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Noise Characteristics Improvements for a New Generation of Variable Capacity Compressor using Linear Motor Technology

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ABSTRACT

The household appliances market noise levels requirements have rapidly increased in the last years. Despite the traditional approach for defining noise requirements focused on steady-state sound power levels, the transient noise is becoming a key factor in defining sound quality specification. Variable speed compressor technologies lead to a significant advantage on this aspect since in standard operation conditions the compressor runs at relatively low speeds for most of the time. Linear motor driven reciprocating compressors present great advantages since this technology allows dealing with cooling capacity variation without changing the motor speed. This allows also easier and more effective design of lower noise generation. This paper presents the benefits of the variable capacity, linear motor driven reciprocating compressors over rotary motor driven reciprocating compressors, either at variable capacity and fixed speeds. Emphasis is given to the physical phenomena and engineering advantages of the linear motor concept.

1. INTRODUCTION

In recent years nongovernmental organizations were created with the objective of helping consumers in many ways. One of these is related to noise pollution which results in sleep disturbance (Goines, 2007; Fidell *et al*, 1995). Sleep interruption can cause physiologic and mental disorder such as increased blood pressure and depressed mood. The sleep interruption can be caused by transient noises, for example, the ones caused by the starting of a refrigerator compressor. This shows the importance of improving the acoustic characteristics of home appliances. This paper analyses the characteristics of variable capacity linear motor driven reciprocating compressors, either at variable and fixed speeds, and the improve in sound quality.

Variable compressors showed significant improvements in performance in the last years (Krueger, 1994; Lee, 2000). A compressor running at different rotational speeds with constant stroke displacement can provide variable cooling capacity to refrigerators. Higher speeds are required for greater thermal charges and it may run at lower speeds at steady state refrigeration condition. This led to an evolution on sound quality assessment due to a reduction on steady state and starting noise levels. Figure 1 shows an example of close correlation between the radiated sound power level (SWL) and cooling capacity at check-point testing condition. Each point in that chart represent an average sound power level of one variable speed compressor model running at a specific rotation speed that provide an specific cooling capacity. Different models are used to create this chart. Cooling capacity measurements are made with compressor stand alone according international standards ARI540, EN12900 and ASHRAE, depending of the application and market. Sound power measurements are performed with the same standards used for calorimeter in a precision grade reverberant acoustic chamber according ISO 3741. Absolute scale was hidden due confidentiality and to avoid commercialism.

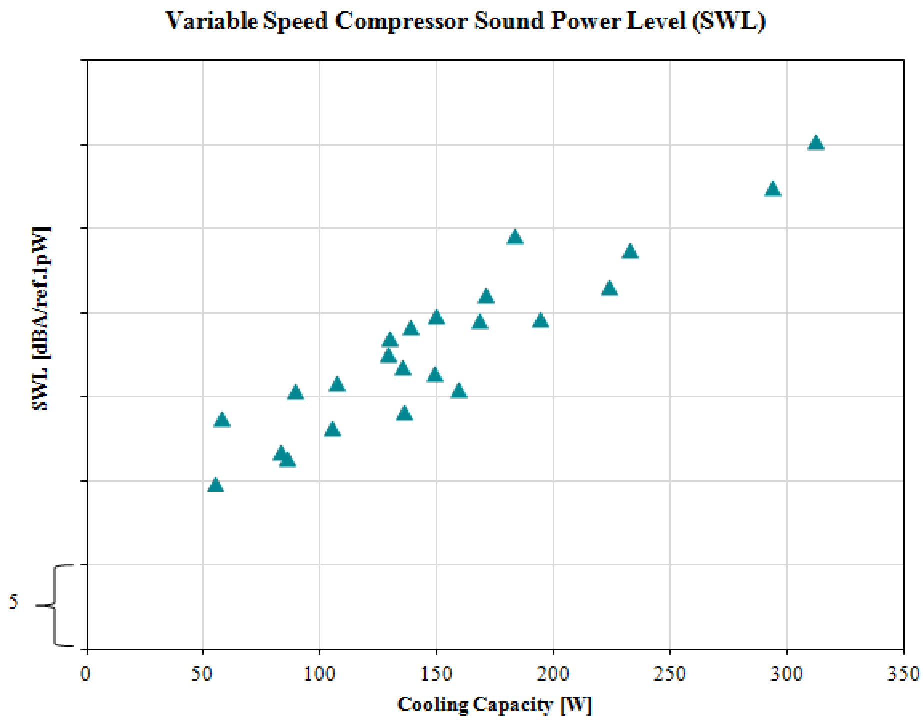

Figure 1 - Variable speed compressor noise as a function of cooling capacity at check-point test conditions.

