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PREDICTION & VISUALIZATION OF A THREE DIMENSIONAL SOUND FIELD TO REDUCE THE NOISE OF ROTARY COMPRESSORS

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ABSTRACT

Computer - Aided Engineering (CAE) approach aims at reducing the time of trial manufacture and experiments at the development stage, which results is the saving the time and cost of development.

In this paper, we describe the CAE approach to the prediction and visualization of a Three Dimensional (3D) Sound Field to reduce the noise of rotary compressors.

With the aid of the 3D Computer Graphics (CG) presentation , anyone can visualize the sound radiating behavior more realistically at a glance , and identify the noise source more easily. As a result , we are able to achieve the reduction of the noise of rotary compressors as well as saving of the development time.

INTRODUCTION

Rolling piston type hermetic compressors have been widely used for residential air conditioners. Vibration analysis of these compressors has been conducted using an original DAIKIN INDUSTRIES. CAE approach [1,2] which is able to establish optimum design procedures.

Recently , in regard to the development of variable - speed rotary compressors , the noise reduction approach involves many problems to be solved. Above all , during the development stage , it has been very important to predict the acoustic characteristics of the compressor. However , very few software tools have been available for acoustic analysis , and there have not been established the noise prediction approach sufficiently. Furthermore , the visualization technique of a complex 3D Sound Field has been an important theme.

From the afore mentioned point of view , we have been investigating the 3D acoustic problems to predict the acoustical characteristics by using the Boundary Element Method (BEM). [3] As an experimental analysis , we have been studying the visualization of sound field , the noise source identification and experimental verification of predicted results by using the Sound Intensity Method. [4] On the other hand , we have been trying to visualize the calculated results realistically and dynamically by using the CG presentation. [5]

This paper describes the effectiveness of the CAE approach to the prediction and visualization of a 3D sound field by using these techniques.

PROCEDURE OF NOISE PREDICTION & VISUALIZATION

CAE approach to the prediction and visualization of a 3D sound field is shown in Fig. 1. We explain a general concept of each procedure briefly in order.

BEM Acoustic Analysis Recently, for acoustic analysis, both the Finite Element Method (FEM) and Boundary Element Method (BEM) have been developed.

FEM acoustic analysis has been used widely to obtain interior acoustic characteristics. But the accuracy of FEM acoustic analysis is determined by the ratio of the element size to the acoustic wavelength, therefore, a large number of elements are required at the high frequencies.

On the other hand, BEM has been formulated as the numerical calculation of an integral equation for which only geometrical data of the boundary surface is required. Therefore, numbers of elements are reduced compared with FEM.

In our study, BEM is applied to solve not only the interior noise problems but also the sound radiation problems.

Boundary Conditions In the application of the BEM, the boundary surface of vibrating structure needs to be divided into small planner elements. For a given vibrating frequency, boundary condition of each elements is defined as it's normal vibration velocity.

In our study, both the analytical and experimental approach have been carried out to obtain the normal vibration velocity. At the resonant frequency, we have been trying to predict the boundary conditions by linking the vibration analysis and the acoustic field analysis. On the other hand, we find it difficult to predict the complex operating mode except for the resonant modes, because of the difficulty in estimating the true damping factor and the structural - acoustic coupling effect. In these case, we have to measure the normal vibration velocity of the vibrating surface instead of linking the vibration analysis. In experimental approach, we apply the laser vibrometer to the measurement of the normal vibration velocity at the vibrating surface of the compressor. In the laser head, the beam generated by a frequency stable He - Ne laser enters an interferometer, where it is split into a measurement beam and a reference beam. Therefor, we are able to obtain the complex vibration velocity in detail.

Experimental Acoustic Analysis In the interior noise problem, we perform the noise source simulation test to investigate the inner sound characteristics.

In this system, for the measurement of the acoustic transfer functions between the sound pressure levels, the Swept Sine Burst Signal is applied for the excitation signal, because of the High RMS to peak ratio and Minimum leakage. Then, to estimate the cavity resonant frequencies, we apply the polyreference modal extraction method as the curve fitting technique. The calculated results are evaluated by the Modal Confidence Factor [6], that lets us distinguish between physical and computational modes.

