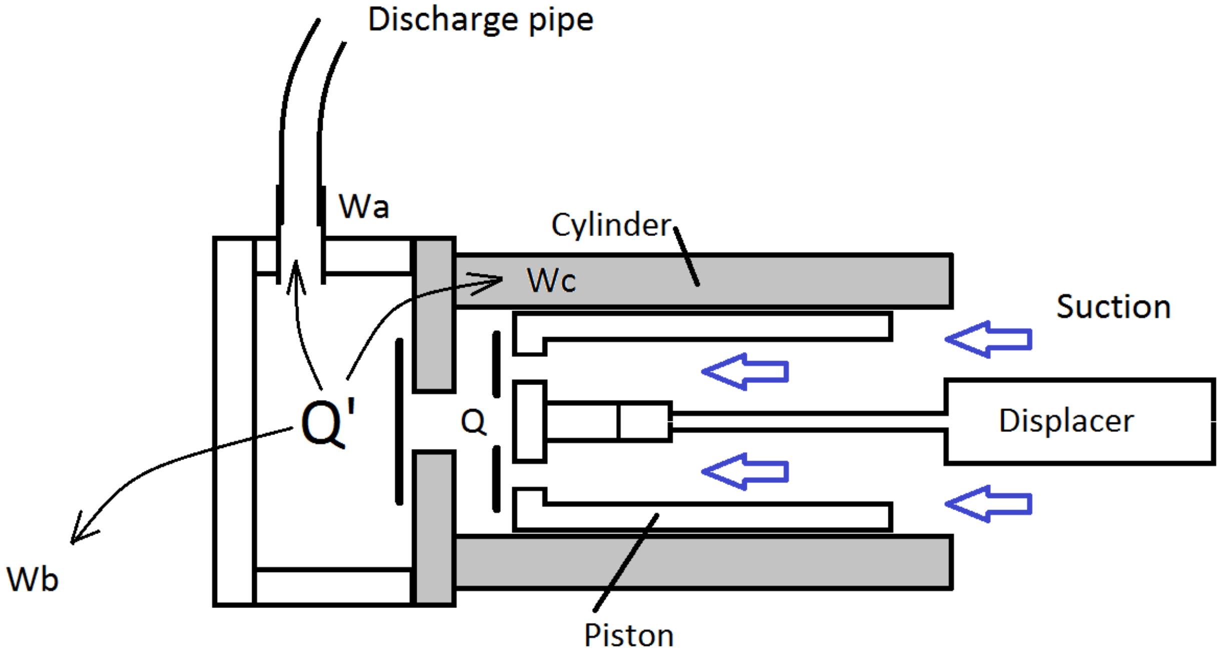

Figure 1: Heat generation and fluxes in the cylinder-manifold system.

Considering the compression efficiency reduction due to this fraction of the heat generated during the compression process which returns to the block and cylinder wall, a new design has been developed in the discharge manifold in order to reduce *Wb* and *Wc*, increasing the amount of heat that is carried by the gas (*Wa*), in that way increasing compressor efficiency.

With relation to the discharge valve pressure drop, the main solution to reduce it, is working on the geometry, flow area and number of valves. This article presents the gains coming from the discharge valve and manifold optimization as well.

2. IMPROVEMENTS IN THE DISCHARGE GAS FLOW

The reference manifold for this part of the analysis is the initial version of the linear compressor technology and which is composed by 4 discharge valves. The vapor is discharged directly into a first volume (*V1*), passing through a tube (*T1*) to the second volume (*V2*). In this reference manifold, the first volume is composed by a metallic material. From the second volume, gas is discharged to the discharge tube (*Td*), and from it to the system discharge line, out of compressor shell. This reference discharge manifold is depicted in Figure 2.

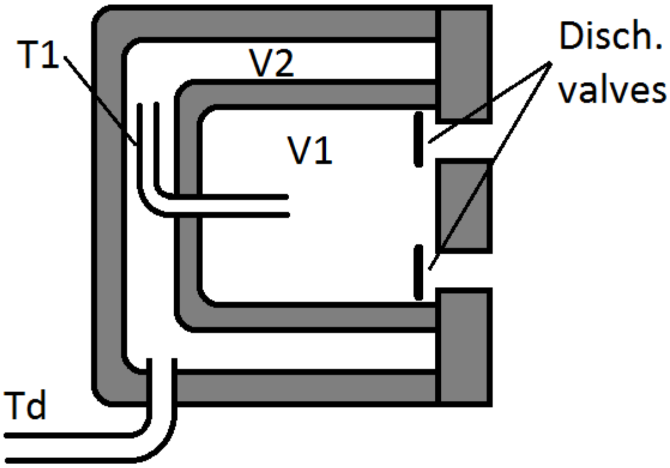

Figure 2: Schematic view of the reference discharge manifold.

