1996

Radiation Analysis of the Reciprocating Refrigeration Compressor Casing

C. Ozturk
Turk Elektrik Endustrisi A.S.

A. Acikgoz
Turk Elektrik Endustrisi A.S.

J. L. Migeot
LMIS Numerical Technologies Belgium

Ozturk, C.; Acikgoz, A.; and Migeot, J. L., "Radiation Analysis of the Reciprocating Refrigeration Compressor Casing" (1996). *International Compressor Engineering Conference.* Paper 1186.
https://docs.lib.purdue.edu/icec/1186

RADIATION ANALYSIS OF THE RECIPROCATING REFRIGERATION COMPRESSOR CASING

Cüneyt Öztürk (1) , Ahmet Açıkgöz (1) and Jean Louis Migeot (2)

(1) Türk Elektrik Endüstrisi A.Ş , R&D Department, Davutpaşa, Litros yolu 1, Topkapı 34020 , İstanbul, Turkey
(2) LMS Numerical Technologies, Interleuvenlaan 68, 3001, Leuven, Belgium

1. ABSTRACT

The calculation of the acoustic field radiated by the compressor casing is based on the information of, finite element and boundary element model, structural mode shapes and measured vibration response on the surface of casing. This paper presents a method of predicting sound pressure levels on a hemispherical field point mesh centered on the shell and the Frequency Response Functions which are located 0.33 meter away from the compressor center whilst still at design stage.

Correlations of modelling with experimental measurement work also continues, to improve knowledge of the best modelling techniques and to gain better data for use in models. The results of our studies shows that it can be possible to obtain the acoustic model of the reciprocating refrigeration compressors long advance of any prototype. The acoustic modelling provide a method to predict the L_{eq} sound pressure levels in operators position , during the design stage and even can provide audible noise of the product before having the actual prototype. This makes considerable savings in prototyping costs and as well as time to market of the products.

2. INTRODUCTION

Developed new design tools based on the numerical analysis techiniques that enable the designer, to be full aware of the noise levels of the products, before prototyping can be inseperable parts of the design process. Using these tools can provide strategic competitive advantages to the users.

Predicted modelling appeared on the vibration data that include all the contributions of the effects of mechanical resonances , dynamic forces electromagnetic forces, fluid dynamics and the features of compressor inner cavity, at the measured points, located on the compressor shell. When these informative data superimposed on the inherent strucutral features, it can provide reliable base to define the boundary conditions of the model.

After predicting noise through acoustic modelling performed in the numerical analysis system, the design engineer can use his findings to hear noise even before prototyping. Time domain, sound pressure signals derived from the calculated acoustic radiation of the compressor casing can be used in systems that share the same Kernell data base as an input signal that comes through the data acquisition. These data also are used and shared by the sound quality analyis program. The direct outcome of numerical analysis can be converted into the audible form. The time-domain data of the sound pressure signal available in the Kernell data base can be processed through the Digital Signal Processing Card and Digital Audio Formatter in the computer environment. Through an optical link this signal can be transmitted from the Digital audio Formatter to the preamplifier. Then, power amplifier amplify the signal before being made audible through the loud speakers or head phones.

3. NOISE GENERATION MECHANISM OF THE RECIPROCATING REFRIGERATION COMPRESSORS

3.1. Noise sources of the compressor

Compressor noise sources are those processes where certain portions of energy are separated from the desired energy flow and transmitted through the internal components of compressor to hermetic shell where it is radiated from the shell as airborne noise on vibration of supporting structure . The vibration of supporting structure will eventually radiate additional airborne noise from some portion of the structure. Noise sources of the reciprocating refrigeration compressors can be classified as, motor noise , compression process noise and valve port flow noise.

3.2. Compressor noise paths and noise generation mechanism

Compressor noise is transmitted both directly and indirectly. Directly transmitted noise is the sound that is radiated from the compressor housing. We can call this "case raditation". Noise that is transmitted indirectly requires some sort of external radiator in order to produce sound. The path for the transmission of the indirect noise is any mechanical connection between the compressor and cabinet. Within a mojor noise path can be paralel subpaths as for example , within the mechanical path, there are the suspension springs and the discharge line. There are also subpaths that cut accross the major paths such as the resonant vibration of the frame of compressor exciting refrigerant gas in the shell cavity. Table 1 illustrate the noise generation mechanism of the refrigeration compressor.

