2006

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# NOISE AND VIBRATION STUDIES IN A $CO_2$ COMPRESSOR

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## ABSTRACT

Many publications have pointed out Carbon Dioxide ($CO_2$) as an environmental friendly refrigerant fluid aiming to reduce the level of $CO_2$ emissions from refrigerating appliances. The possibility of replacing HFCs by employing $CO_2$ compressors has been leading the refrigeration industry to a continuos research on all the related fields. Concerning $CO_2$ application, significant progress in terms of both energy performance and reliability have been made by the optimization of the reciprocating compressor to meet $CO_2$ design demands. From a broader perspective, this paper intends to assess the acoustical performance of an energy efficient, reliable $CO_2$ reciprocating compressor through the identification of the sources and transmission paths, associating them to the overall sound level of both the compressor itself and a representative refrigerating appliance. Advanced methods are applied including numerical analysis, operational deflection shape (ODS), and acoustical holography to investigate the potential of a brand new reciprocating compressor platform designed for $CO_2$ application . The methodology employed is presented and has its scope on identifying, quantifying and judging the sources of the noise, transmission paths, and respective influences in the final radiator acoustical performance. Preliminary results point to a very positive perspective for the acoustical performance of the $CO_2$ compressor investigated, showing similar sound level when comparing to current baseline.

## 1. INTRODUCTION

Reciprocating compressors that uses $CO_2$ as refrigerant fluid operate with high pressure levels in the suction and discharge lines, and therefore the pressure transients associated are high as well. An additional feature of the $CO_2$ particular reciprocating compressor evaluated in this work is that it does not have any suspension spring to support the electrical motor which is directly connected to the shell/crankcase. Thus the compressor has a strong excitation on the mechanism, generating higher noise, vibration and pulsation levels than currently observed in refrigerating compressors.

When the above reffered $CO_2$ compressor is applied to a refrigeration system, the overall sound power level is potentially affected by the high pressure transient. However, the design of the interface beteween compressor and system components is another important sound level determinant as well. This constitutes a major challenge for noise and vibration control since the final sound level is affected not only by sound sources, but by both vibratory energy propagation paths and irradiation of several parts and components.

In order to provide an outstanding performer not only in terms of energy efficiency and reliability but in sound irradiation as well, a new approach was developed. This paper presents the methodology applied and some of the respective results.

## 2. METHODOLOGY

The first step of the methodology developed is to divide the problem into three different courses of action: sound sources, transmission paths and radiators.

Most of the main sound sources can be summarized as it follows:

- Head, including suction and discharge valves and mufflers;
- Compression mechanism, including piston, crankshaft, crankcase, bearings and oil pump;

- Electrical motor, including stator and rotor, and
- Starting system.

Regarding the transmission paths the most important ones identified are:
- Shell cavity;
- Crankcase/shell interface, and
- Suction and discharge lines.

Among the most contributing radiators are:
- Shell;
- Connecting tubes;
- Heat exchangers, including evaporator and gas cooler, and
- Metal sheets/panels.

All of the exposed above can be summarized in the figure 1 below:

