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THE ACOUSTIC CURTAIN - A NEW LOCAL METHOD FOR GLOBAL ACTIVE NOISE CONTROL

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Abstract
The paper presents numerical investigations on a local approach for global active noise control. This method is based on the interruption of the sound transmission into an interior by a local approach of anti noise generation. Using the Finite Element Method the concept has been applied to analyze the acoustic field of a rectangular enclosure. In order to eliminate a primary disturbance, a secondary sound field has been superimposed created by sound sources that have been placed next to a local hot spot. The amplifications of these secondary sound sources have been determined by the application of the LSQR-Algorithm. The results of numerical investigation show that a significant global reduction of the sound pressure level can be expected by the application of the new local concept. Furthermore, it has been found that the amount of noise reduction depends not only on the number of sensors but also on their placement.

INTRODUCTION

In many situations global pollution of interiors with noise is caused by a local transmission of sound through a limited number of transmission paths. In order to reduce unwanted noise globally, global sound reduction techniques have been applied in the past. But this is not necessary, if a local hot spot – responsible for the transmission or radiation of sound – can be identified.

Several sound source identification techniques have been described in the past, see [1]-[3], [7], [11]-[14] whereas studies about active noise control systems (ANS) can be found in [4]-[6] and [8]-[10]. It is obvious that due to the numerous publications in this field the list of references cited in this paper is not complete.

Recently numerical investigations have been performed to study a new concept – the acoustic curtain. They prove that the sound transmission into an interior can be blocked successfully by a local approach of anti noise generation, if a local hot spot, like an open window has been identified.

Following, the main idea of this concept is presented by the example of a reverberation room that is polluted with tonal noise – transmitted trough a window. The primary noise that results in sound pressure levels of 100 dB in the reverberation room is generated in an associated anechoic chamber. In order to eliminate this primary disturbance, a secondary sound field is created by secondary sound sources that have been placed next to the window. The amplification of these secondary sound sources has been determined by the application of the LSQR-Algorithm. This example has been studied numerically. Therefore, the Finite-Element-Method has been applied.

GLOBAL CONTROL OF INERIOR NOISE

Problem definition

The problem that has been investigated is illustrated by Fig. 1. A primary disturbance is generated by the sound sources – placed in an anechoic chamber – and afterwards transmitted into a reverberation room.

The transmission path is given by an open window. Therefore, the acoustic hot spot is known. An identification process, as described in [2] and [12], is not necessary.

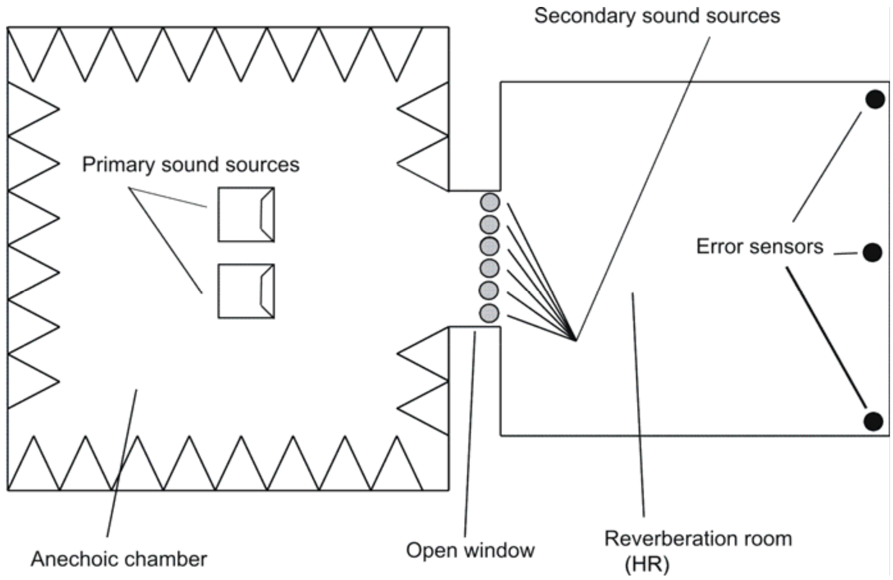

Figure 1 – Local transmission of sound into interior

Due to the assumption that a global reduction of the unwanted noise is possible if the anti-noise is generated at the local hot spot the secondary sound sources – symbolized by grey circles – are placed at the end of the transmission path.

