REDUCTION OF COMPRESSOR NOISE BY THE ACTIVE CASING APPROACH

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The active casing approach is a method to reduce noise generated by a device enclosed in a casing. If the casing provided with the device is thin-walled, control inputs can be applied directly to it, and the whole structure can be used as an active noise barrier. It results in a global noise reduction instead of local zones of quiet when appropriately implemented. However, many devices and machinery do not possess such ready-made casings. Then, the device can be enclosed in an additional casing designed specially for the active control purpose. In this paper such scenario is experimentally investigated, where a compressor is surrounded by an additional light-weight active casing and the real noise generated by the working device is actively reduced. A feedforward adaptive control strategy is used. Filtered-x Least Mean Square (FxLMS) based algorithm in a multichannel structure is used to update control filter parameters. Advantages and limits of the proposed approach are pointed out and discussed.

Keywords: Active structural acoustic control, active noise control, real device noise, adaptive control.

1. Introduction

An excessive noise generated by devices and appliances has become a subject of high interest for recent years, both in academia and industry sector. A common protection mean is to apply passive sound-insulating or sound-absorbing materials. However, passive barriers are ineffective at low frequencies, or are inapplicable due to increase in size and weight of the device, and its potential overheating [1]. An alternative way is to use active control methods by applying a set of sensors and actuators, and running a control algorithm. Such approach has been found useful in numerous applications, including vehicles [2], aircrafts [3], windows or other openings [4, 5]. It stimulated the development of active control algorithms [6, 7]. On the other hand, the sound radiation of elastic plates and other barriers was also analyzed, e.g. in [8, 9]. It provides an appropriate theoretical background for the active control of noise emission [10, 11].

If the device generating noise is delivered with a thin-walled casing, actuators can be applied directly to the structure, and as a whole it can be used as an active barrier improving acoustic isolation of the device (e.g. a washing machine, cf. [12]). Such technique is referred to as the active casing approach, and was successfully developed and applied by the authors in previous publications [13]. On the other hand, if the device casing cannot be controlled or the device do not possess a casing of its own, it can be
enclosed in an additional casing designed specifically for the purpose of active noise reduction. When appropriately implemented, the active casing method results in global noise reduction (in an entire room or space) instead of local zones of quiet.

The aim of this paper is to further develop the active casing approach and to obtain a better insight into it. To this end, the method is applied and evaluated in this research for a real device generating excessive noise, which is a compressor, in its regular and unimpeded operations. The compressor is not originally delivered with a casing of requested properties, hence it is enclosed in an additional active light-weight casing. The mechanical structure and the laboratory setup are described in Section 2. A high number of control inputs is considered, what makes a challenge to implement such control system satisfying the real-time constrains. Therefore, the Switched-error FxLMS modification is employed [14], which reduces the computational demand. An overview of the adaptive feedforward control algorithm used to control the casing panels’ noise emission is presented in Section 3. Subsequently, the control experiments are described and the results are presented in Section 4. The paper is summarised with conclusions, advantages and limits of the proposed approach.

2. The laboratory setup: an active light-weight casing

The light-weight casing investigated in this paper is one of the three types of casings employed by the authors in the role of an active device casing [15] (remaining two are a rigid casing, with single- or double-plate panels [13]; and a real device casing, e.g. of a washing machine [12]). The considered structure is presented in Fig. 2. In contrast to a rigid casing used in the previous research, the light-weight casing is made without an explicit frame. It is made of 1.5 mm steel plates bolted together, forming a closed cuboid of dimensions $500 \times 630 \times 800$ mm. Such structure results in strong vibrational couplings between individual panels, in addition to couplings through the acoustic field inside and, to a lesser extent, outside the casing.

In this research, the casing is placed in the corner, what is a beneficial location for an active casing

Figure 1: A photograph and a schematic representation of the laboratory setup. All dimensions are given in millimetres [mm].
Figure 2: A photograph of the compressor placed inside the casing.

(it facilitates providing the global noise reduction, in the entire room or space). The active casing is placed on a sound-insulating basis. Inside the casing a compressor is placed, which generates excessive noise that needs to be reduced. The active noise reduction is achieved by controlling vibration of the casing panels in a specific manner that reduces actual noise emission (captures the noise inside). In order to achieve such goal, twenty one electrodynamic actuators EX-1 are employed. They are light-weight (115 g) actuators of small dimensions (ø 70 mm), comparing to the size of the casing. They are mounted on the casing panels from the inside. Five actuators are used for the top wall and four actuators are used for the remaining panels (the bottom is not controlled). The actuators’ arrangement and the optimization procedure used to calculate their locations have been described in [15] (the optimization index involved maximization of the controllability measure of the system).

Ten measurement microphones Beyerdynamic MM-1 are used as sensors for the experiments. The reference microphone is placed inside the casing, next to the compressor, providing the reference signal. Five error microphones are located outside the casing (as shown in Fig. 2). Such arrangement provides appropriate information related to the actual noise emission to the environment in a given frequency range (more details on this approach are given in [16]). Error microphones provide error signals used by the control algorithm. On the other hand, there are also four room (monitoring) microphones employed to evaluate the global noise reduction. They are placed at several larger distances from the casing, corresponding to potential locations of the users.