The optimization work was done for the gas flow initially by performing analytic and numerical analyses in the way of testing different configurations and finding out the best arrange for minimizing the gas flow restrictions without impacting sound quality characteristics. The manifold was modeled parametrizing the main characteristics of the volumes and tube lengths. This model was implemented into an optimization procedure, using ModeFrontier commercial package and many alternatives could be simulated, aiming the minimization of the pressure pulsation and restriction for the gas flow. In addition, the experimental technique was used to measure the pressure profile in the first volume right after the valves chamber. The experiment consists in installing a pressure transducer and measuring the pressure during compressor operation. Some of the alternatives were experimented and tested using this method.

The analysis and optimization resulted in a configuration composed by 6 discharge valves. Vapor is discharged and passes through a funnel that concentrates the flux to a first volume (*V1*) of the discharge manifold. From *V1*, the vapor passes through a tube (*T1*), directed to a second volume (*V2*). From *V2*, vapor is discharged to the system's discharge line through a discharge tube (*Td*). The third volume (V3) is semi-hermetic and has thermal function as is going to be described in the next section. Figure 3 shows schematically the optimized discharge manifold configuration for this linear compressor generation.

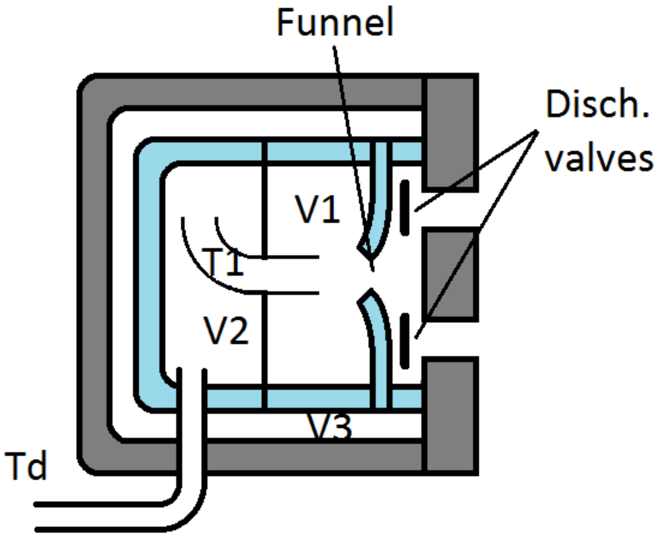

Figure 3: Schematic view of the optimized discharge manifold.

The gain obtained with the use of this optimized gas flow in discharge manifold can be observed in the graphic of Figure 4, that shows the pressure profile right ahead the discharge valves. It can be observed that the integration of the pressure for this manifold represents a reduction in discharge power of 1.2%, with relation to the reference.

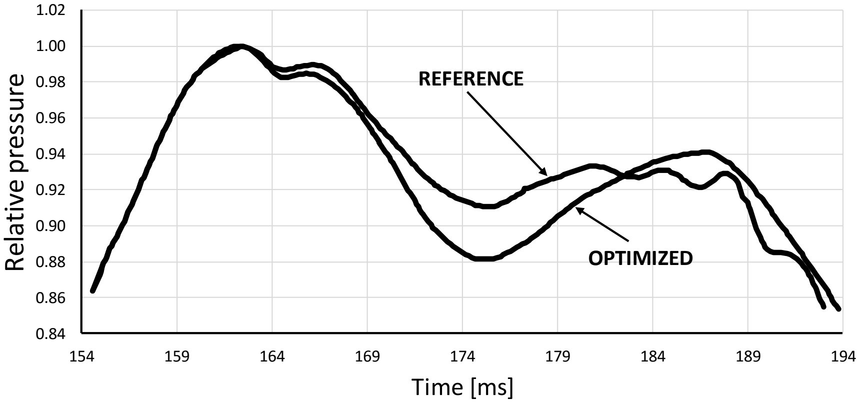

Figure 4: Pressure profile comparison between optimized discharge manifold and reference.

3. IMPROVEMENTS IN THE THERMAL EFFICIENCY

Shiva Prasad (1998) presented an excellent review of research on the effect of superheating in the reduction of thermal efficiency of compressors. The author included in his work an account about major developments of theoretical, numerical and experimental methodologies, part of them used in this work.