This shows the benefits on noise radiation at steady state operation condition of variable speed compressors compared to on/off compressors. Conventional variable speed compressors however have some disadvantages. They operate smoothly when the suction and discharge pressures are equalized, but it takes some time to reach these pressures. For instance, they start at a rotational speed of about 3000rpm, it means high cooling capacity, for a few seconds, which is reduced to a lower speed about 2000rpm, lower cooling capacity, also for some seconds and finally settles at the set point rotational speed, according with refrigerator control strategy. The noise radiation at this initial transient regime can be significantly high.

Another disadvantage of conventional variable speed compressors is the increasing noise level with cooling capacity, as showed at Figure 1. It means that the same variable speed compressor the sound power level increases till 10dB from minimum to maximum cooling capacity. Variable speed compressors driven by linear motor can reduce this disadvantage.

2. LINEAR CONCEPT

The scheme of the variable capacity compressor driven by linear motor is shown in Figure 2. The principle of operation of this compressor is very simple. An electronic device supply the power modulated at the resonant frequency of the mass / spring system which is composed of the “fixed structure” (electric motor, cylinder, cylinder head, spring support and shell), the resonant spring and the moving components (piston, magnets and their support).

An inductive sensor monitors the piston displacement providing feedback information to the control system. The variable capacity is obtained by controlling the piston displacement.

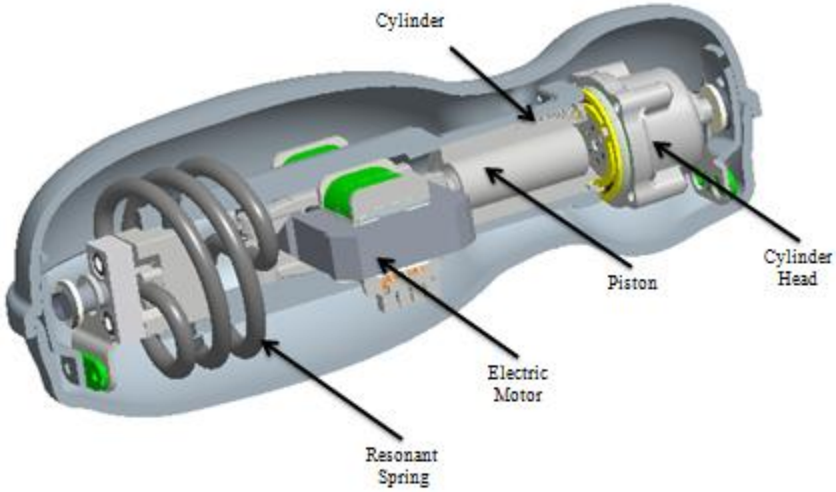

Figure 2 - Variable capacity linear motor driven scheme.

Figure 3 shows a height comparison between midi variable speed, mini variable speed and linear variable capacity compressors. This reduction is possible due the linear concept, and also able the noise improvements by reducing of the radiation shell area.

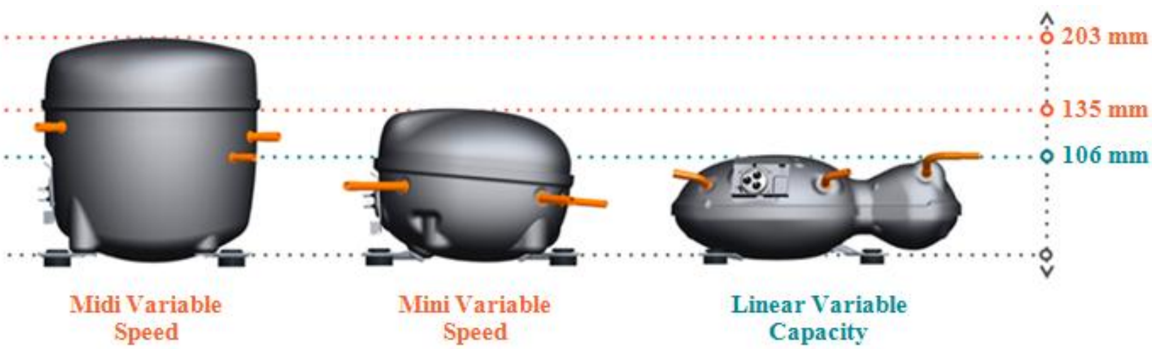

Figure 3 - Variable capacity linear driven compressor comparison with current variable speed technology.

3. STARTING NOISE

At the starting process of a conventional compressor with rotating motor the maximum displacement is reached already at the first cycle due to constant stroke. This leads to a need for a more robust motor design to overcome the inertial forces at the first cycle. If the application demands a non-equalized pressure start, the starting motor torque must be larger. This becomes apparent at the starting noise generated by the compressor.