Structure borne	Fluid borne	Air borne
Noise generation mechanism Impact Inertia Friction Magnetic field Unbalance	**Noise generation mechanism** Turbulence Shock Pulsation	**Noise generation mechanism** Acoustic cavity resonances
Velocity &force transmission	**Velocity transmission**	**Velocity transmission**
Radiation through casing	**Radiation through casing**	**Radiation through casing**

Table-1. Noise generation mechanism of the compressor casing

3.3. Contribution of the effective forces on the radiation of the casing

Compressor noise results from interactions of complicated set of processes. Mechanical resonances that expose the inherent dynamic features of the system, dynamic forces include the effects of moving parts, torsional vibrations and inertial effects , electromagnetic forces specifically appear in the air gap and on rotor and stator surfaces, together with the features of compressor cavity are the all considered as effective contributors to the radiation. These contributions are tied to the vibration data obtained on the specific points , located on the shell. Table -2 shows all the contributing forces on the vibration data.

Contributing forces	Description
• Mechanical resononces	• Inherent dynamic features of the casing
• Dynamic forces	• The inertial effects. Out of balance forces, •Torsional vibrations caused by mismatching load torque and motor drive torque. •Instabilities caused by the friction generated by rotating parts
•Electromagnetic forces	•Local magnetic forces calculated in radial and axial direcitons
•Fluid dynamics	•The turbulent nature of the flow through the valve ports
•Acoustic radiation	•Acoustic modes of the cavity

Table-2 , Contributions of the effective forces on the experimental data

4. IDENTIFICATION OF THE MECHANICAL FEATURES OF CASING

Eigen frequencies and modes of mechanical systems were calculated by structural FEA. Figure-1 illustrates mode shapes appeared on the mode frequencies of 3635 Hz, 3900 , 4006 and 4029 Hz respectively.

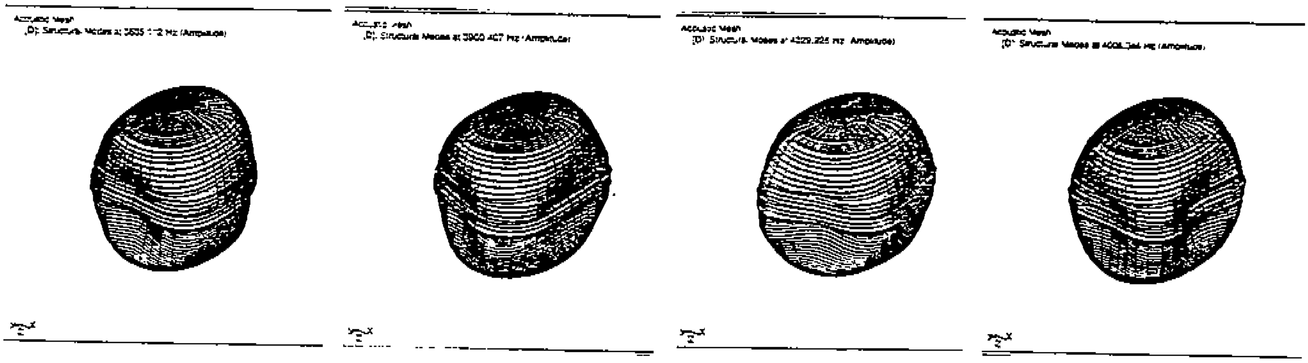
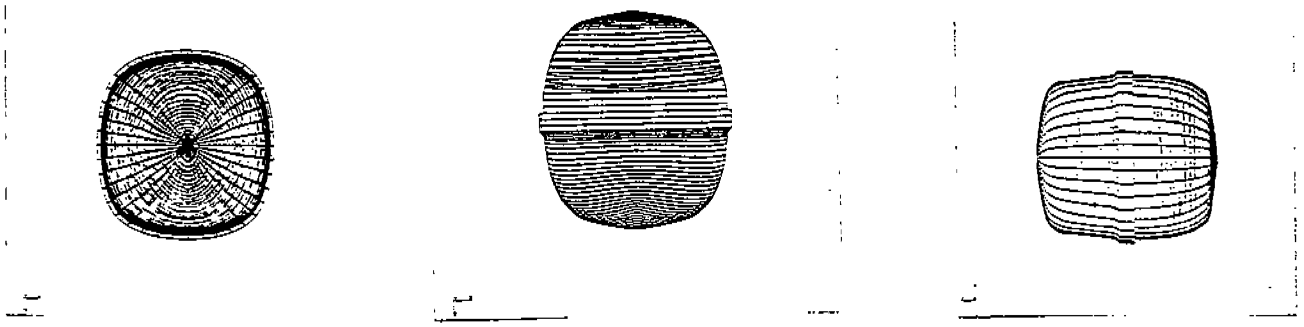


Figure-1, Modes 8-11 appeared on the frequenices of 3635 , 3900, 4006 and 4029 Hz respectively.