Ribas et al. (2008) performed a critical review of different approaches for reciprocating compressors thermal analysis they showed that gas superheating may account for up to half of the thermodynamic losses in a small reciprocating compressor. A good understanding of the compressor thermal dynamics is a requirement for the development of high efficiency compressors.

In this work, some of techniques pointed in the previous articles were used. The strategy adopted for the thermal optimization was initially mapping the compressor temperatures through thermocouples. In an equivalent way, Thermal simulation was used in order to evaluate the temperature distribution inside the compressor, in order to map the hot spots of the machine. Reference configuration is the same shown in Figure 2. It this case, the first volume is composed by a metallic material, as the second volume, which is the cylinder head wall. Both have poor thermal insulation characteristics and the amount of heat that flows to the internal compressor shell volume is high.

The absence of oil in this compressor allows, beside other features, new geometric solutions, because there is no risk that the lubricating oil becomes trapped in specific geometric points. Considering this benefit, many alternatives could be modeled and simulated using a commercial package, making it possible to find a configuration that could fit the initial purposes.

In that way, the proposed solution as well illustrated in Figure 3 for reducing pressure drop. In terms of superheating reduction, the improvement is achieved by using *V1* and *V2* manufactured in polymeric material, with low thermal conductivity. Beside that fact, there is a third volume (*V3*) semi-hermetic, with an additional thermal insulation between volumes *V1* and *V2* vs. cylinder head cover. Hot gas from the compression process is conducted through the discharge tube to the system, out of the compressor.

The optimization result was evaluated, as mentioned, by the measurement of the temperature profiles of the compressor and compared to the reference. Figure 5 illustrates in a compressor scheme the measured points, and Table 1 illustrates the experimental results for the optimized configuration.

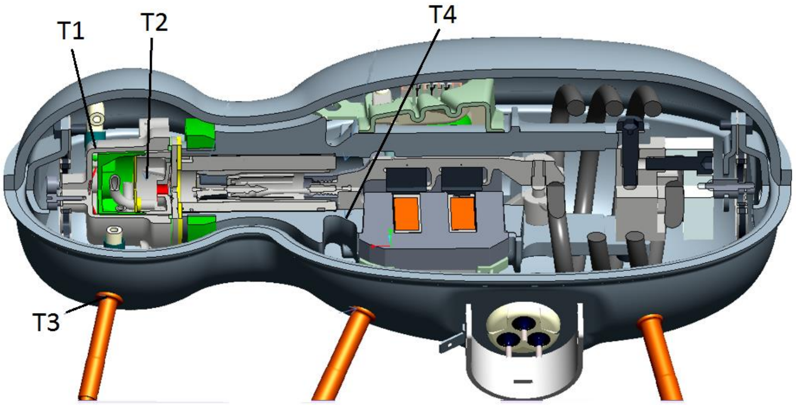

Figure 5: Thermocouples distribution inside compressor.

Table 1: Temperature results.

Thermocouple	Position	Reference	Optimized	Improvement
T_1	Cylinder head wall	109°C	85°C	- 24°C
T_2	First volume (*V1*)	119°C	119°C	0°C
T_3	Discharge pipe	74°C	96°C	+ 22°C
T_4	Block wall	51°C	54°C	+ 3°C

A final evaluation was done in terms of energy efficiency. This evaluation showed an increase of around 1% due to the new temperatures distribution, which is result of the new heat balance in the optimized discharge manifold. It can be observed that the cylinder head walls temperature (T_1) decreased 24°C, even internal volume V_1 temperature (T_2) remaining the same. This indicates that the amount of heat transmitted to the internal shell volume *Wb* is lower. In the other hand, the temperature on the discharge pipe (T_3) increased 22°C, indicating that the gas is carrying more heat *Wa* to outside the discharge line. Finally, the amount of heat transmitted to the block and cylinder did not increase significantly, indicated by the block temperature (T_4) that increased only 3°C.

4. RESULTS AND DISCUSSION

The design of the new discharge manifold for the linear compressor was performed taking into account the absence of lubricating oil. This characteristic allowed the use of new concepts in terms of materials, gas flow with lower pressure drop, and thermal barriers.

The optimization of the gas flow, with 6 valves instead of 4, and the use of the discharge funnel ahead of the first volume *V1* resulted in a decrease of 1.2% in the discharge power.

New materials like the use of polymers could be applied, with lower thermal conductivity, as well as the application of semi hermetic volumes, aiming to avoid heat conduction to the internal volume of the shell. This result is a consequence of the increase of heat carried by the gas to outside the compressor through the discharge line, and the reduction of the heat transmitted to the internal shell volume.

These thermal concepts resulted in an increase of around 1% in the thermal efficiency of the compressor.

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