3. Adaptive control strategy

A feedforward control structure with a normalized Filtered-x Least Mean Square (FxLMS) algorithm is employed in the presented research [17]. A reference signal is acquired by a reference microphone placed next to the noise source. For the active casing problem it has been found sufficient to use a scalar reference signal.

A multi-input multi-output (MIMO) control system is employed in the presented research. However, the full MIMO FxLMS control system implementation represents a very high computational load (the considered plant has 21 inputs – vibration actuators, and 5 outputs – error microphones). A real-time implementation would require a very high computational power of the control unit. To reduce the computational complexity, a switched-error modification is applied to the control algorithm [14]. The schematic...
representation of the control system given in Fig. 3. Symbol $W$ is the adaptive control filters vector (of dimension $I \times 1$, where $I$ is the number of actuators), $P$ is the primary paths vector (of dimension $J \times 1$, where $J$ is the number of error sensors), defined between the reference and error sensors. $S$ stands for the secondary paths matrix of dimension $J \times I$ defined between the inputs of the actuators and outputs of the error sensors. The symbol $\hat{S}$ stands for the secondary path model. In turn, $x(n)$ is the estimated scalar reference signal, $r(n)$ is the filtered-reference signals matrix of dimension $J \times I$, $u(n)$ is the control signals vector of dimension $I \times 1$. Further, signals $d(n)$ and $e(n)$ are the primary disturbances vector and the error signals vector, respectively, both of dimension $J \times 1$, at positions of the error sensors where noise reduction is desired. Signal $e_k(n)$ is the $k$th selected error signal currently employed for adaption and cyclically changed as described in [14]. For more details of the control system, the reader is referred to [13].

4. Experimental results

Results of active control experiments for the light-weight casing are presented in this Section. The goal is to reduce the emission of noise generated by a compressor (primary noise source) enclosed in the casing by controlling five casing panels. Two of them (back and right panels) face the corner walls, however, vibrations they generate transfer to the other casing panels due to strong cross-couplings, therefore they are participating in the active noise reduction. The error signals are provided by the error microphones located outside the casing. Instantaneous square values of error signals are minimized by the feedforward adaptive control system employing the FxLMS algorithm. The primary disturbance is generated by a working compressor, operating in a regular manner. The considered frequency range is limited to 300 Hz, which are the low frequencies most difficult to reduce using passive sound absorbers. Such frequency range includes the fundamental frequency of the compressor equal to 66 Hz and following three harmonic frequencies.

The control performance is evaluated as noise reduction level observed by room microphones. A 300 seconds experiment was performed and presented in this paper. During its initial phase the active control was off, and the power spectrum densities (PSDs) of the signals acquired by different sensors were estimated. Then, active control was turned on. When the control algorithm converged, final 10 seconds of the experiment were used to estimate the PSDs of the signals acquired by corresponding sensors.

A set of frequency characteristics obtained for the performed experiment is presented in Fig. 4. In the last row of the Figure, the mean reduction obtained at the room microphones is shown. It is considered as the main point for evaluation of active control performance. Remaining plots present PSDs in dB scale of signals acquired by error sensors and individual room microphones, without (red) and with control (black). The levels in Fig. 4 are not scaled to SPL, however, to provide a reference point, the measurements done with a certified sound level meter at the error microphones’ locations showed approximately 75 dB SPL with the compressor turned on and without the active control system. Additionally, below each individual frequency characteristic, a reduction characteristic is also presented, calculated as a difference between noise level without and with control (reduction is marked with a blue colour).
Figure 4: Frequency characteristics for the active control experiment performed for the enclosed compressor. Red and black colours represent power spectrum densities (PSD) of acquired signals, with active control off and on, respectively. The blue colour represents the achieved noise reduction calculated as a difference between respective PSDs.
5. Conclusions

The active control of a compressor noise using the light-weight casing has been performed in the presented research. The control system reduced the excessive noise generated by a real device in its regular operations, not impeding its work. The feedforward adaptive control system with the Switched-Error FxLMS algorithm has been used. Its performance has been evaluated for multiple microphones in the room. Significant levels of global noise reduction have been obtained, reaching over 13 dB on average, and more than 20 dB for individual frequency components. It confirms high potential of the active casing approach to reduce excessive noise generated by real devices.

The evaluated configuration performed well for the fundamental frequency of the compressor noise and following two harmonic frequencies. The third harmonic was not reduced. The main reason is that the third harmonic (and following harmonics, which are not included in the presented plots) was significantly weaker than previous frequency components, what would make it less noticeable by the control algorithm adaptation in the minimised error signals. On the other hand, the employed configuration of five error sensors limits the operational frequency range of the control system, for which the global noise control can be achieved (for higher frequencies, the noise reduction at error microphones may not result in a global reduction). This is due to lack of observability of the actual noise emission of the casing at higher frequencies. This aspect has been discussed in more details in [16].

It is noteworthy that the microphones placed outside the casing can be replaced with structural sensors (e.g. accelerometers) utilizing the Virtual Microphone Control technique [18, 19], therefore making the solution more practically feasible. Such approach would also enable to increase the number of (virtual) error signals extending further the operational frequency range of the system, without obstructing the space around the casing.

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REFERENCES


