ARCHIVES OF ACOUSTICS
33, 4, 643–652 (2008)

REDUCTION OF STRUCTURAL NOISE INSIDE CRANE CAGE BY PIEZOELECTRIC ACTUATORS – FEM SIMULATION

Marek S. KOZIEŃ[(1)], Jerzy WICIAK[(2)]

[(1)] Cracow University of Technology
Institute of Applied Mechanics
Al. Jana Pawła II 37, 31-864 Kraków, Poland
e-mail: kozien@mech.pk.edu.pl

[(2)] AGH University of Science and Technology
Department of Mechanics and Vibroacoustics
Al. Mickiewicza 30, 30-095 Kraków, Poland
e-mail: wiciak@agh.edu.pl

(*received March 15, 2008; accepted November 5, 2008*)

In the paper the finite element simulations of the reduction of the noise inside the crane cage by piezoelectric actuators glued to chosen external walls is discussed. The whole cage structure and internal acoustic medium is modelled and piezoelectric elements are dispersed. The first two lower natural frequencies are considered. The completely different results of reduction are obtained for the analysed modes. The aim of the analysis is to show the possibility of application of piezoelectric elements to active noise and vibration cancellation for the realistic machine structure as crane cage.

Keywords: piezoelectric elements, finite element method, structural noise, active method.

1. Introduction

The fields of active control and adaptive structures have evolved over the past 25 years. Early efforts focused on the integration of distributed sensors and actuators to target specific structural modes for application in sensing, actuation, or both [2, 8, 12].

DIMITRIADIS *et al.* [9, 10] developed a detailed model that characterize the interaction between the piezoelectric material and the structure so that they could investigate the use of piezoelectric actuators to reduce the sound pressure radiated by thin circular and rectangular plates. They concluded that these types of actuators show great promise for controlling the vibration in distributed systems and subsequently the control of sound radiation. It was shown that the shape and position of the actuators markedly affects the distribution of the response among the different modes.

It was also shown that actuators directly coupled to the structure in coupled structure-acoustic problems yield a higher noise reduction [13, 14] (active structural acoustic control – ASAC).

The active control methods were effectively implemented in a wide variety of applications, including control of vibration of the large space structures, vibration and noise in an aircraft, or in cars [18, 19, 30, 31].

Feed forward and feedback control schemes have been studied and various models and control techniques have been established in the field of active noise control and ASAC e.g.: linear quadratic regulator, linear quadratic Gaussian, X-filtered LMS algorithms, adaptive filter techniques, robust control techniques, modal control techniques [15–17, 24, 29, 34].

There are well known papers discussed the noise and vibration passive cancellation problems in the whole cages of cranes, building machines or tractors analysed experimentally and numerically by SEA, BEM and FEM [11, 25, 27, 28]. However there is no papers presented the problems of active reduction by piezoelectric elements.

The aim of the paper is to model and simulation of vibrations of the cage and to show possibilities of application of piezoelectric elements to reduction of structural vibrations, and thus to reduction of radiated structural noise. These elements are mounted (glued) to external surfaces of the cages elements and are activated by the applied voltage variable in time. To reduction of vibration, the elements should be placed in optimal positions on the elements, which depends on the forms of vibrations (modes). Moreover, the amplitude of voltage is important. The next important problem is choosing the optimal control algorithm which can activate, in the case of broadband excitation, a few modes. The simulations were done by the authors previously, to answer some of the mentioned problems. The finite element computer package Ansys [1] was applied in the analyses.

The first authors' simulations [21] in which system of two L-shaped plates was modeled, shown possibilities of application of the finite element method in low frequencies and statistical energy analysis in high frequencies to analyse the acoustic radiation by vibrating systems of plates. In the second simulations [22, 23, 32] the whole cage of heavy duty machine was modeled. It was shown possibility of influence on the sound radiation by changing geometrical parameters of the realistic system (thickness of the roof and walls). The third simulations was connected with reduction of noise radiation by the vibrating single plate with system of piezoelectric elements in the forms of line and crossed strips. The analysis show possibility of application of the finite element package Ansys to analyse such group of problems, and show influence of applied voltage amplitude on the sound radiation. The configuration of the elements were not so optimal, therefore the next, fourth group of analyses were preformed [35–37, 39, 40]. In this simulations the single plate with dispersed configuration of piezoelectric elements were analysed. It was shown, that configuration of the elements has important influence on the level of radiated noise.