As regarding the experimental evaluation in the sound radiation problem, we apply the 3D Sound Intensity analysis.

Sound Intensity is the flow of sound energy through a unit area in unit time and is defined mathematically as the product of the instantaneous sound pressure and the instantaneous air particle velocity at the same point in the same time. In our experimental study, the active Sound Intensity radiated from the vibrating surface of running compressor is calculated by using the cross - spectral technique. [7] The microphone probe used here is the 3D probe consists of four microphones. By using this probe, we are able to combine the 3D Sound Intensity vector at the same time instead of changing the probe direction.

Computer Graphics Presentation As displaying system, we utilize the intelligent Graphic Workstation. (COMTEC 4D Series)

Sound Intensity is a vector quantity, having both direction and magnitude. So, in our presentation of the Sound Intensity vector, the degree of Sound Intensity level is indicated by the length of vector, and acoustic energy flow direction by the direction of vector, and scalars such as sound pressure level by the color of vector.

Moreover, the sound pressure distribution pattern is displayed not only the 2D color fringe display but also as the 3D contour map display. Both Sound Intensity vector map and Sound Pressure contour map are able to be displayed simultaneously and dynamically.

While, rotary compressor consists of the various component. These variety objects created through 3D Solid Modeling can be displayed ; including semi - transparent display, hidden surface removal, perspective transformation, depth - cueing, and simultaneous display with color shading, the resultant display can be made to look exceptionally realistic and natural.

Thus, by superimposing these compressor models with 3D sound field, any one can visualize the sound radiating behavior more realistically at a glance and identify the noise source more easily.

ANALYSIS AND APPLICATIONS

The basic verification of the BEM program developed at DAIKIN has already been reported. [3]

In this paper, we describe some applications to predict the 3D sound field of the compressor by following CAE approach as shown in Fig. 1. First, the analytical approach was applied for the Inner / Outer sound field of the accumulator, the vessel equipped for the suction pipe of the compressor to separate the liquid component from suction refrigerant. (See Fig. 2) Second, as the sound radiation problem, the experimental approach was applied for the compressor housing in operation.

Interior Noise Problems As the calculation model of the accumulator, the boundary surface including the inner suction pipe was divided into 594 quadratic elements. Maximum length was about 15mm for keeping the analytical accuracy up to 5 KHz. While, to visualize the cavity resonant modes, the measurement surface inside the accumulator was divided into 354 elements (two crossed plane in vertical direction and three annular plane in radius direction).

As the boundary conditions, the relative vibration velocity was calculated by linking the typical results of the vibration analysis and was given each element of the inner suction pipe. While the inner surface of the accumulator was reflective barrier and the edges of suction pipe were non - reflective. After all, the resonant frequencies were obtained the changes of the calculated sound pressure levels by sweeping the calculation frequencies.

Table 1 shows the comparison between the measurement frequencies by the noise source simulation test and the predicted ones by BEM. Both results show very good agreement and the effectiveness of BEM is verified.

As the presentation of the calculated results, three typical resonant modes were shown by the sound pressure distribution behavior in Fig. 3. In Fig. 3, including semi - transparent display of the accumulator surface, we can visualize the interior acoustic behavior more clearly.

Sound Radiation Problems The experimental relationship between vibration pattern and sound radiation pattern at the typical resonant frequency of the accumulator was shown in Fig. 4. In Fig. 4, it becomes obvious that the yawing resonant mode of the accumulator dominates the Sound Intensity distribution pattern at it's resonant frequency (1056 Hz).

Next, in order to predict the sound radiation behavior of vibrating surface, we proceed following procedures described below.

(1) Create the 3D Solid Model to define the Rigid body component, and compute inertia properties.

(2) Define each components which constitute a system : Rigid body component, Beam component, and Scalar connector.

