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VIBROACOUSTIC CHARACTERIZATION OF REFRIGERATING COMPRESSORS AS A FUNCTION OF OPERATING CONDITIONS

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ABSTRACT
The paper deals with experimental vibroacoustic characterisation of refrigerant compressors. Three commercially available compressors have been tested for different operating conditions. The selected compressors are based on two compression technologies – piston and "scroll". The measurements have been performed on compressors running under steady state thermodynamic conditions. Temperature and pressure parameters corresponding to heating and air-conditioning applications have been used. Sound power level, gas pulsation in suction and discharge lines, vibration of compressor shell, pipe fixations and feet are evaluated.

1 - INTRODUCTION
In the growing air-conditioning market, one of the most important demand considers the low noise performances of the equipment. The individual house air-conditioning/heating systems are one of the most sensitive markets when acoustic is considered. To improve the noise and vibration performance of such machinery, manufacturers need information about the main vibroacoustic source: the refrigerant compressor. Related physical phenomena which may cause noise problems are vibration of pipes and compressor feet, gas pulsation in suction and discharge pipes and sound radiated by the compressor shell. Different vibroacoustic measurement procedures are used to characterise the noise transmitted by the compressor to the machinery in the form of air-borne, fluid-borne and structure-borne vibroacoustic energy.

2 - VIBROACOUSTIC CHARACTERISATION AND OPERATING CONDITIONS
In order to characterise the noise directly radiated by the compressor and the noise transmitted to the machinery in the form of structure-borne and fluid-borne energy, a vibroacoustic measurement procedure has been defined using a specific test-rig. The vibroacoustic behaviour of compressor depends on thermodynamic operating conditions. The selected compressors are tested for three thermodynamic points. The first thermodynamic point AC1 corresponds to the air-conditioning application of compressor. It is characterised by a low compression ratio (ratio: discharge pressure / suction pressure). The last two thermodynamic points (denoted by HE1 and HE2) correspond to regular and low (external) temperature heating. They are characterised by a medium and high compression ratio, respectively. Two of selected compressors are based on "scroll" technology, while the third one is a piston compressor. The cooling capacities of the three selected compressors are about 10 kW when running under ARI standard thermodynamic conditions. All the tested compressors are using R22 refrigerant. The radiated sound power level, gas pulsation and vibration are evaluated and compared in terms of amplitudes and frequency distributions for chosen operating conditions.

3 - GAS PULSATION RESULTS
The fluid borne noise, emitted by compressor is characterised using spatial average of gas pulsation amplitudes. The spatial average of gas pulsation is evaluated using a three transducers array. Such

Figure 1: The test-rig for vibroacoustic characterisation of refrigerant compressors under controlled operating conditions.

transducer antenna account for the interaction of incident and reflected waves. Measurement results indicate that the energy of gas pulsation is concentrated within frequency range [0-800] Hz (about 20 harmonics). Approximately twenty dB difference between the lowest and the highest harmonic can be observed for all operating conditions in the frequency range of interest. The amplitudes of discharge gas pulsation are 20 dB higher than suction ones. In order to compare different compressors and operating conditions, the spatial average of gas pulsation can be integrated in the frequency range of interest. The integrated discharge spatial average increases with compression ratio for scroll compressor while decreases for piston compressor. The frequency distribution of gas pulsation depends on compressor technology.

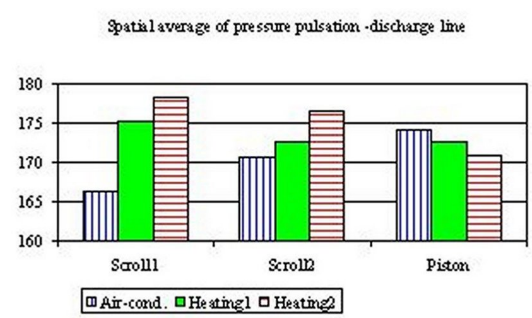


Figure 2: Spatial average of pressure pulsation measured with a 3 transducer array, integrated over [0-800] Hz frequency domain.