Error sensors are symbolized by black circles. They are necessary to determine the sound pressure of the uncontrolled and the controlled system.

Numerical investigations

In order to analyze the problem that has been formulated in the first section the Finite Element Method has been applied to a rectangular enclosure (length: 18 *m*, wideness: 4 *m*). The FE-Method for the time-harmonic analysis of undamped interior noise problems is based on the Helmholtz equation

$$\Delta p(\mathbf{x}) + k^2 p(\mathbf{x}) = 0; \qquad [k] = [m^{-1}] \tag{1}$$

where Δ represents the Laplace-Operator and $k = 2\pi f / c$ the wave number that is determined by the excitation frequency f and the speed of sound c. The corresponding boundary conditions (BC) are given by the Neumann BC for the acoustic pressure

$$p = \overline{p} \qquad on \qquad R_p , \tag{2}$$

and the Dirichlet BC for the normal component of particle velocity

$$-\mathbf{n} \cdot \frac{1}{\rho} \nabla p = i(2\pi f)\overline{v}_n \quad on \quad R_v . \tag{3}$$

As stated in [3], discretization of (1) using the FE-Method leads to a set of algebraic equations for the sound pressure that can be summarized as:

$$\mathbf{Kp} = \mathbf{v} . \tag{4}$$

$\mathbf{K}$ is the stiffness matrix, $\mathbf{p}$ the vector of the excess pressure and $\mathbf{v}$ a vector that is proportional to the particle velocity in the sound field, and therefore called generalized velocity vector. The solution of (4) with respect to the BC leads to the unknown pressure field $\mathbf{p}$.

As described in [10], the sound pressure of the controlled sound field measured at the positions of the error sensors is given by the superposition of the primary disturbance $\mathbf{p}_p$ and $\mathbf{p}_s$, the sound pressure generated by the secondary sound sources

$$\mathbf{p} = \mathbf{p}_p + \mathbf{p}_s = \mathbf{p}_p + \mathbf{T}\mathbf{p}_s^L . \tag{5}$$

The vector $\mathbf{p}_s^L$ contains the sound pressure at the secondary noise sources. $\mathbf{T}$ is the transfer matrix between the sound pressure generated at the positions of the secondary sources and the sound pressure measured at the positions of error microphones.

In order to minimize the sound pressure at the error sensors the LSQR-algorithm has been used to find the optimal solution of (5). As outlined in [10] the optimal solution is given by

$$\mathbf{p}_s^{L,opt} = -\left(\mathbf{T}^H\mathbf{T}\right)^{-1}\mathbf{T}^H\mathbf{p}_p \,. \tag{4}$$

Three different sets of error sensors have been considered. For the first one all nodes of the finite element mesh have been used to compute the residual error. The second set includes the error sensors (1) – (4), as shown in Fig. 2. The third set consists of the error sensor (1) – (5).

