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CHARACTERIZING OF ACOUSTIC RADIATION OF HERMETIC RECIPROCATING COMPRESSOR USING VIBRATION MEASUREMENTS

L. Gavric

CETIM, 52 av Felix Louat, 60304, Senlis, France

Tel.: 03 44 67 33 66 / Fax: 03 44 67 36 17 / Email: leon.gavric@cetim.fr

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ABSTRACT
Noise and vibration performance of refrigerating and air-conditioning machinery and systems becomes a very important selling argument. The main vibro-acoustic source of such machinery is refrigerant compressor. Two principal components of the noise generation by the compressor can be distinguished: the noise directly radiated by the compressor and the noise transmitted to the machinery in the form of structure-borne and fluide-borne vibro-acoustic energy. The relative contribution of the different noise components depends on the type of compressor considered. The paper deals with a method of vibro-acoustic characterisation of small size refrigerant compressors. The sound power level radiated by the compressor shell, the vibration of the pipe fixations and the vibration of feet can be evaluated using the 6 accelerometer antenna/array and the post processing described in the paper.

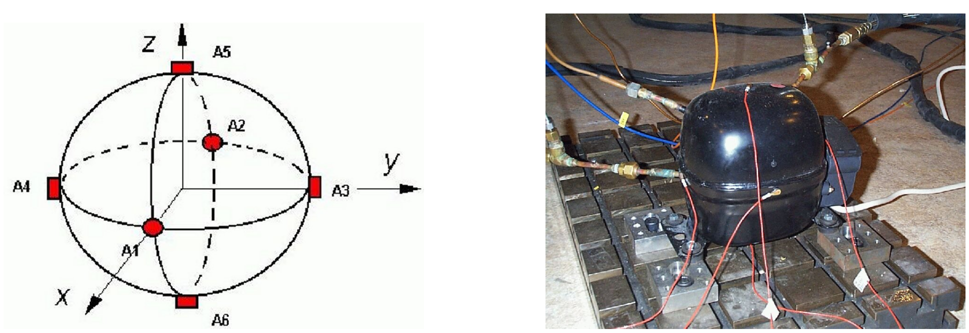
1 - NOISE GENERATION AND TRANSMISSION MECHANISMS
Hermetic reciprocating piston compressors are chosen to drive the refrigerating circuit for a number of refrigerating and air-conditioning machines of a small and medium size. This is an approved and reliable compressor technology. The hermetic piston compressor is a relatively compact machine. From the mechanic point of view, two principal elements of the small refrigerant compressor can be distinguished. One is the hermetically sealed compressor shell and the other is the compressing mechanism, linked to an electric motor drive. The two mechanical sub-systems are connected by the springs and by the discharge pipe. These create an elastic system, which suspends the electric drive and compressing mechanism, inside of the compressor shell. The high frequency vibration and the structure borne sound are transmitted through these link elements to the compressor shell. The transfer of vibro-acoustic energy through the springs and internal pipes can be referred as mechanical vibro-acoustic transmission.
From the acoustic point of view the shell cavity represents the sound transmission element between the compression mechanism and the external shell. The energy transmission phenomena rely on the resonance/modal behaviour of the cavity. The interior of the acoustic shell is filled with a refrigerant gas. The suction of the compressing mechanism creates the fluctuation of the pressure inside of the shell cavity. This phenomenon is known as compressor gas pulsation. Inside of the shell the multiple reflection of acoustic field is created. Consequently, the modal behaviour inside of the compressor shell can be observed. The pressure pulsation exert an additional vibro-acoustic excitation of the compressor shell. The similar transmission phenomenon can be observed when a lubrication oil bath of compressor is considered. The resonance of the oil bath can lead to the significant sound transmission. The paper deals with a vibro-acoustic characterisation of small refrigerant compressors used for home refrigerators.

2 - REFRIGERANT COMPRESSOR AS A NOISE SOURCE
The compressor is the source of airborne, of fluid-borne and of structure-borne sound. The airborne sound is created by the vibration of hermetic shell. The simplest modes of the compressor shell vibration are rigid body modes. There are 3 rigid body modes which can efficiently radiate the sound. Each corresponds to the displacement in one of 3 principal directions X, Y and Z. The rest of the vibration movement of the shell can be approximated by breathing deformation of the shell. The 4 principal modes

correspond to 4 simple acoustic sources: 3 dipoles and 1 monopole, [1]. The sound power generate by such complex sources is equal to the sum of the powers of its 4 constitutive elementary sources. The amplitudes of the constitutive sources can be computed using an appropriate software for simulation of the vibro-acoustic behaviour of small refrigerator compressors [2], [3], [4]. The conventional FEM/BEM software can, also, be used for this purpose. In such a case a supplementary knowledge on the thermodynamic and on the mechanic behaviour of the compressor is needed. The simulations should be carried out for all the relevant working conditions of the compressor. The shell vibration generates the structure-borne sound. The structure borne sound is transmitted by the pipe walls which are connected to the compressor shell. Generally, the compressor is mounted on resilient elements. The elastic mounts transmit the vibration of the compressor legs/fixations to the refrigerator cabinet. The significant gas pulsation is observed at the outlet of the compressor. It is transmitted by the discharge pipe in a form of fluid-borne sound. The theoretical model of the one-dimensional acoustic field is valid within the discharge line. Due to the reflection phenomena standing waves can occur. The spatial average of the gas pulsation seem to be most appropriate quantity for characterising/ranking the fluid-borne sound generated by refrigerant compressors.