5.SIGNIFICANCE OF THE VIBRATION DATA

Measured vibration data provides all the information about the contributions of forces that causes the noise and vibration on the compressor casing. In order to pick up the vibration data needed, the frequency response functions were obtained by consecutively placing an accelerometer at the different measurement points while keeping a reference accelerometer on the top of the casing, thus allowing the measurement of both amplitude and phase. Figure 2 shows the location of the measurement points on the mesh. Figure-3 shows the superimposed FRF's measured at points 1-4.



a-Points 1-4 b-Points 5 to 8 c-Points 17 to 20

Figure-2. Location of the measurement poins on the surface of casing

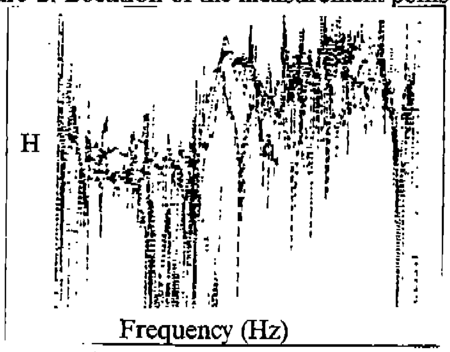


Figure-3 FRF's measured at points 1-3 when measured between 0-8000 Hz

6.MODAL EXPANSION OF EXPERIMENTAL DATA

The modal expansion technique is based on the fact that structural displacements can always be represented as a linear combination of structural modes:

$$u(P,\omega) = \sum_{i=1,,n} a_i(\omega)\phi_i(P) \qquad (1)$$

where the a_i are the modal participation factors (function of the frequency but independent of the position of the point P on the compressor's surface) and ϕ_i the modal displacements (independent of the frequency or more precisely defined at one frequency and function of the position of the point P). In our case, the mode shapes have been obtained using a structural model of the shell and the structural analysis software. The modal expansion technique is then a two-step process. First, we are writing the above equation for all measurement points P_m:

$$u(P_m,\omega) = \sum_{i=1,,n} a_i(\omega)\phi_i(P_m) \qquad (2)$$

in this equation, $u(P_m,\omega)$ is a known (measured) function and $\phi_i(P_m)$ a known (calculated) quantity. The a_i are, on the contrary unknowns that can be obtained by solving the system of equation. Once they are calculated, the displacement at the other points P_c can be obtained by the same relationship:

$$u(P_c,\omega) = \sum_{i=1,,n} a_i(\omega)\phi_i(P_c) \qquad (3)$$

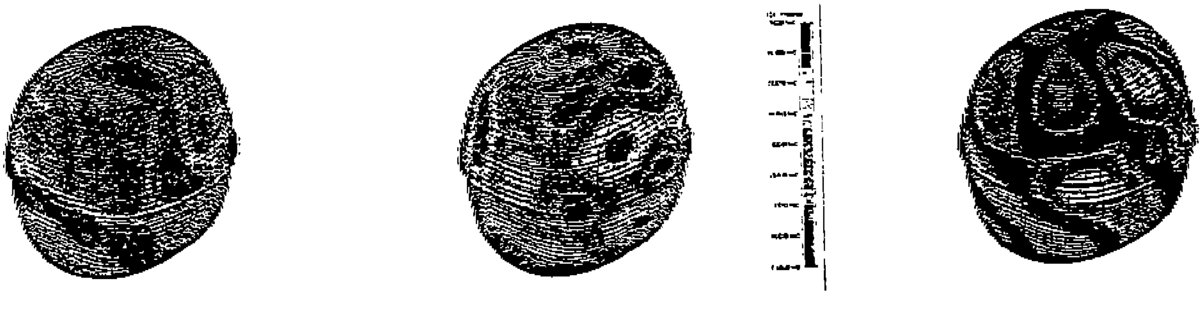
but where now $u(P_c,\omega)$ is unknown and a_i and $\phi_i(P_m)$ known. This process can also be seen as an intelligent interpolation between the measurement points in order to obtain the best possible estimation of the vibration at all points which is required for the radiation analysis.

