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# SOUND PRESSURE LEVELS EVALUATION OF A COMPRESSOR BY BEM METHOD AND COMPARISON WITH EXPERIMENTAL MEASUREMENTS

Enrico Gargano, Alessandro Bartolini

Istituto di Tecnologie Industriali e Automazione (I.T.I.A.)
Consiglio Nazionale delle Ricerche (C.N.R.)
Cinisello Balsamo (MI) ITALIA

The study of acoustic fields is becoming very important for industrial design:in fact it allows to predict the emitted noise levels of a source and to correlate them to the vibrations that are the origin of acoustic phenomena. In such way we have the possibility to make structural changes during the design of a product to decrease the noise level. In our paper we have considered as noise source an air compressor and we have utilized the boundary element method (BEM) to study the acoustic field behaviour produced in nearby field; let us suppose as condition that the normal component of particle velocity of fluid equals the normal component of vibrational velocity of structure surface. After a preliminary survey of correlation between noise and structural vibration autospectra we have choosen meaningful frequencies utilized for the experimental check of sound pressure levels detected on a reference plane 0.5 meter far from the superior surface of the air compressor.

## INTRODUCTION

It becomes more and more important in the industrial design field to find a method that allows to predict the emitted noise level and particularly to quantify the noise caused by the vibrations due to the machine working.
This kind of noise can be either internal or external, the first is generated inside the vibratory structure, the second is irradiated in the surrounding medium. Both the problems can be solved by numerical methods that use respectively finite or boundary elements.
Now in the study of acoustic fields genarated inside closed structure it is better to use finite element method while for the study of acoustic fields radiated by vibratory structure it is better to use the boundary element method.

## FUNDAMENTALS OF BEM ANALYSIS

The radiation of acoustic waves in an elastic medium is controlled by the linear wave equation:

$$\nabla^2 u = \frac{1}{c^2}\frac{\partial u}{\partial t^2} \qquad (1)$$

were "u" is velocity potential and "c" is the sound velocity in the medium.
The "u" potential is function of either position (x,y,z) or the time (t).
If the potential is a harmonic function of the kind:

$$u(x,t) = u(x)e^{j\omega t} \qquad (2)$$

equation (1) becomes:

$$\nabla^2 u = -K^2 u \qquad (3)$$

were K represents the wave number. Equation (3) is known as Helmoltz Equation where the potential depends only from position. From the linear equation of Eulero that controls acoustic processes of low amplitude in non-viscous media, by successive approximations we obtain the relationship that connects the acoustic pressure to the velocity potential. In the case of harmonic function the potential becomes:

$$p = -j\omega\rho u \qquad (4)$$

where $\rho$ is the density of acoustic medium.
To obtain the solution of an acoustic problem by boundary element method it is necessary to express the equations by values that belong to the boundary. From the divergence theorem that equals a volumic integral to a surface integral:

$$\int_V div\bar{A}\,dV = \int_S \bar{A} \times n\,dS$$

and using Green's second identity we obtain the boundary integral equation:

$$c(P)u(P) + \int_S v^* u\,dS = \int_S u^* v\,dS \qquad (5)$$

where "c(P)" is a multiplier depending only by the geometry, "u" is the potential function of velocity, "v" is the normal component of particles velocity and "S" is the surface defining the space of acoustic phenomenon.
So equation (5) describes completely the distribution of potential (velocity) and of normal velocity on the boundary surface. Only in a few cases the boundary integral equation can be solved analytically: otherwise it is necessary to use numerical integration. For this reason the boundary surface is divided in elementary elements.

## TEST PROCEDURES

The source under test is an air compressor powered by an eletric motor; a driving belt with two sheaves gives a gear ratio 1:1.

The picture (1) shows the sound source in a semianechoic room where we made the experimental test. The measure of sound pressure levels has been made on an ideal reference surface parallel to the floor at a distance of 0.5 meter from the upper surface of the compressor. The figure (1) shows the BEM model with the barycentres of the elementary surfaces where we measured the vibratory velocities.