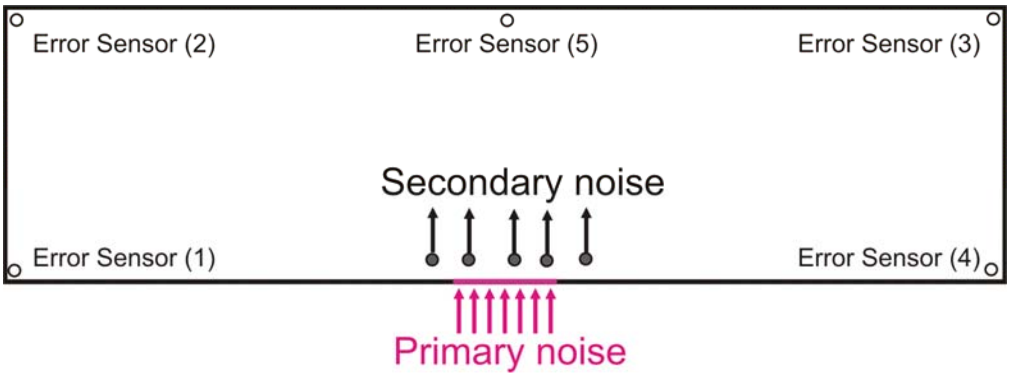

Figure 2 – Different set of error sensors

The controlled sound field has been computed for three different excitation frequencies ($f_1 = 90\,Hz,\ f_2 = 180\,Hz,\ f_3 = 270\,Hz$). The corresponding numerical results are shown in Fig. (3) – (4) where the sound pressure level ranges between a minimum value of $0\,dB$ (blue) and a maximum value of $110\,dB$ (red).

It is obvious that an acceptable global reduction of the unwanted noise can be obtained, if the first set of error sensors is used to calculate the secondary sound pressure $\mathbf{p}_s^{L,opt}$. But it turned out that the residual noise can be reduced further, if less error sensors (sensor second and third set) are used – especially at low frequencies ($f_1 = 90\,Hz,\ f_2 = 180\,Hz$) as shown in Fig. 3.

The influence of the set of error sensors on the performance of a local ANS is described in [5] and [9]. The present study shows that the optimal placement of error sensors will be very important by the application of the new concept to real systems too. Furthermore, it was found that a successful global control of sound can not be expected with locally generated anti-noise using a reduced set of error sensors, if the number and positions of these sensors are not optimized, as illustrated by Fig. 4.