(3) Assemble the system model from each component and connector data, verify the system model and solve the system modes. (See Fig. 5)

(4) Transform each mode shape coefficient to the normal value by the measured one.

(5) Using these Boundary Conditions, Sound Radiation pattern is calculated by using BEM.

In this case, considering the effect of diffractive phenomenon and analytical precision, the boundary surface was divided into 522 quadratic elements which maximum length was about 30mm. Fig. 6 shows the comparison between experimental results and predicted ones. The sound pressure distribution pattern agree generally with experimental results.

Furthermore, in order to estimate the complex radiated 3D Sound Field in detail, the measurement surface around the compressor was divided into 5760 hexahedral elements.

Fig. 7 shows the 3D sound radiation pattern by displaying the 3D Sound Intensity vector map and 2D & 3D contour map of Sound Pressure distribution pattern. In Fig. 7 it seems that the low magnitude of sound pressure levels at the behind the compressor has been caused by the effectless of sound diffraction, because the acoustic wavelength of 1056 Hz has been almost equal to the form dimension of the compressor.

As the final application, we predict the sound radiation behavior of the running compressor by using the experimental approach and estimate the noise sources of several frequency.

In the experiments, we removed the accumulator from the compressor and measured the normal vibration velocity of a semi-cylinder of the compressor housing, because of the restriction of the laser vibrometer. On the other hand, the boundary surface was divided into 1116 quadratic elements. Maximum length was about 10mm and the measurement value was given to each element located semi-cylinder of the boundary. Moreover, the measurement surface faced to the same side was divided into 5880 hexahedral elements.

Fig. 8 shows the typical results of the sound pressure distribution pattern radiated from the different noise source location. In Fig. 8, the estimation of the noise source for various frequencies are summerized as follows.

(a) The noise at 875 Hz were caused by the cavity resonance in the hermetic shell space upward of the cylinder and stator, and radiated from the compressor housing.

(b) The noise at 1900 Hz were caused by the polygonal force due to slot harmonics, and radiated from the stator core and frame.

(c) The noise at 3800 Hz were caused by the collision and the sliding between compressor parts and radiated around the cylinder.

As the above results, we were able to identify the noise source by visualizing the 3D sound field at a glance.

CONCLUSIONS

We have described the CAE approach to the prediction and visualization of a 3D sound field of the rotary compressors. In our research, experimental data and calculated results show good agreement and the effectiveness of BEM is verified. Throughout the tasks, 3D Computer Graphics presentation provide us with significant informations.

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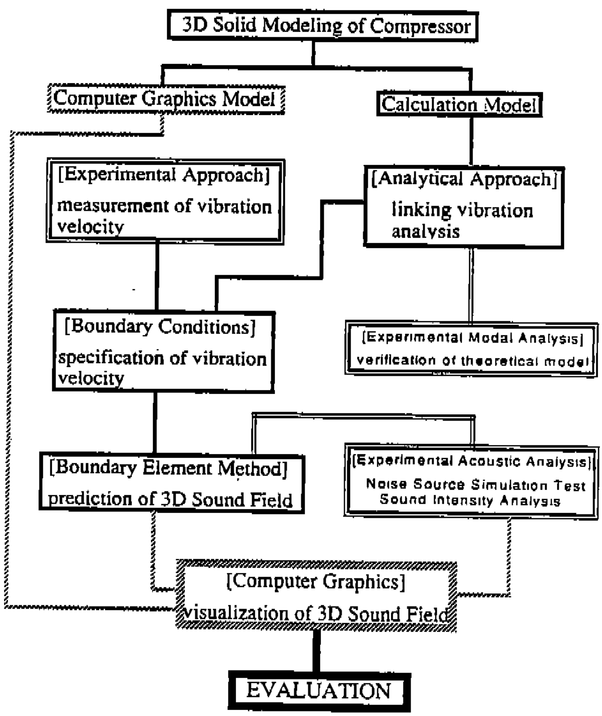
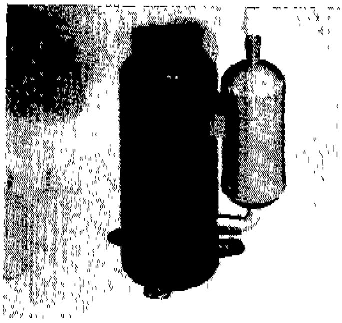