Picture 1

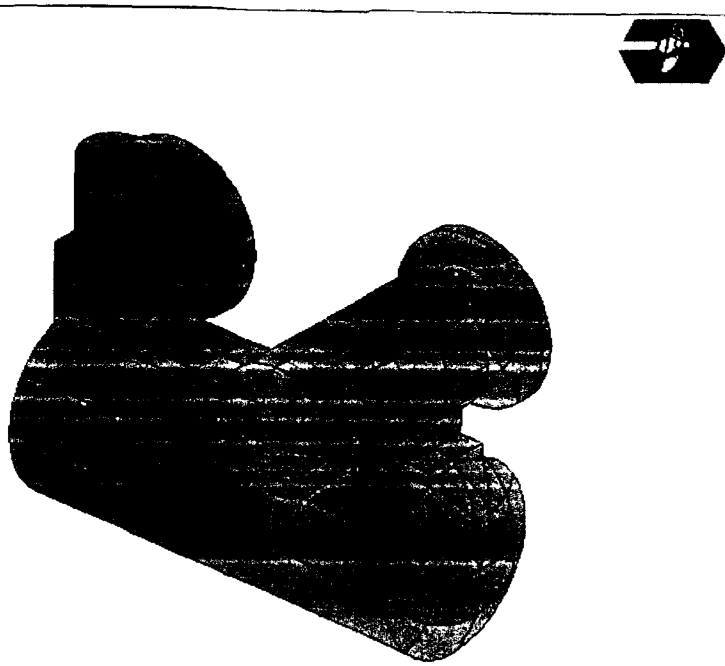


Figure 1

ACOUSTIC VIBRATIONAL CHARACTERIZATION

The radiated noise in the surrounding air during the compressor running has different origins because can be generated either by vibrations or by internal fluid. The emitted noise at speed is then correlated to the overall aspect of the phenomenon. Then to characterize the acoustic radiation spectrum we have correlated the airborne noise to the structural vibration of the source. We have used coherence function that allows to detect how much two signals are correlated each other; in our case the signals are vibratory acceleration and noise. This algorithm locates in the spectrum those acoustic frequencies with the same phase of vibratory frequencies. We used for that analysis a two channel Fast Fourier Transform Analyzer Bruel&Kjaer connected to a 1/2" condenser microphone and an accelerometer. The frequency range was from 0 to 800 Hz with a frequency resolution of 1 Hz. The graphic of figure (2) shows the noise signal autospectrum detected by the microphone set on the vertical axis of source at a distance of 0.5 meter; the graphic of figure (3) shows the vibration velocity signal autospectrum obtained by integration of acceleration signal measured by accelerometer set on the upper surface of the source, as illustrated in picture (2).

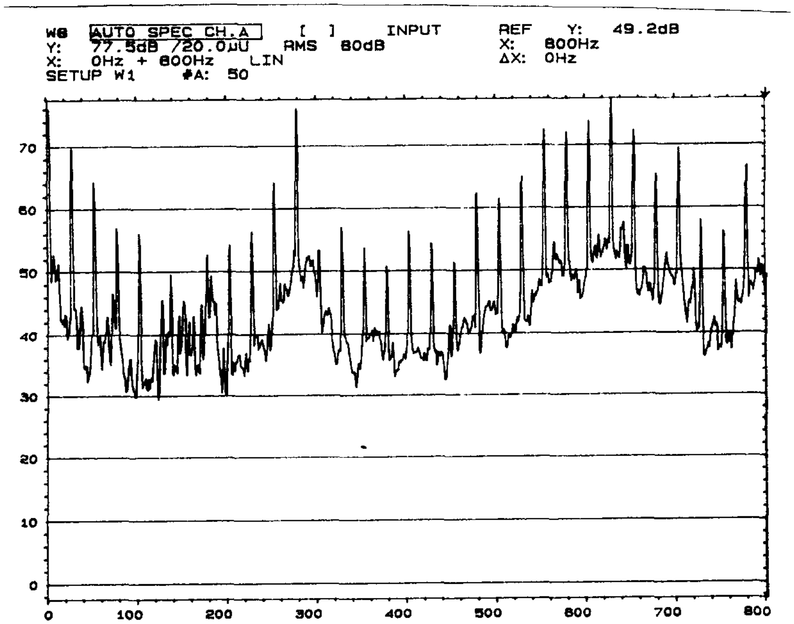



Figure 2

We have choosen the most meaningful frequencies of the noise spectrum examining the graphic of figure (4) that shows the coherence function. Table (1) shows the mean value of sound pressure levels measured on the reference plane on the intersection of the barycentric axis of the compressor perpendicular to the the reference plane itself.