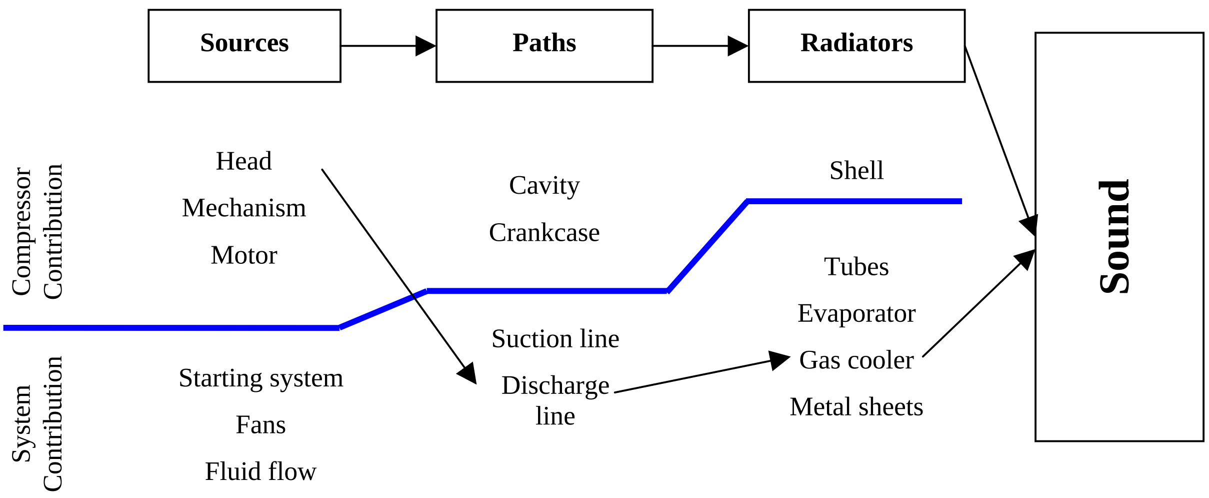



**Figure 1** – Methodology used to study the $CO_2$ compressor noise and vibration. Ilustrated is how the gas pulsations affect the sound level.

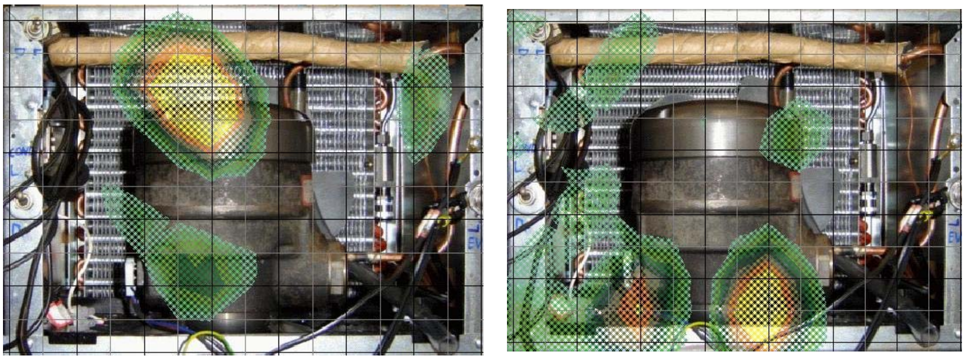
The second step is to analyze each of the interactions referred to in the figure 1. This aims to identify what of those interactions are more important and effective in the noise reduction targeted. This is the most difficult stage of the methodology. Figure 1 shows as an example an interaction involving compressor head, discharge line and gas cooler. The pulsation is generated in the compression cycle by the upward movement of the piston and valve system. The discharge line tube transports the pulsation generated to the gas cooler. The gas cooler, in its turn, has an intense radiation efficiency which amplifies this gas pulsation generating an undesired sound level.

In the third step the purpose is to find the best course of action (sound sources, transmission paths or radiators) to address the problem and reduce de sound and vibration levels.  For example, in the interaction showed in figure 1, one can have three possibilities to act upon: adding damping in the gas cooler; redesinging the discharge line geometry to attenuate the gas pulsation; or adding/increasing the discharge volume that reduces the generation of gas pulsations.

## 3. INVESTIGATION TECHNIQUES

A sort of different techniques can be used to define and identify most important interactions like: acoustical holography, ODS analyses, modal analyses, sound power measurements and others kinds of instrumentation in the compressor including pressure, force and acceleration sensors.

Acoustical holography is a powerful tool for the investigation of the sound sources and transmission paths. Figure 2 presents a picture of an acoustical holography of the $CO_2$ compressor investigated, applied in a beverage cooling vending machine at frequency of (a) 250 Hz , and (b) 3200 Hz. It can be seen the velocity at the plane of the compressor. At 250 Hz the maximum velocity is in the region of the gas cooler. This noise is generated at the compressor and is amplified by the gas cooler. At 3200 Hz the holography shows a maximum velocity at both cylinder head and electrical connectors of the compressor. This sound level can be generated by the impact of the piston in its upper and lower position.



**(a)** **(b)**

**Figure 2 –** Acoustic Holography of $CO_2$ compressor applied in a refrigeration system. (a) at 250 Hz and (b) at 3200 Hz.