The discussed simulations makes possible to built the general finite element model of the whole realistic cage with piezoelectric elements dispersed on chosen walls and roof. The model gives possibility to perform many of simulations which show effectiveness of application of the piezoelectric concept of sound radiation for the realistic systems of vibrating plates. Some aspects of simulations are discussed in the paper.

2. Methods of numerical simulations of vibroacoustic processes in cages

The following computer methods can be applied to analysis of vibroacoustic process of radiation of structural sound: the finite element method (FEM), the boundary element method (BEM) and the statistical energy analysis (SEA). The acoustic analyses often apply the energy attempts, and use the definition acoustic intensity vector. Among this methods the hybrid one [20] is useful. It makes possible to estimate the acoustic intensity vector, produced by system of small areas, in chosen point in acoustic medium. The application of previously mentioned theoretical methods depends on the frequency range. For the low frequencies, the finite element method or the boundary element can both be applied. For the high frequencies the statistical energy analysis has to be applied. The low frequency analysis and the high frequency names do not simply connected with the range of frequency, but is combined with the modal characteristics of the analysed system i.e. modal density and modal damping.

3. Reduction of vibration and structural noise in cages

3.1. Geometry of cage. Finite element model

The realistic crane cage has been taken to the analysis. The cage was previously experimentally investigated, having in mind its vibroactivity [33, 38]. The structure of cage was modeled by solid element *solid45* in elastic case. Piezoelectric elements was

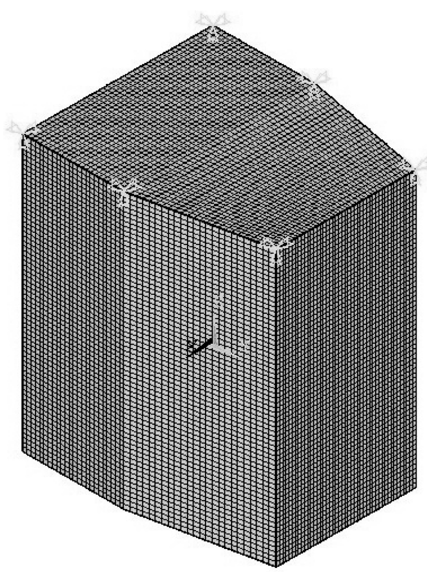

Fig. 1. FEM model of the crane cage.

modeled by the structural-electric elements *solid5*. The internal acoustic volume was modeled by structural-acoustic element *fluid30*. The finite element model of the structure is shown in Fig. 1. Due to solid character of applied elements the junction between plates (walls) must be modeled separately. The finite element mesh near the corner of cage is shown in Fig. 2. The boundary conditions was modeled as fixed for displacements for all directions for the whole six corners of the cage's roof.

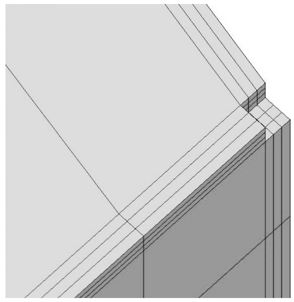

Fig. 2. FEM mesh near corner of the cage.

The piezoelectric elements in the form of cuboid form with dimensions $200 \times 200 \times 1$ [mm], were placed in the form of four pairs on all external surfaces of the cage's walls of its back part. Configuration of the glued elements comes from the mode shapes of the lowest modes and is based on the experiences from the previously made analyses. Distribution of piezoelectric elements is shown in Fig. 3.

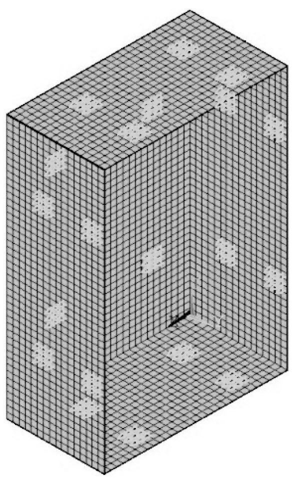

Fig. 3. Distribution of piezoelectric elements.