| Hz | 25 | 50 | 100 | 125 | 275 | 575 | 625 |
|---|---|---|---|---|---|---|---|
| dB lin | 70 | 65 | 55 | 46 | 76 | 71 | 77 |

Table (1)

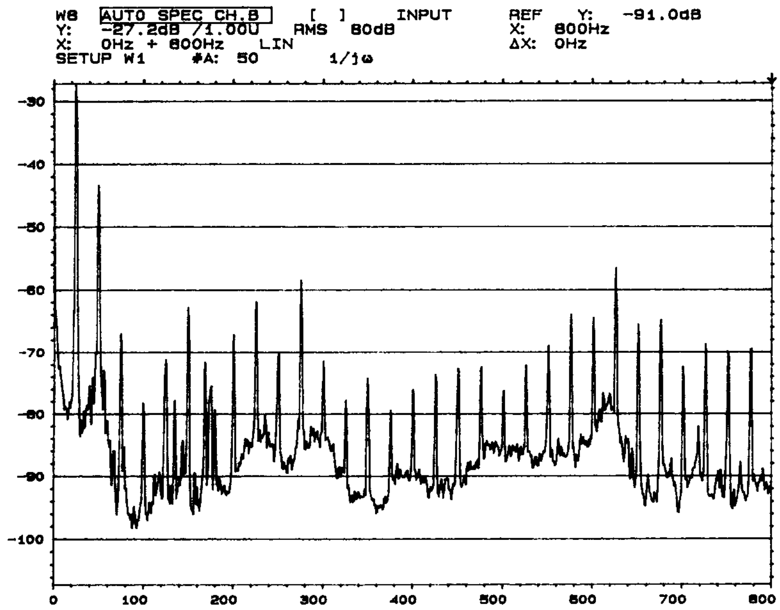



Figure 3

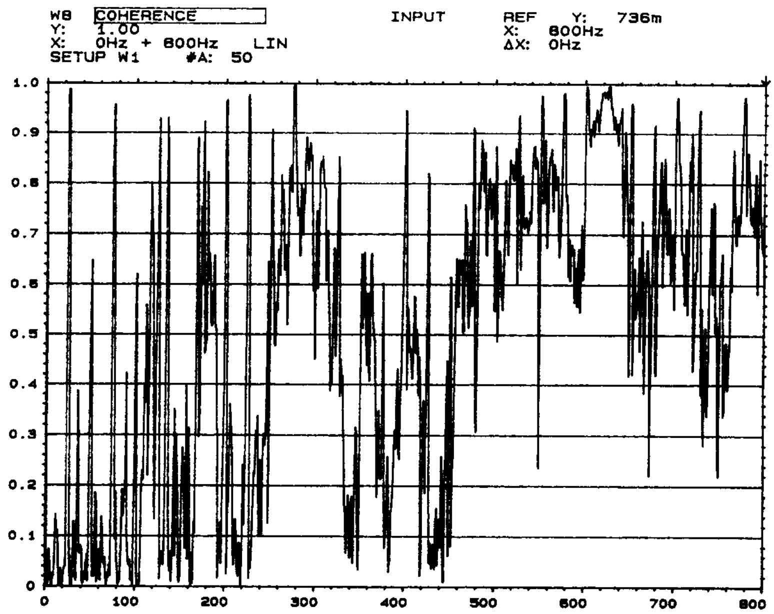
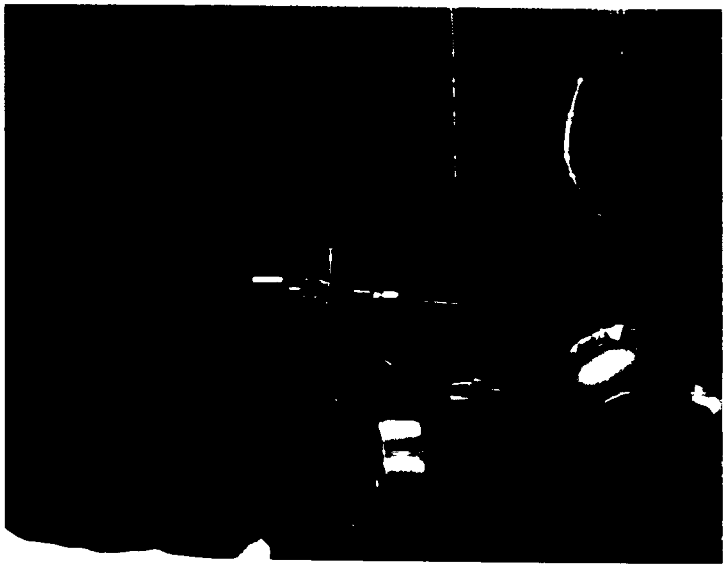



