Acoustic Features of the Reciprocating Refrigeration Compressors

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ABSTRACT

The A weighted sound pressure level permits only the judgement of sounds that have particularly negative effects. Measuring sounds by means of 1/3 octave spectrum gives hardly the complete information. Often such a measurement does not tell anything about sound quality. Binaural signal processing takes advantage of the directional hearing selectivity. Audible observations with sound power measurements can yield information for efficient sound quality engineering and quiter design of products.

This study describes the successful endeavor of identification of the noise sources of reciprocating compressors. Studies based on the analysis of acoustic radiation both in the time and frequency domain and consideration of the binaural analysis techniques and acoustic holography. Depending on the transient characteristics of noise, signals are most easily analyzed in the time domain where they can be analyzed on a cycle to cycle basis.

2. INTRODUCTION

A unique ability of human hearing is its selectivity, such as the identification of single sounds. Binaural digital signal processing within a computer controlled measuring system allows input, storage and processing of an event and listening to selected segments that can be continuously repeated without audible artifacts. The measuring system displays both right and left ear signals in the time and frequency domains. The sound segment sample can then be directly manipulated with the result being displayed and reproduced by headphones in "real time."

Compressor noise depending on the operating principles and the design features has had impulsive characteristics. Therefore, behind the inspection signal characteristics, time of occurrence, spectrum and amplitude from each location and the binaural recording and replaying and further analysis of the acoustic holography may be considered as efficient tools to understand the nature and radiation characteristics of the compressor noise.

3.NOISE SOURCES AND CHARACTERISTICS

3.1.Operating Principles

The hermetically sealed motor compressor comprises, in general a motor compressor unit including a motor assembly mounted with a frame and sealed housing within which the motor compressor is supported by coil springs each having one end spring with the frame and the other end connected with the interior of housing.

Refrigerant gas is introduced from the suction coupling into the sealed casing is led directly into top end of the compressor cylinder through the suction muffler at a low temperature to minimize the influence of the heating.

3.2.Noise Sources

Depending on the noise events in reciprocating refrigeration compressors, grasping the acoustical features of reciprocating compressor is not such an easy task for the engineers. Noise in a reciprocating compressor generally arises during the cyclic compression, discharge expansion and suction processes. The character of noise sources is harmonic due to the periodic nature of the compression process. The rest of the noise sources in reciprocating compressors are turbulent nature of the refrigerant gas flow occur due to the passage through valve ports, secondly, valve impacts on their seats appeared during the usual opening and closing and possible amplifications when matched with mechanical resonance (1).

Table -1 illustrates the classification of the noise sources. Noise sources depend on the mechanical resonances, electromagnetic forces in the air gap of hermetic motor, aerodynamic and dynamic features of the refrigerant, cavity resonances and dynamic forces.

Noise sources	Frequency "Hz"
Unbalance	50
Rotor slots	Fundamental frequency X # of slots
Electromagnetic noise	Supply frequency and its harmonics
Magnetic hum	Twice the supply frequency
Rotor frequency Magnetic Shaft resonances	500
Crank shaft resonance	490
Electromagnetic	315, 500, 100
Inertial forces	>3400 At rotational frequency and its harmonics At supply frequency and its harmonics
Pressure pulsations	Pumping frequency and its higher harmonics up to 40th harmonics, Dramatic changes around 22nd and 38th which appear between 1200-2100 Hz
Valve modulation effects	>1000 Hz

Table-1, Noise sources of the reciprocating compressor

Table-2 illustrates the classification of the noise sources of the reciprocating compressor.

Motor noise	Compression process noise	Valve port noise
1.Electromagnetic noise Magnetic forces, Flux density variations	Pumping pulsations at pumping frequency and its harmonics	Valve motion provides an important modulation effect
2.Mechanical noise Mechanical resonances Bearings Unbalance		
3.Aerodynamic noise Rotor slots		
4. Dynamics		

Table -2 Classification of the noise sources

3.3.Contributing Forces to the Noise Radiation

Inherent dynamic features of the casing structure, dynamic forces that include out of balance forces, inertial forces and the features of suspension , friction of the rotating parts, Electromagnetic forces that appears in the air gap between rotor and stator and or the surface of rotor and stator, together with fluid dynamics and acoustic features of the cavity are all considered as the main contributors of the noise emissions. Figure-1 illustrates noise spectrum of the reciprocating refrigeration compressors.