The concept of variable capacity linear motor driven compressor allows it to start smoothly with small piston displacements. At each cycle the piston displacement increases a small proportion until it reaches the maximum stroke according a desired desirable cooling capacity. That behavior creates a soft and constant starting noise without peaks and run-up, or acceleration noise.

Figure 4 shows a comparison of the sound pressure levels (SPL) for the first four minutes of the variable capacity linear motor driven and a conventional variable speed compressor measured in a reverberation room at one meter from compressor and at one meter above floor. To construct this curve the global sound pressure level was measured in the range from 100 Hz to 10 kHz once per second, starting three seconds before compressor starting instant. The suction and discharge pressure conditions were not equalized and cooling capacities were equivalent.

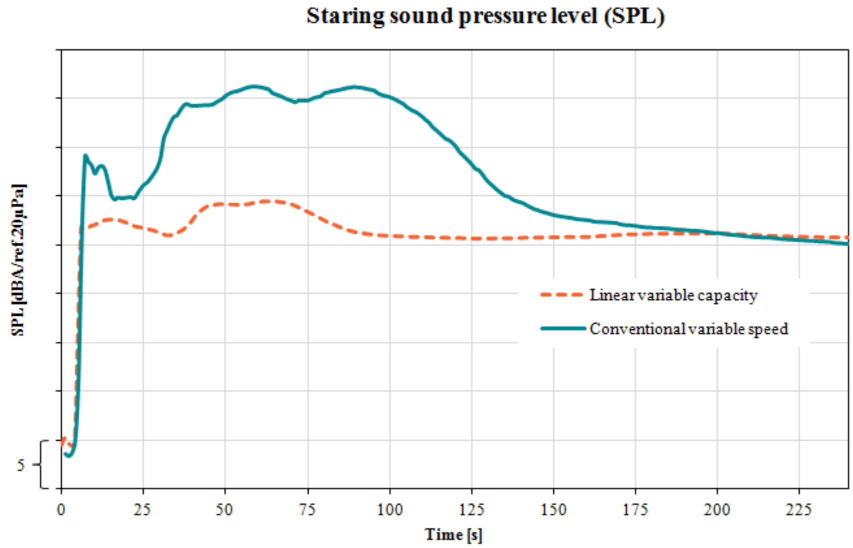

Figure 4 - Starting sound pressure level comparison.

Is possible to see at Figure 4 that the conventional variable speed compressor present a high peek of six seconds duration at the starting moment and a second peek of longer duration, nearly two minutes, with level 10dB higher compared to the variable capacity compressor driven by linear motor. The conventional variable speed compressor needs at least three minutes to reach the same sound pressure level that is reached by the linear compressor from the starting instant.

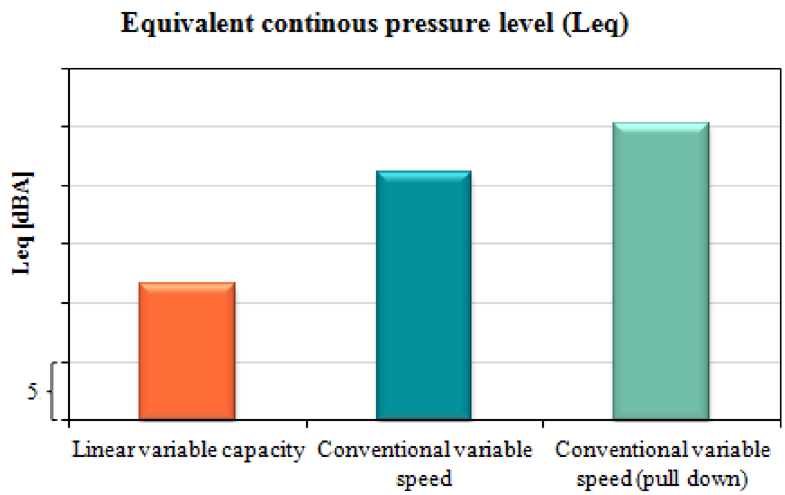

Figure 5 - Equivalent continuous sound pressure levels for compressor starting instant.

The equivalent continuous sound pressure level (Leq) related to the first four minutes radiating from a variable capacity compressor driven by linear motor is 10dB lower than that of a conventional variable speed compressor at the same conditions. This difference increases to 15dB for pull down condition, as shown in Figure 5.