All the walls of the back part of the cage and the roof are made of steel, and the walls of the front part of the cage and the bottom wall were made of glass as windows. The piezoelectric elements are made of PZT material. The acoustic medium inside cage is air. The assumed material properties are given in Table 1.

Table 1. Material properties.

Material	PZT 4	Steel	Glass
Young modulus	–	207 GPa	53 GPa
Poisson ratio	0.29	0.29	0.22
Density	7500 kg/m^3	7820 kg/m^3	2500 kg/m^3
Modal damping coefficient	0.0003	0.0003	0.0003
Charge constants	d_{31} $60 \cdot 10^{-12}$ m·V^{-1}	–	–
	d_{33} $200 \cdot 10^{-12}$ m·V^{-1}	–	–
	d_{51} $265 \cdot 10^{-12}$ m·V^{-1}	–	–
Relative permitivity	$\varepsilon_{11}/\varepsilon_0$ 680	–	–
	$\varepsilon_{33}/\varepsilon_0$ 800	–	–

3.2. Free vibrations of cage

In the beginning, to known the dynamic properties of the cage, the free vibrations analysis was performed. The results give the frequencies and mode shapes. Values of the low natural frequencies are given in Table 2. The results show the high modal density of structure. For the lower mode shapes there is no nodal lines on all the cage's walls.

Table 2. The lowest eigenfrequencies of the cage.

Mode No.	1	2	3	4	5	6	7	8
Frequency [Hz]	11.16	14.45	14.87	15.20	19.09	19.39	22.01	23.52

4. Reduction of structural noise by piezoelectric elements

For the analysis of noise and vibration reduction by piezoelectric elements, the excited vibrations of the cage was analysed. It was assumed, that excitation has the form of concentrated load (force), harmonically variable in time, with amplitude of 1 N, and put in the middle of the line of connection of the rectangular and trapezoid elements of the cage's roof. The reduction of vibrations, and structural noise were done by activate of piezoelectric elements glued to the steel walls of the cage in its back part. The first two modes was examined.

In the beginning the optimal value of the voltage was found by step by step method. Voltage amplitudes were been changed in the range of 0–300 V, taking into account polarization too. The control parameters were amplitudes of bending vibrations for plate elements with maximal modal displacements and the amplitudes of pressure level in the volume, where hand of the operator is placed.

The results of simulation are completely different for the considered modes. For the first mode the noise reduction is not spectacular. The reached value of reduction is only about 2 dB (from 87.5 dB to 85.5 dB), and distribution of pressure inside cage, especially in the chosen control volume seems to be not enough and show difficulties of the method. In Fig. 4 the amplitude of pressure level for the cross-sections of the volume are shown for the case of the first mode with no activated elements is shown.

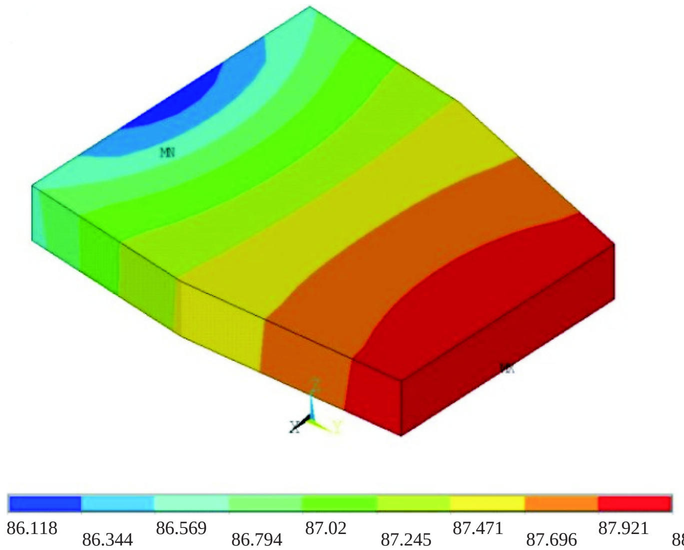

Fig. 4. The sound pressure level in the horizontal cross-section ($z = 0.7$ m) for the first resonance frequency (non activated piezoelectric elements).