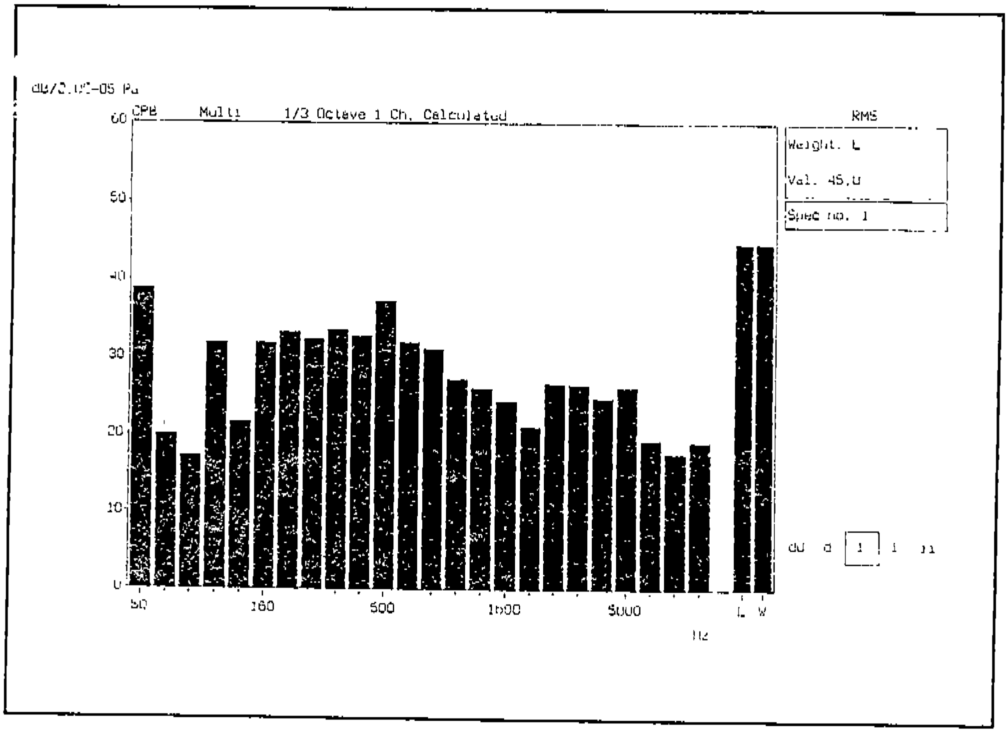

Figure-1, Noise spectrum of the reciprocating compressors.

3.4. Factors that Effect the Measurements

Basic factors that may effect the measurements of the reciprocating compressor noise emission are listed in table-3.

Flexibility of the system	•The shell is not perfectly rigid contribution of shell resonances exists •The compressor itself is not a rigid concentrated mass but is spatially distributed with inherent features •Suspension springs have also resonances at higher frequencies
Shell motion effects	•Shell resonances can have effect from the pumping harmonics around their resonances
Compressor internal resonances	•Internal deformation of the compressor around resonances
Gas cavity resonances	•Gas resonances can transmit sufficient energy to drive the mechanical paths within the compressor
Lubricating oil path	•Impedance matching between the oil and surrounding casing may cause the transfer of higher energy.
suspension springs	•Wave effects of the suspension springs can effect the alteration of transmissibility at their mechanical resonances.

Table-3, Factor that effect the measurements on reciprocating refrigeration compressors.