Fig. 1 Procedure of Noise Prediction & Visualization



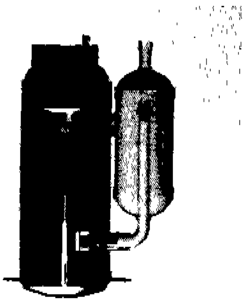
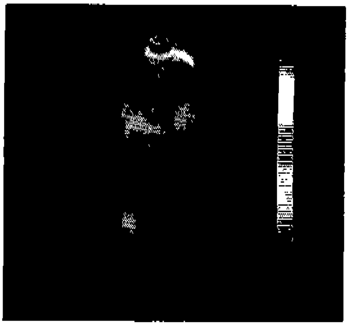


Fig. 2 Computer Graphics Model of the Rotary Compressor

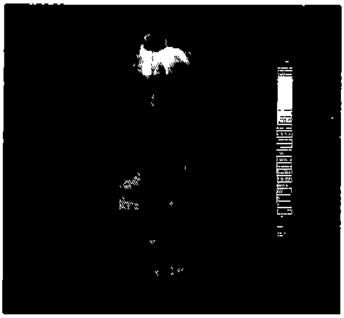
Cavity Resonant Mode	Resonant Frequency (Hz) (Error)	
	Experimental value	Calculated value
1st vertical direction Mode	1088	1130 (+3.9%)
1st circumferential direction Mode	3790	3845 (+1.5%)
1st vertical-circumferential direction Mode	4010	4155 (+3.6%)

Table 1 Comparison of the Resonant frequencies



(1st. vertical direction mode)

(1st. circumferential direction mode)



(1st. vertical-circumferential direction mode)

Fig. 3 Predicted Cavity Resonant Mode

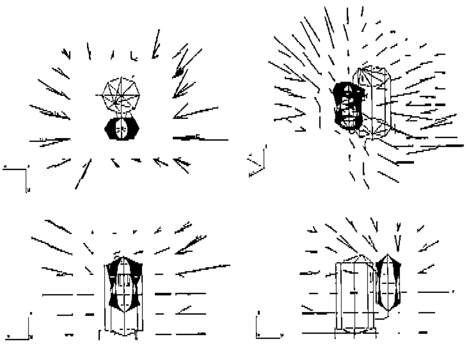


Fig. 4 Experimental Result

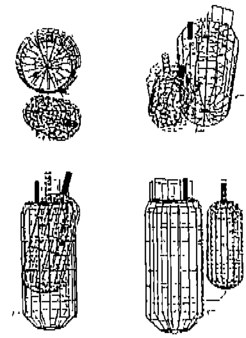
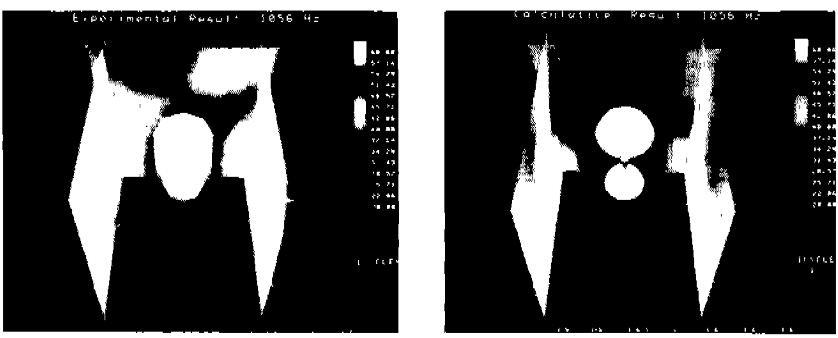


Fig. 5 Calculated Eigen mode



(Experimental Result) (Calculated Result)