Modal analysis was used to identify the natural vibration modes of the compressor shell, as showed in figure 3. The natural frequency (first vibration mode) of the upper cover is 4950 Hz. This high frequency is due to the high thickness of the shell and cover to withstand the high pressures demanded by the $CO_2$ application.

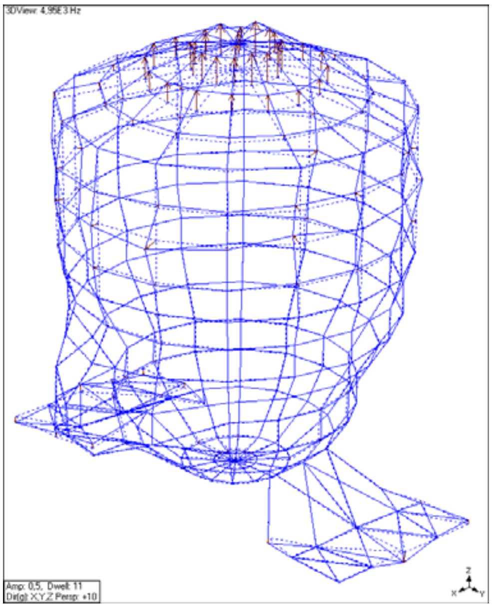


**Figure 3** – Modal analysis of the compressor showing the first mode of the upper cover at 4950 Hz.

Figure 4 is an example of an instrumentation in the $CO_2$ compressor, showing the suction and discharge valve movements during one compression cycle, and the acceleration measured in the compressor shell. One can see that the shell has two high acceleration peaks in different moments, the first one when the discharge valve is closed and a second when the suction valve is opened. This is a very important information to know how the vibratory energy transmission on the compressor flows.

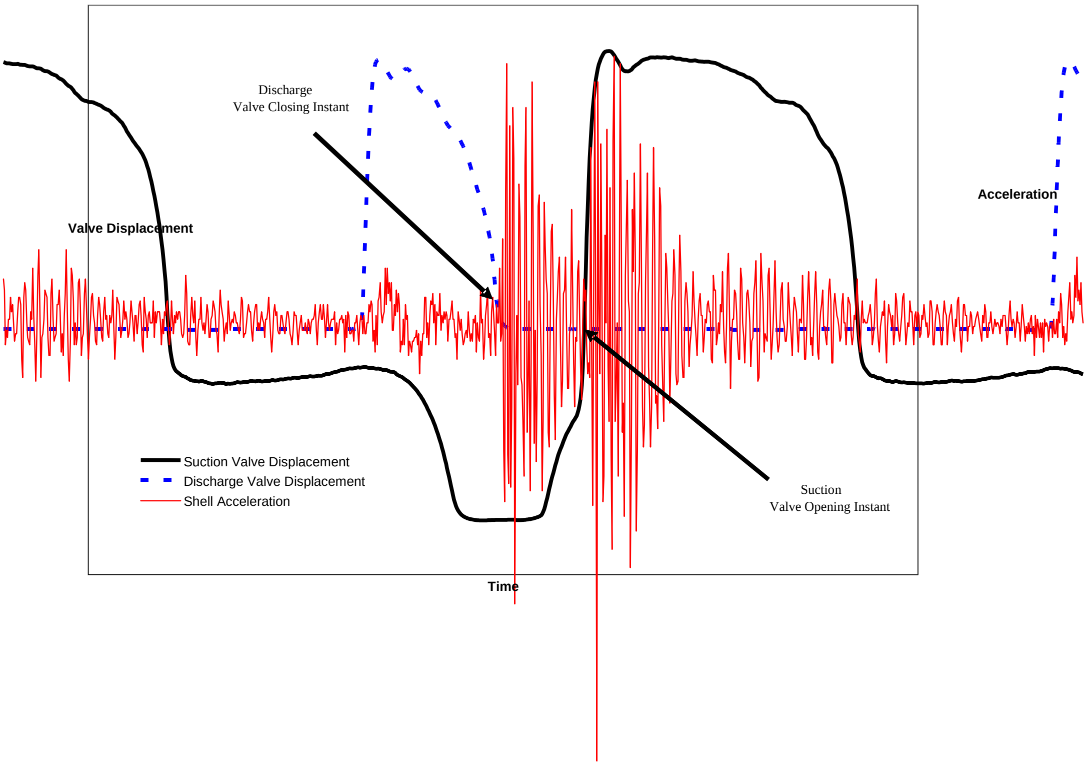



**Figure 4** – Example of instrumentation of the $CO_2$ compressor, showing valve movements and shell acceleration, in the time domain.