3 - VIBRO-ACOUSTIC CHARACTERISATION OF COMPRESSOR

The manufacturers characterise the vibro-acoustic behaviour of their hermetic compressors by: the sound power level, the vibration measured at the pipe connections, the vibration of compressor feet and the gas pulsation measured at inlet and discharge of compressor. Such, characterisation methodology gives very complete information on the compressor as the source of airborne, of fluid-borne and of structure-borne sound. The drawback this experimental strategy is use of a large number of different transducers and an exhaustive measurement campaign for each noise component (fluid-borne, structure-borne and airborne).
The fluid-borne noise emitted by the compressor is characterised using the gas pulsation measurements. The gas pulsation readings depend on the measurement point position. Using a 3 transducer antenna/array a spatial averaged of gas pulsation in a refrigeration line can be evaluated.
The structure-borne noise levels are measured using the accelerometers and a FFT analyser. For an exhaustive characterisation of the compressor as a structure-borne source the number of the accelerometers needed and the corresponding channels can be prohibitive. For example, if 3 direction measurements are needed to be measured simultaneously for 4 compressor feet and 2 pipe connections, 18channels/accelerometers are needed.
The airborne noise is characterised by the sound power level. It can be evaluated by applying well known conventional methods: using sound pressure levels measured in reverberant or in anechoïc chamber or by integrating the sound intensity readings over a closed surface containing the source.
In this paper an experimental method for evaluating the airborne and structure-borne noise generated by the compressor is presented. The method is based on 6 accelerometer measurements. The method decomposes the vibration of the shell in 4 elementary vibration movements: 3 "rigid body" displacements and "breathing" shell deformation.

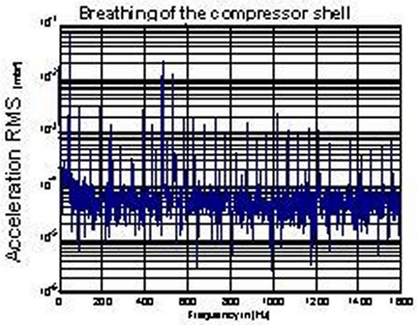


(a): Schematic presentation of 6 accelerometers antenna/array.

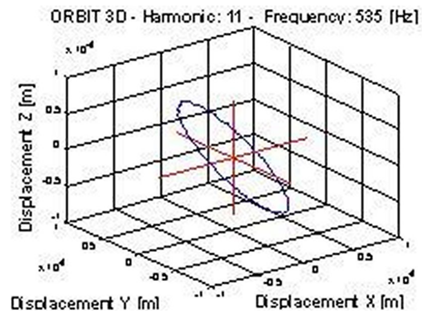
(b): Measurement antenna/array applied to a small refrigerant compressor.

Figure 1: The 6 accelerometer antenna/array.

The "rigid body" vibration can be used to compute the orbit/trajectory of the centre of gravity of compressor. Using an appropriate post −treatment of measurement results the vibration at any point of the compressor shell can be evaluated. For the structure-borne noise characterisation, the points of suction and discharge pipes and feet fixation are of particular interest. The vibration due to the breathing of the compressor shell is presented in Figure 2. Two harmonics 10-th and 11-th corresponding to the 500 Hz 1/3 octave band are particularly present in the auto-spectrum



(a): Auto-spectrum of breathing vibration of the compressor shell.



(b): Trajectory of the centre of gravity of the compressor.

Figure 2: The 11-th harmonic (535 Hz) is analysed.

The measured data can be used to characterise the airborne noise using a specific post-treatment. The method is based on modelling the acoustic radiation of compressor shell by 4 simple acoustic sources − 1 monopole and 3 dipoles. The monopole accounts for the change of the volume of the compressor shell, known as shell "breathing", while each of 3 dipole stands for the "rigid body" vibration movements in the direction of one of 3 principle axe − X, Y and Z. The amplitudes of vibration corresponding to the 4 simple acoustic sources are computed from the measurement results. The sound power level is then evaluated by the superposition of the sound power levels of the 4 simple acoustic sources. The method is applied on a small refrigerator compressor ∼0.12 kW. The same quantity is measured using the intensity probe and a measurement procedure described in ISO − 9614-1 standard. The obtained results are discussed.

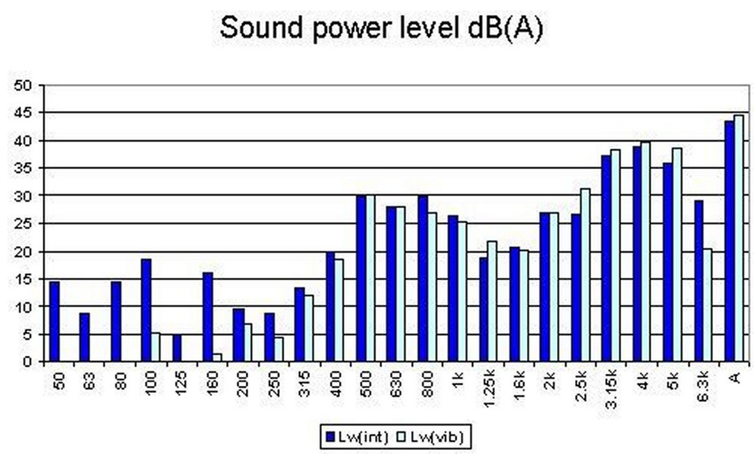


Figure 3: Sound power level radiated by a refrigerant compressor; dark columns − results obtained using the intensity measurement; light columns − results obtained using the vibration measurements and the computation procedure described in the paper.

4 - CONCLUDING REMARKS

For the moment, the 6 accelerometer method is applied to 9 different small and medium size refrigerant compressors for refrigeration and air-conditioning applications. The obtained results are very encouraging. The developed method gives excellent results for the evaluation of sound power level and for the vibration level at the pipe fixation points.

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