4. SOUND QUALITY ASSESSMENTS

Sound from discrete components such as the gas pulsations, valves and the hermetic motor can add or detract the perceived quality of the reciprocating compressors. In considering the particular sound quality problem of the reciprocating compressors, consideration must also be given to the masking effect of other sources in the environment Valves will normally be operate when the hermetic motor running while the casing will still be retracting after the motor has been operated. Also, the suction and discharge valves did not itself to a quality sound signature. The periodic impacting of the valves to the valve seat often generated an impulsive noise, found objectionable by the consumer. The major issue to address would be quality of the sound developed by the mechanism.

4.1. Sound Recording and Signal Processing

Binaural technology comprises recording of sound means of a head and torso simulator measuring system and incorporating an evaluation algorithm analogous to human hearing. Aurally adequate sound measuring technology is not therefore an alternative to but an useful extension of existing sound measurement techniques. In complex situation like in the case of reciprocating refrigeration compressors, which could not be defined in terms of A weighted sound pressure alone, it can be used for gathering additional information (2, 3).

Binaural sound was acquired by the data acquisition front end which were interfaced to the work station. The compressors were recorded under various operating modes. Figure-2 illustrates the recording of three seperate compressors in time domain and in the frequency domain.

Many metrics have been developed to allow numerical evaluation of sound quality. Not all of these metrics will have significant correlation to subjective evaluation of a given sound. Examination of a narrow band FFT of the time data for the steady state section, shows that the majority of the sound power is bellow 6000 Hz, however there are also peaks in the sound pressure in the 6000-8000 range. The center frequency, amplitude and width of these peaks vary between the different companies but it is present in all samples.