## 4. RESULTS

The aim of this methodology when applied to a refrigeration system is to propose design alternatives for the compressor taking into consideration the sound level and vibration targets. In this work the overall sound level of $CO_2$ compressor was decreased 9 dB, as showed in figure 5. The solid black curve in the graph is the sound level of the R134a compressor employed as a baseline for the $CO_2$ compressor.

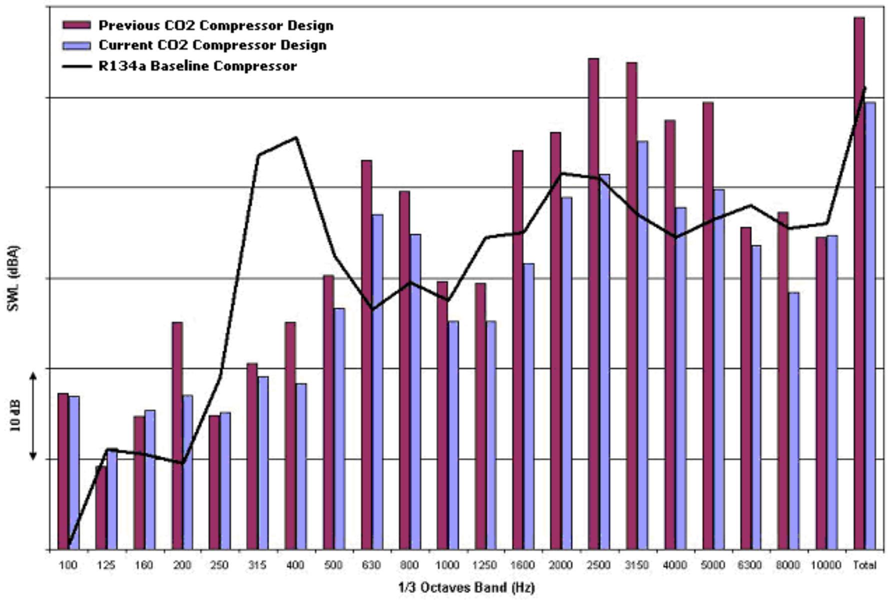



**Figure 5 –** Sound level comparison among the initial $CO_2$ compressor design, the $CO_2$ compressor design after modifications proposed by applying this methodology, and R134a baseline.

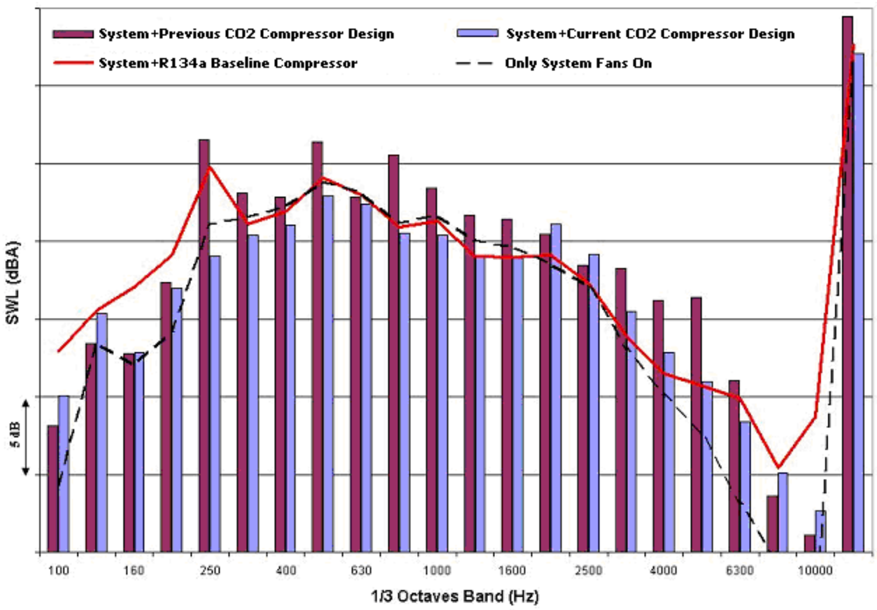



**Figure 6** – Sound level comparison among the same refrigeration system with the R1343a baseline compressor, the initial $CO_2$ compressor design, and the current $CO_2$ compressor design. It can be also seen the sound level when only the heat exchangers fans are on.