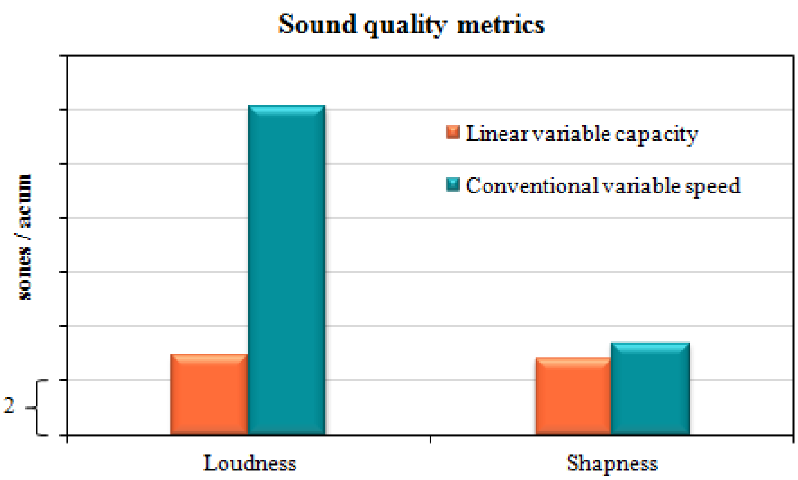

Figure 6 - Sound quality metrics for compressor starting.

Figure 6 shows results of two sound quality metrics calculation, loudness and sharpness, for both compressors starting process noise. It can be seen that the variable capacity linear motor driven compressor presents great advantage with regards to loudness metric. Based on this result one can conclude that the starting process noise of this compressor has an improved sound quality from the customer point of view.

4. NOISE VARIATION WITH COOLING CAPACITY

The linear motor concept has also an important characteristic which is the fairly constant noise radiation as function of the cooling capacity. Figure 7 shows steady state sound power level results of the variable capacity liner motor driven compressor for different cooling capacities. It can be seen an increase of less than 2dB when the cooling capacity is increased from 100W to 250W. This figure shows also an increase of about 10dB in sound power levels of a typical conventional variable speed compressor for a similar variation in cooling capacity.

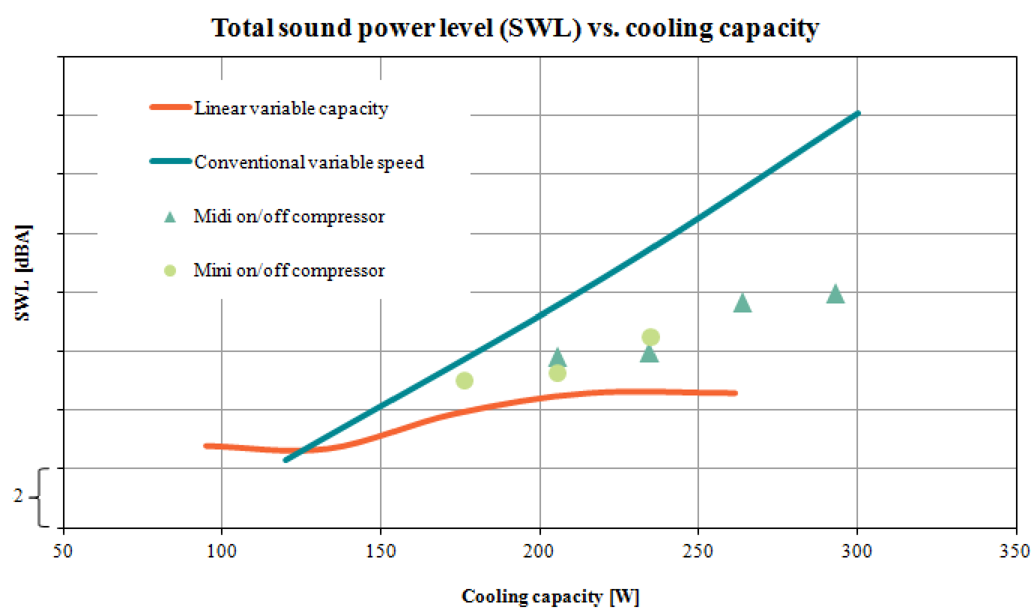

Figure 7 - Total sound power level of linear compressor in function of cooling capacity.

5. CONCLUSIONS

This paper presented two significant noise characteristics of the variable capacity linear motor driven compressor which improve the sound quality from a final customer point of view. The first one is related to the quitter starting process of this compressor even for different pressures at suction and discharge lines.

The second advantage of this compressor compared to conventional technology is the tendency to constant noise levels for a significant cooling capacity range. This enables the design of refrigerators with fairly acoustic performance for different thermal loads, leading to improved sound quality assessment by the final customer.

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