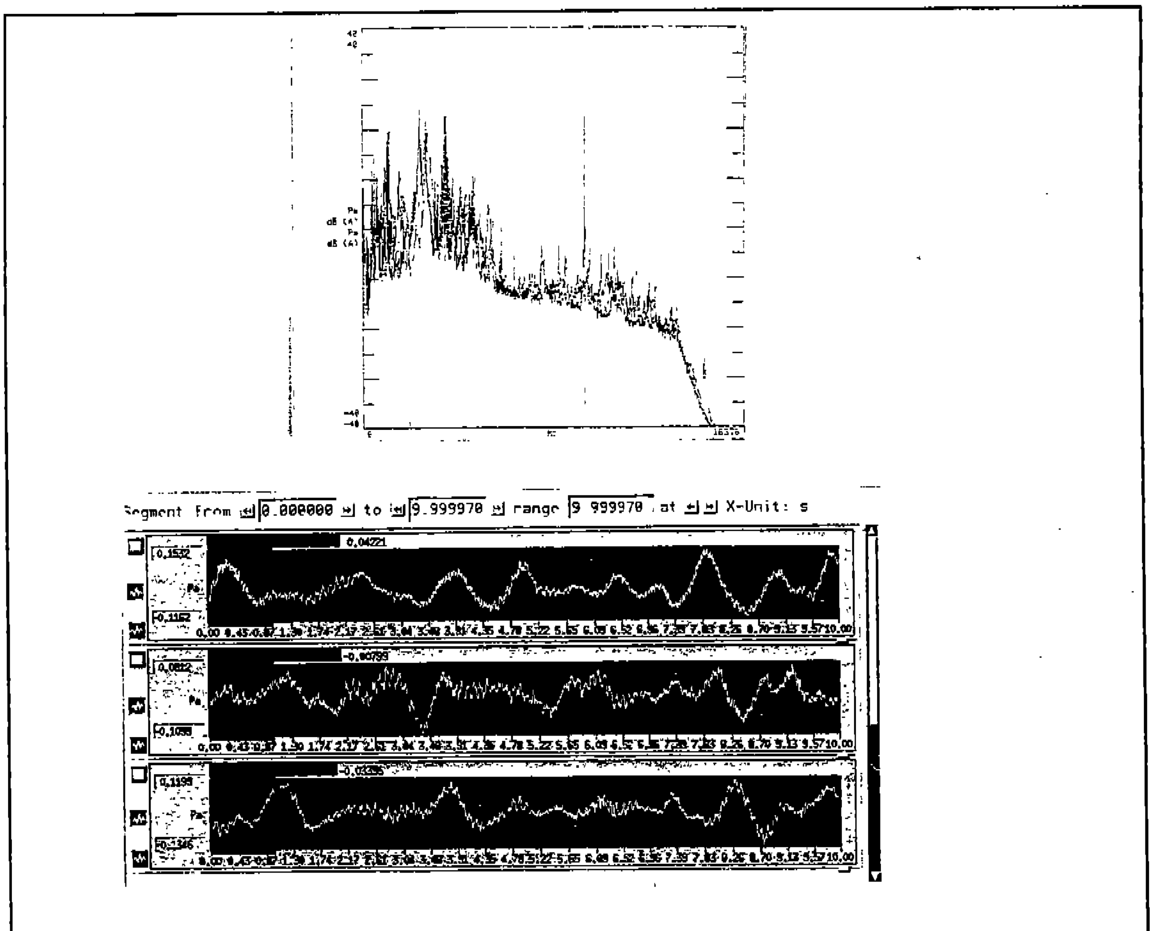

Figure -2, Binaural recording obtained at 3 different reciprocation compressors in time and frequency domain

4.2.Frequency modulation

A second feature of the reciprocating compressor is their time dependent characteristics. Although nominally running at a constant speed some of the mechanisms show significant variation with time. This effect of the modulation gives rise to frequency modulation. The effect explains the broad peak in the sound power seen in the averaged spectra which are actually discrete harmonics modulated in frequency.

The modulation frequencies exhibited by the mechanism conclude with the two physco acoustic phenomena referred to as fluctuating strength and roughness. These terms describe a sensitivity of human hearing. The speeding up and slowing down can be interpreted as a subjective feeling of weakness about the motor.

4.3 Metric analysis

Each of the measured sounds were evaluated for different metrics. Examination of the results showed that the range of values for some of the metrics was not very broad. In order to increase the range for new sounds were created by modifying the existing sounds to accentuate certain characteristics.

4.4.Replaying the records

Before the sound could be used for evaluation the steady state section of the sounds was edited to make all the files in uniform length to eliminate this variable from the analysis. The sounds were auditioned using free field headphone connected with the sound quality work station with the auditioner selecting the sound by mouse. The choices were registered by the computer into data file.

4.5. The evaluation of the results

This basically means identifying the relationships between the objective data, represented by the set of metrics computed for each sound and the subjective data, the preference scores resulting from the auditioner evaluation. The general problem is to study the relation between a dependent variable (the preference) and independent variables (sound quality metrics) (4, 5). The three auditioner involved in this compressors evaluations have used simple logic in order to transform the qualitative data into quantitative data . They have classified the compressors in five groups of very good (+1), good (+0.5), fair (0), bad (-0.5) and very bad (-1). The qualitative features of the compressor noise led to the consideration that the model should contain the sound quality metrics which represent, loudness, modulation (due to the speed variation of the hermetic motor when loaded), impulsivenens (due to the valve motions and impacts). In dependent variables was based on the knowledge of characteristics noise under investigation. Table-4 lists the results of findings.

Compressor no	First auditioner	Second auditioner	Third auditioner	Metrics rank
1	3.5	3.5	4	2
2	4	3.5	3.5	1
3	3	3.5	3	3
4	3	2.5	2.5	5
5	3.5	3	3	4

Table-4 , Comparisons between the recorded preferences and sound quality

5.ACOUSTIC HOLOGRAPHY

Product characterization often involve not only the measurement of sound pressure and sound power but also vibrational velocities of radiating surfaces and energy flow information, such as acoustic intensity vector maps, in order to locate the sources of acoustic energy . A practical Acoustic holography is based on a two dimensional scan over a plane close to the test object. The reason of application of the Acoustic holography techniques in this study, based on the validation of the source identification that came through the previous measurements and binaural hearing. .