Fig. 6 Comparison of the Sound Radiation pattern

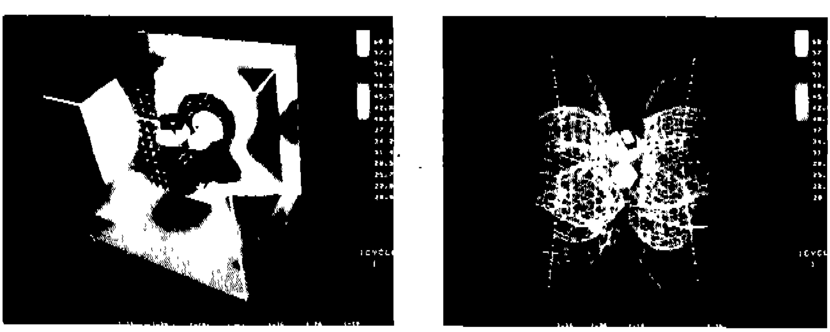
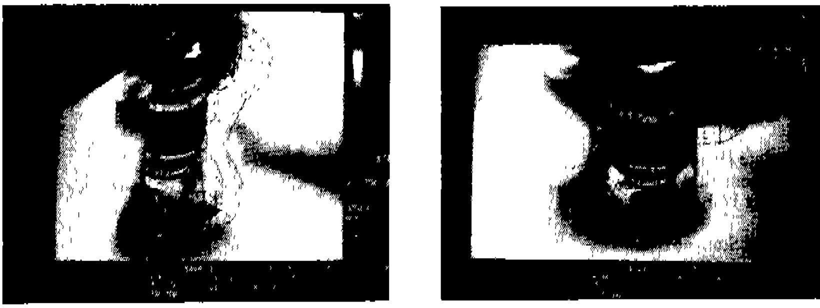
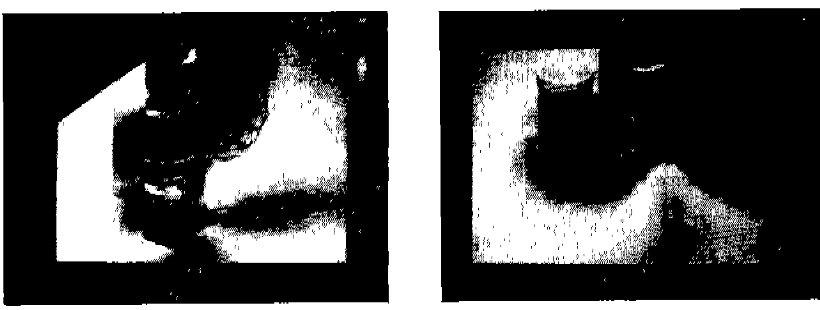


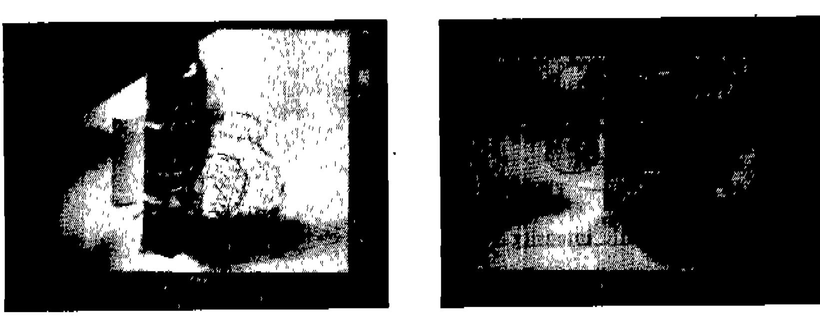
Fig. 7 Predicted Result by using BEM (1056Hz)
(visualization of the noise radiated from the accumulator surface)



(a) Cavity Resonant Noise (875Hz)



(b) Magnetic Noise (1900Hz)



(c) Mechanical Vibration Noise (3800Hz)

Fig. 8 Typical Predicted Results by using BEM
(visualization of the noise radiated from the compressor housing)