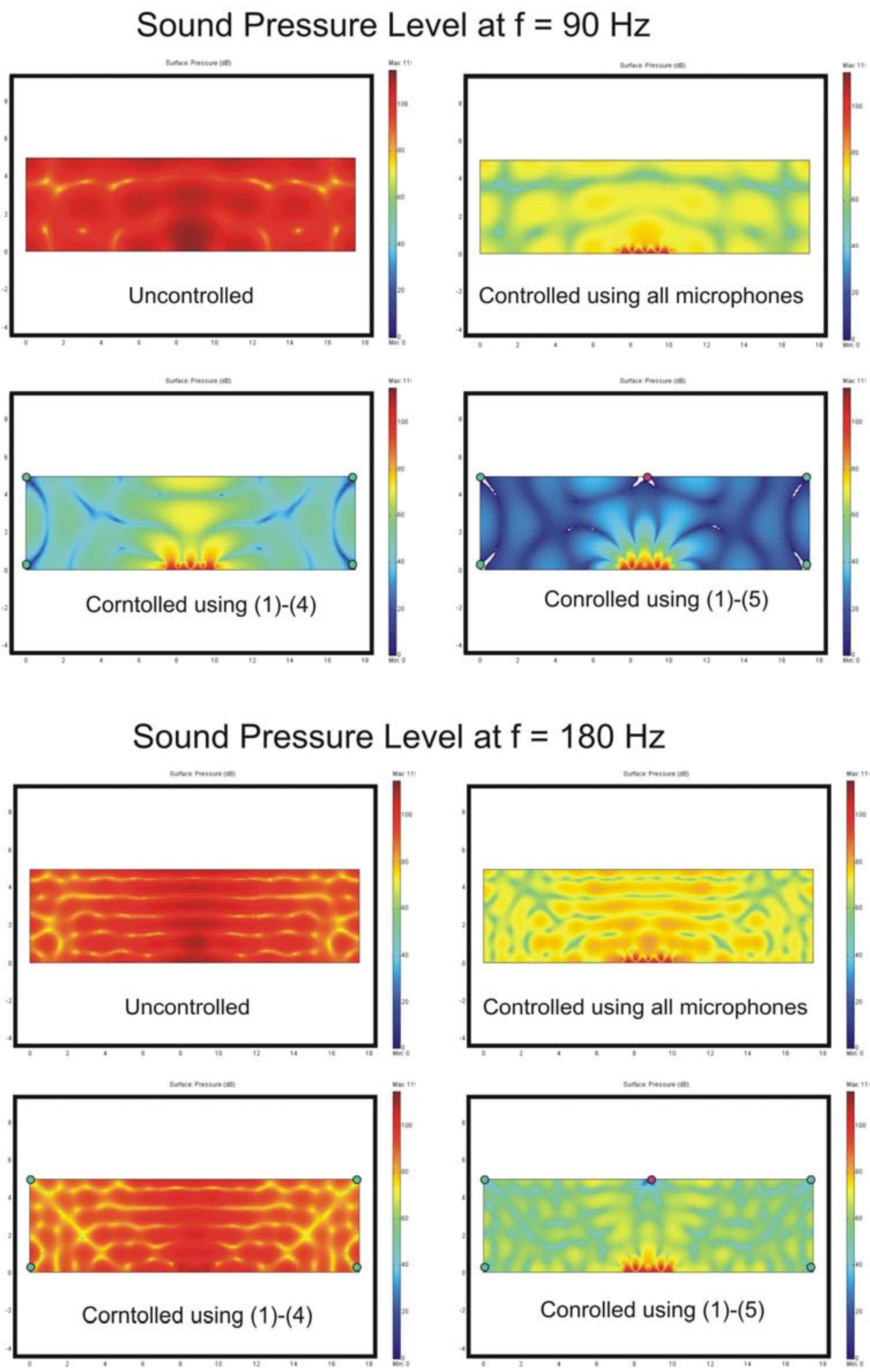

Figure 3 – Active control of sound at f_1 = 90 Hz and f_2 = 180 Hz

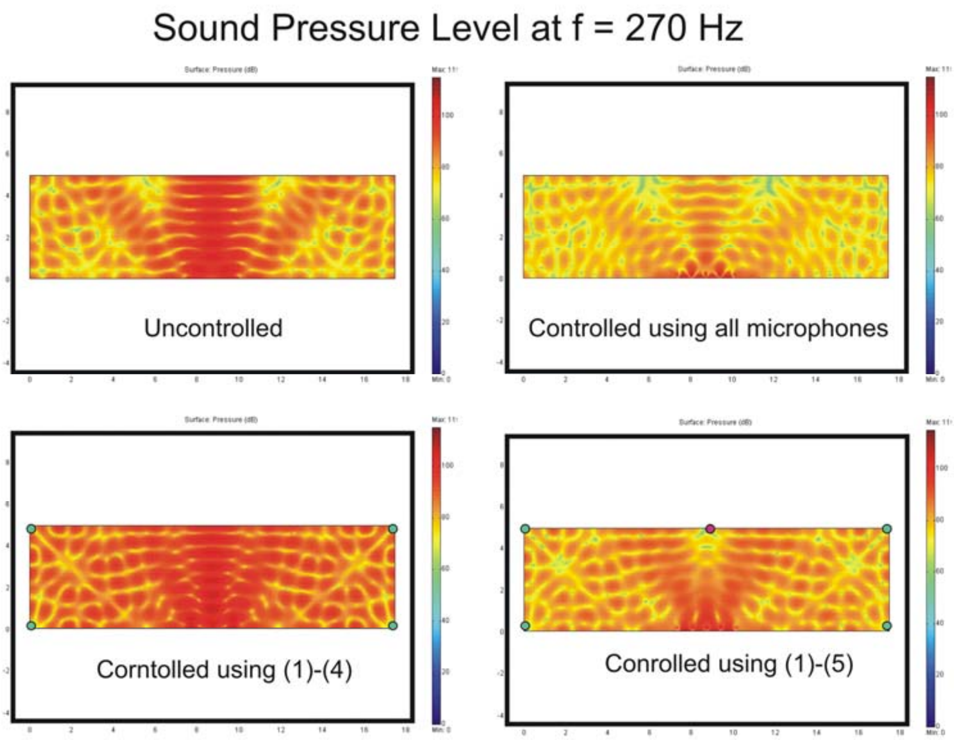

Figure 4 – *Figure 3 – Active control of sound at f_3 = 270 Hz*

Some remarks on first experiments

In order to verify the results of the numerical calculations first experiments have been performed. Therefore, an experimental setup has been build that corresponds with the problem definition given above. As shown in Fig. 5, four secondary sources and three error sensors have been used.