7.MODELLING OF ACOUSTIC RADIATION

Based on the boundary conditions created by the modal expansion procedure, BEM indirect analysis has been conducted. For each frequencies, potential distribution on the casing, pressure distribution on the field point mesh and directivity diagrams and frequency response functions are obtained

7.1.Acoustic radiation on the casing

Acoustic radiation on the casing are illsutrated in figure 4 for frequencies 2000 Hz, 3024 Hz and 4048 Hz respectively . Double layer potential (Pressure jump) on the casing indicate that towards the mechanical resonances of the casing radiation gains increase in dB value.



a-At 2000 Hz

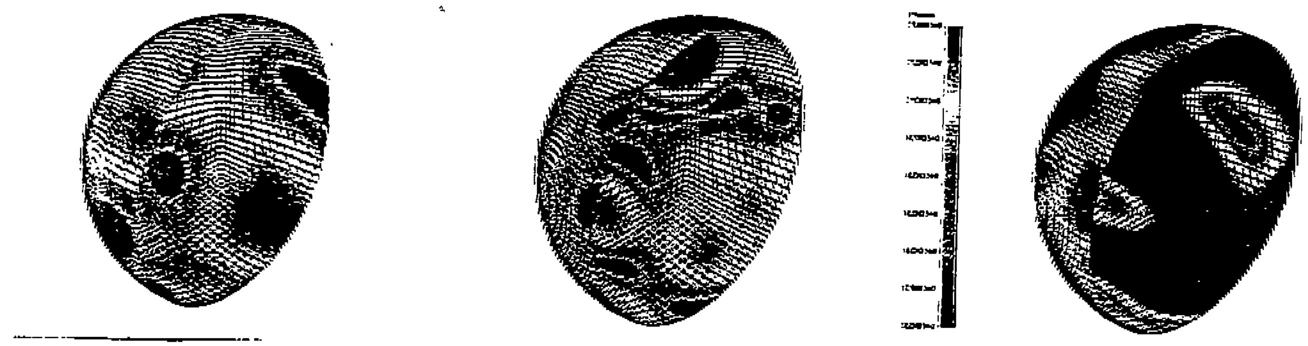
b-At 3024 Hz

c-At 4048 Hz

Figure-4 Double layer potential on the surface of the casing

7.2.Acoustic radiation in the field

Acoustic radiation on the surface of the hemisphere located one meter away from source are illstrated in fugure 5 , for frequencies 2000 , 3024 and 4048 Hz respectively.



a- At 2000 Hz

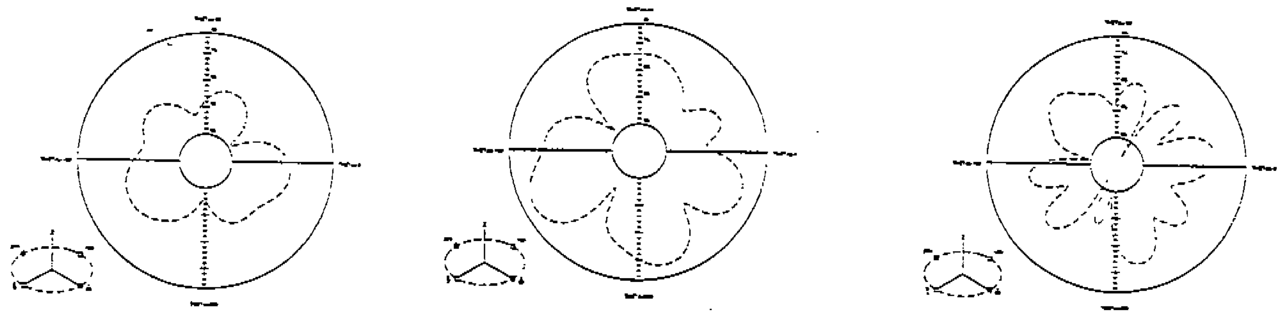
b-At 3024 Hz

c-At 4048 Hz

Figure-5 Acoustic raditaoin on the surface of field

7.3.Directivity of the sources and frequency response functions

XY directivity of the radiation that comes though the source is shown in figure 6 for the frequencies



At 2000 Hz

b-At 3024 Hz

c-At 4048 Hz

Figure-6 XY directivity of the source when measured at 2000, 3024 and 4048 Hz respectively.