Figure 4

We measured the vibratory velocity on 54 points on the surface of the compressor. The vibratory velocity values, measured in the normal direction to the surface, represent the boundary condition to apply to the acoustic model of the source for the solution by boundary element method. We suppose that there isn't a sensible reaction of the fluid (air) on the structure and then we can accept the condition that the normal component of the particles velocity equals the vibratory velocity normal to the structure.



Picture 2

ACOUSTIC MODEL CONSTRUCTION

The main steps in the acoustic model construction are:
1- Geometry definition
We examined the case of a sound source emitting in the surrounding air, that is a common problem of "infinite" or "external" kind, so the directions of the normals to the surface are fundamentals in the model construction and they must be directed to the internal of the source. In the BEM program called BEASY, used for the problem solution, the following commands allow the automatic check for surfaces orientation:

CHECK-GEOM
DIRECTIONS

After the geometric construction of the surface, it is important to define the elements on the surface itself. It is recommended to have at least four square elements for wavelength, and this number must arise if the element order decreases.
2-Material Property Definition
The following commands allow to define the materials properties:

FLUID DENSITY
REFERENCE PRESSURE
SOUND SPEED

In our case we have set the characteristic values of medium air that is the fluid interested to the propagation of acoustic phenomenon. The reference pressure $p_0 = 2 \cdot 10^{-5} \frac{N}{m^2}$ allows to calculate the sound pressure levels of sound pressure (spl) in dB.
3-Load Definition
The loads are defined by the BODY-LOAD menu with three options:

FREQUENCY
POINT SOURCE
LINE SOURCE

The set frequency must be congruent with the mesh kind created before. In our test we found the problem solution for seven frequencies and we utilized for each frequency the same material properties with different boundary conditions.

4-Boundary Condition Definition

The LOAD+BCS menu allows to apply the boundary conditions or on the patches or on the elements. The main available boundary conditions are:

VELOCITY POTENTIAL
NORMAL VELOCITY
ACOUSTIC IMPEDANCE
ACOUSTIC PRESSURE

All the boundary conditions can be expressed as complex values, composed by real and imaginary parts.

## CONCLUSIONS

The model BEM solution provided the data in table (2)

| Hz | 25 | 50 | 100 | 125 | 275 | 575 | 625 |
|---|---|---|---|---|---|---|---|
| dB lin | 59 | 60 | 49 | 52 | 77 | 72 | 78 |

Table (2)

These data are referred to the barycentre of reference plane utilized for experimental measurements. From the comparison between the experimental data (table 1) and numerical data (table 2) we can see that for low frequencies the values are different enough because of complex nature of medium acoustic impedance, while for high frequencies the reactive component of acoustic impedance decreases and the values coincide. This because we approach to the plane wave condition and so the acoustic impedance tends to be real.

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