Figure 6 shows the sound level results of the $CO_2$ compressor application in a refrigeration system, particularly in a vending machine. In this picture the R134a baseline compressor, the initial $CO_2$ compressor design, and the current $CO_2$ compressor design are compared when applied each one at a time in the system referred to. It can be seen the sound level when only the system fans (gas cooler and evaporator) are on. Reducing the $CO_2$ compressor sound level (refer to figure 5) aimed the overall sound level of the system to be dropped by 2.3 dBA when compared to the initial $CO_2$ compressor design. This brougth the sound level of the system running with $CO_2$ to the same level of the baseline R134a compressor, however with a notable reduction of the sound level at the low frequency of 250 Hz. This reduction came mainly from the reduction of the discharge line pulsation in the same frequency. Figure t illustrates the discharge gas pulsation reduction.

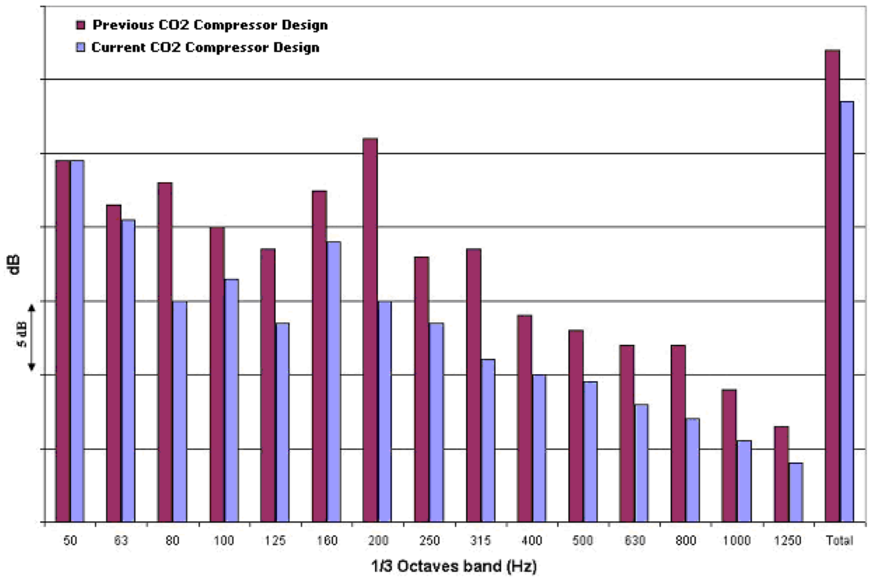



**Figure 7** – Comparison of the discharge line pulsation between initial and current $CO_2$ compressor design.

## 5. CONCLUSIONS

- This paper presented a very powerful methodology to improve the acoustical performance of a $CO_2$ compressor and or a $CO_2$ refrigeration system. The methodology applies to all the refrigerant fluids currently in use but particular attention was given to $CO_2$ in order to demistify its application in ligth commercial refrigeration. Current HFC sound levels acan be achieved in $CO_2$ application emplying the proper methodology.

- A $CO_2$ compressor design was investigated in face of a R134a baseline compressor acoustical performance. Based on the methodology presented, a reduction of 9 dB in the $CO_2$ compressor design was achieved showing a competitive performance to current compressors. The sound quality was improved as well and as a consequence of the sound level reduction in a frequency band highly perceivable by the final end-user.

- Embraco's acoustical laboratory is prepared to help the refrigeration industry, and mainly its customers, to improving the system sound levels and the overall sound quality.

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## ACKNOWLEDGEMENT


We acknowledge all the invloved people in this work, particularly Edson Miguel and Luciano Oliveira, both of them co-authors of this paper, for their outstanding contributions and dedication in the acoustics laboratory at Embraco.