Figure 5 – Local transmission of sound into interior

Due to the performance data of the secondary sound sources the primary disturbance has been generated at $f = 107\,Hz$. In order to control the sound field a multi-channel FxLMS-Algorithm running on a digital signal processor has been used. Details about the structure of this algorithm and its Matlab-implementation can be found in [5].

While four error signals at fixed positions have been used for the adaptive algorithm the global noise reduction has been determined using a handheld analyzer. It was found that the sound pressure level was reduced globally. A noise reduction of approximately $-20\,dB$ has been measured at the positions of the error sensors. At all other positions a reduction of at least $-14\,dB$ has been determined. The results of these first experiments prove that the active acoustic window is capable of reducing unwanted noise globally, especially at low frequencies.

SUMMARY

A new local approach to global active noise reduction has been presented. This method is based on the interruption of the sound transmission into an interior that can be achieved, if the secondary sound sources are located next to the sound transition area. The results of numerical investigation indicate that a significant global reduction of the sound pressure level can be expected by the application of the new local concept.

It turned out that the amount of global sound pressure level reduction depends not only on the number of sensors but also on their placement. In order to choose the optimal position, the sound pressure distribution of the primary noise field has to be analyzed. Future research will be focused on the improvement of the presented method in order to control higher frequencies using an optimized set of error sensors.

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REFERENCES

[1] Christensen J., J., Hald, J., “Beamforming“, Techn. Review, Brüel & Kjaer, No. 1, (2004).

[2] Drenckhan, J., Sachau, D., “Identification of sound sources using inverse FEM”, Proceedings of the 11th Int. Congress on Sound and Vibration, Stockholm, Sweden, (2003).

[3] Drenckhan, J., Sachau, D, “Identification of sound sources using inverse FEM” 7-th Int. Symposium “Transport Noise and Vibration 2004“, St. Petersburg, Russia, (2004).

[4] Elliott S. J.: Signal Processing for Active Control. (Academic Press, San Diego, CA, 2001).

[5] Gerner, C., “Optimale aktive Geräuschreduzierung in Flugzeugkabinen für hohe tonale

Lärmpegel", Dissertation, Helmut-Schmidt-University/University of the Federal Armed Forces Hamburg (2005).
[6] Gorman, J. et al.: "Active Sound Control On The flight Deck Of A C130 Hercules", Active 04, Williamsburg, VA, USA, (2004).
[7] Hald, J.: "Non-stationary STSF", Techn. Review, Brüel & Kjaer, No. 1, (2000).
[8] Hansen C., H., Snyder, S., D., "*Active Control of Noise and Vibration*", E & FN SPON, (London, 1997).
[9] Kletschkowski, T.; Sachau, D.; Böhme, S.; Breitbach, H., "Optimized active noise control of semiclosed aircraft interiors", 9th CEAS-ASC Workshop, Active Control of Aircraft Noise Concept to Reality , Stockholm, Sweden, (2005)
[10] Kuo, S. M., Morgan, D. R, "*Active noise control systems: algorithms and DSP implementations*", (Wiley, New York, NY, 1996).
[11] Maynard, J.D., Williams E., G., Lee, Y., "Nearfield acoustic holography: Theory of generalized holography and the development of NAH", J. Acoust. Soc. Am., **78**(4), 1395-1413, (1985).
[12] Reibold, R., "Sound source reconstruction using fourier optics", Acustica, **63,** 60-64, (1987).
[13] Sachau, D., Drenckhan, J., "*Active control to achieve acoustic free-field in an one-dimensional environment*", 11th Int. Congress on Sound and Vibration, St. Petersburg, Russia, (2004).
[14] Sachau, D., Drenckhan, J., Kletschkowski, T., Petersen, S. "Entwicklung von Messtechniken zur Lärmquellenidentifizierung in Kabinen", Final report LUFO HH TUT-34, Helmut-Schmidt-University/ University of the Federal Armed Forces Hamburg, (2005).