Positions of points left where FRF have been calculated , 0.33 meter away from compressor center is shown at figure-6

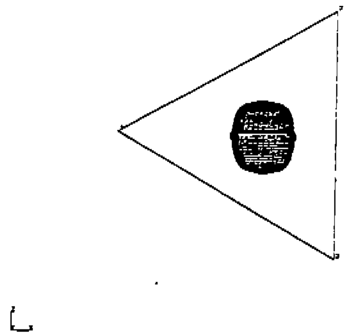
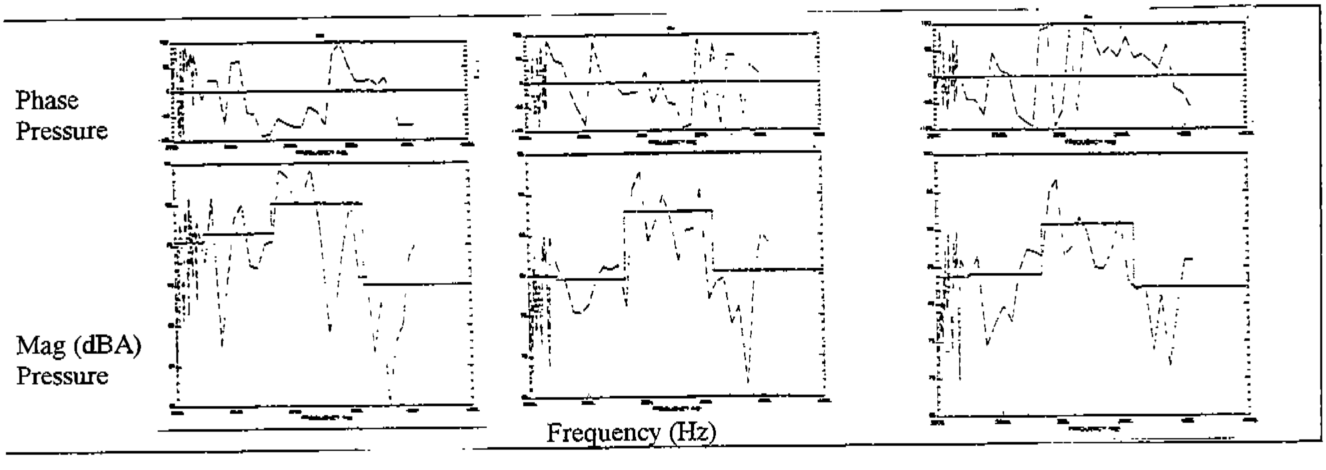


Figure-7 Position of the three points located 0.33 meter away from the source

Frequency response function showing the narrow band and third octave band sound pressure level are shown at figure-8.



a-) At point 1 b-) At point 2 c-) At point 3

Figure-8. Frequency response functions showing the narroww band and third octave band sound pressure levels when calculated between 2000 Hz and 4000 Hz

8.CONCLUSIONS

The most diffucult part of this studies to obtain good vibrational data as input to the modal expansion. Once the vibration date reliable then the acoustic radiation predictions can be accurate and reliable. The correct experimental data can then be used to calculate the radiated power or the acoustic radiation field in any point that stays around the source even the Frequency response functions at the specific points When the appropriate vibration data available, it is very efficient design tool to proedict the acoustic radiation and have a signal to be used to obtain the audible format in suitable computer environment.

In this stud , correlation of acoustic modelling with experimental measurements still countinues, in order to improve knowledge of the best modelling techniques and to gain better data for use in models.

This study indicates that acoustic radiation predictions may give very satisfactory results and it can be very efficient design tools that enable designers to have strategic competitive advantage to use and as well es reductions in the cost of prototyping and time to market of the product.

REFERENCES

(1) Hamilton J. F.," Measurement and Control of Compressor Noise ", Purdue University, 1988, USA
(2) Öztürk C, Açıkgöz A., Migeot J L "Predicting, Hearing Compressor Noise Before Prototyping ", Appliance Manufacturer, Business News Publications, June 1996, , USA
(2) Viersbach U. and Maurell R. , Guisset P, Rossion J. P. and Wynendaele H. "Comparing Acoustic Measurements with Combined MSC/NASTRAN-SYSNOISE Sound Radiation Predictions of an Engine Block", The 1994 MSC World User's Conference, 20-24 June 1994, Lake Buena Vista, Florida, USA
(3) Jeyapalan R. K. and N. A. Halliwell, "Machinery Noise Predictions at the Design Stage Using Acoustic Modelling" , Journal of Applied Acoustics, Vol 14, 1981, UK
(4) Nieter J J and Singh R. "A Computer Simulation Study of Compressor Tuning Phenomena", Journal of Sound and Vibration, Vol. 97(3), 1984 , UK
(5) To C. W. S. "The Acoustic Simulation and Analysis of Complicated Reciprocating Compressor Piping Systems, II:Program Structure and Applications", Jouranl of Sound and Vibration , Vol. 96(2), 1984, UK