4 - VIBRATION OF PIPE CONNECTIONS AND FEET

Vibration of compressor shell, pipes and feet are measured in three directions. The vibration measured at the upper part of the shell is 10 to 20 dB higher than the vibration on bottom or side of the scroll compressor. It increases with the compression ratio. It seems to be generated by the gas pulsation in discharge line of scroll compressor. For the piston compressor, vibration of shell seems to be partially induced by the suction gas pulsation. Vibration depends on modal behaviour of the shell for both compressor technologies. Frequency of lowest shell mode of scroll compressor is about 2.5 kHz. First eigen frequency of the hermetic shell of piston compressor is situated between 1.5 to 2.0 kHz.

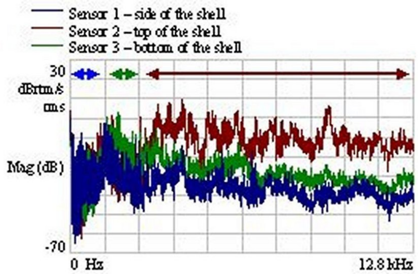


Figure 3(a): Vibration measured on compressor shell at different positions.

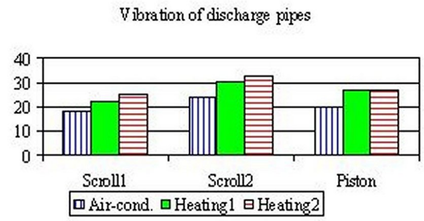
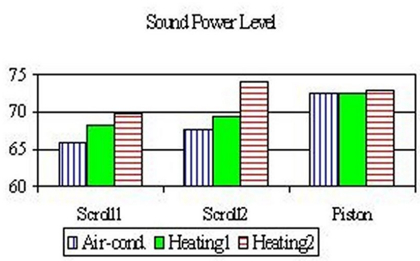


Figure 3(b): Vibration of discharge pipes integrated over [0-10] kHz frequency band.

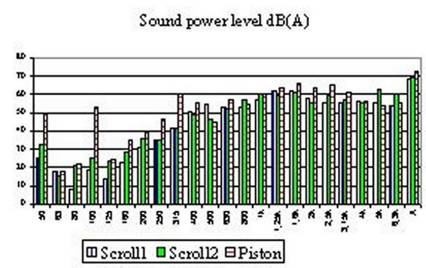
The feet and pipe vibration are mostly generated by the shell vibration. Generally, the highest vibration amplitudes are measured at the discharge pipe connection.

5 - SOUND POWER LEVEL

Intensimetry probe is used to evaluate sound power level according to the standard ISO 9614. The measurement mesh of 20 points is used. The measurement results are given in a form of A-weighted third octave band.



(a): Integrated dB(A) level for different compressors and operating conditions.



(b): Third octave band spectra of the three selected compressors for HE1 operating condition.

Figure 4: Sound power level measured using intensity probe.

For the same operating conditions, different compressors radiate different sound power. The sound power level, also depend on operating conditions. For example, sound power levels corresponding to air-conditioning (AC1) and to low temperature heating (HE2) conditions may differ more than 6 dB(A). The sound power spectra are characterised by important energy at medium and high frequencies. The sound power level of scroll compressor increases with the compression ratio while the sound power level of piston compressor stays constant. Low frequency energy, corresponding to first harmonics – 50 and 100 Hz, is relatively high for piston technology compressor. Low frequencies are more difficult to deal with using passive acoustic attenuation measures. Generally, the piston compressor radiates largest amount of acoustic energy for all operating conditions. Only for high compression ratios, the scroll compressor may radiate more sound power than piston compressor (see fig. 4).

6 - CONCLUSION

Measurements were performed on several compressors running under steady state conditions in order to obtain their vibroacoustic characteristics. Different procedures were selected to evaluate sound power level, gas pulsation in suction and discharge lines and vibration of compressors. The vibration, gas pulsation and sound radiation are measured for different operating conditions. The frequency distribution of the radiated noise depends on compressor technology. The vibroacoustic characterisation of compressor and understanding of the physical phenomena involved in sound generation and transmission are necessary for noise reduction of refrigerating and air-conditioning machinery.

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