The completely other results were obtained for the second mode. The value of pressure reduction is about 17 dB (from 80 dB to 63 dB), and optimal pressure distributions inside cage, with minimal values in the control volume (see Fig. 5 and Fig. 6) show possibility of application of the method for realistic structure.

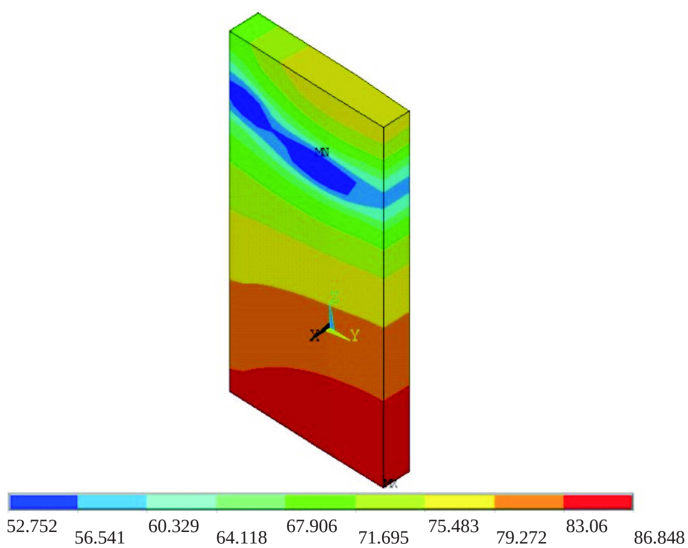

Fig. 5. The sound pressure level in the vertical cross-section ($x = 0.7$ m) for the second resonance frequency (activated piezoelectric elements).

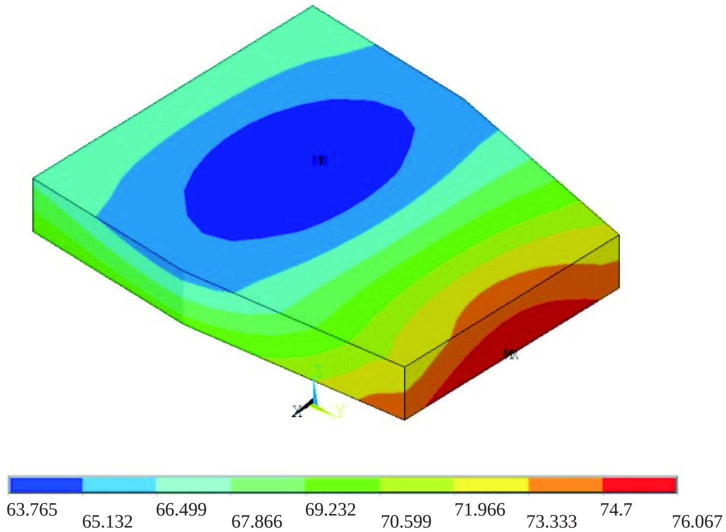

Fig. 6. The sound pressure level in the horizontal cross-section ($z = 0.7$ m) for the second resonance frequency (activated piezoelectric elements).

The two different results of reduction for the analysed forms show indeed, that further analysis should be performed. They should be focused on configuration of piezoelectric elements and the control algorithm.

5. Conclusions

Results of the numerical analyses show the possibility of application of the piezoelectric elements to reduction of the structural vibration for realistic big engineering structures made of plate type elements, as crane cages. However, the obtained results show, that for such relatively big elements, the piezoelectric damping effect has to be designed for spectacular results. The effect can be increased by:

- Optimization of the number and distribution of piezoelectric elements. These depends on the actively vibrating mode shapes.
- Optimization of the voltage amplitudes. They can be different for different vibrating modes (thus depends on amplitudes of vibration of modes).
- Choosing the groups of piezoelectric elements due to different mode shapes controlled separately with different voltage amplitudes.
- Application of the control algorithm for choosing element and amplitudes, as eg. LMS algorithm for ANC.

The next simulations and experimental tests, having in mind the discussed new ideas, are in progress.

Acknowledgment

This study is a part of the research project 4T07B 03429 supported by the Ministry of Science and Higher Education, Poland.

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