The Acoustic radiation mapping obtained by the acoustic holography techniques on the insides of casings are used to validate to our previous knowledge and assumptions. During the measurements twelve microphones were mounted on the line of array. At each position of microphone sound pressure was captured. B&K 3551 front ends and number of microphone arrays were used together with the LMS Acoustic holography software. Figure 3 illustrate the pressure distribution in dB at the frequency of 2000 Hz.

In all implementations of the Acoustic holography the acoustic field is measured measured on a two dimensional surface near a set of sources. This gives as a result a two dimensional spatial frequency spectrum with similar information content i.e. direction and magnitude as the single axis case (6).

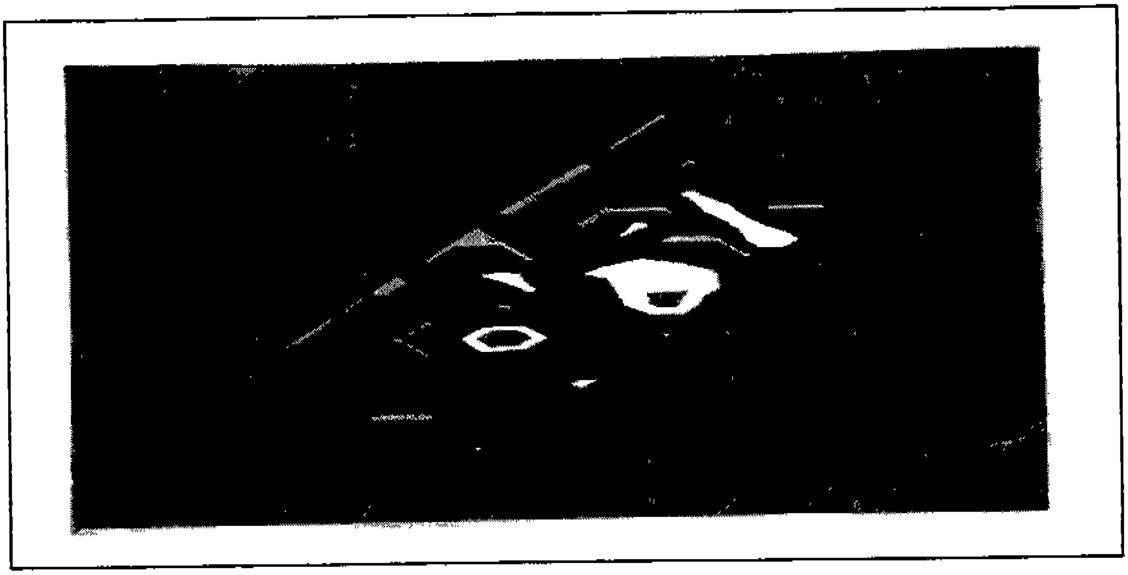

Figure-3, Sound pressure radiation on upper surface of the casing at 2000 Hz when measured by using the Acoustic Holography.

7.CONCLUSIONS

Noise sources and characteristics of the reciprocating refrigeration compressor have been analyzed. When the knowledge on the compressor mechanism and noise sources obtained then various techniques to capture the feature of compressor noise considered.

The nature of the compressor noise can not enable the engineers to have comparable values just by performing simple measurements in octave band spectras, engineers fully need to use the sophisticated techniques of the signal processing and the influence of our perception on the sound quality of the reciprocating refrigeration compressors.

Binaural recording and replay techniques can enable the auditioners to evaluate the compressor by taking our perception of sound quality. It became obvious that a human hearing equivalent analysis of sound quality or noise is only possible if all the properties of human hearing are taken into the consideration. It means a simple measuring microphone can not do, but a special head and torso simulator are needed with transfer functions comparable to human hearing. The analyzer can not be just a simple octave band or fast fourier transform analyzer, we need an analyzer or computer equipped with digital signal processing cards that had high resolution in time and frequency domains and a high dynamic range comparable to human hearing.

Binaural recording and analysis techniques and acoustic holography are very effective noise control engineering tools that integrates each other, in the sense of the identification and estimation on the directivity and amplitude of source. Noise control engineers have a challenging task to use the rich and informative data they have , for the purpose of achieving ultimate reach of quiet products.

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