Applying an active noise barrier on a 110 KV power transformer in Hunan

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ABSTRACT

There are increasing needs to reduce the transformer noise recently in China because some residential buildings developed recently are located more and more close to the pre-existing substations. Passive barriers are often used around the outdoor transformers to block the noise. However, the noise reduction performance of the barriers is poor in low frequency range, especially when the noise wavelength is larger than the height of the barrier. Consequently, active noise control (ANC) system has been investigated to enhance the insertion loss of traditional barrier in low frequency. In this paper, a prototype active noise barrier (ANB) was developed and applied to a practical case. Physical system of the ANB was designed in first. Then a decentralized feedforward ANC system composed of the cascaded active units was developed, and the waterproof structures were developed to protect the elements of the system. Again, experiments were carried out on the rooftop of a five-floor building to verify the effectiveness of the system. Finally, the practical application in Hunan is investigated, in which the noise reduction of the 110kV power transformers was needed.

Keywords: Active control, Barrier, Transformer noise
I-INCE Classification of Subjects Number(s): 38.2

1. INTRODUCTION

With the urban expansion, the noise pollution of the transformer has become prominent recently in China, because many new buildings, such as residential buildings, business buildings and schools, are located more and more close to the pre-existing substations. The transformer noise is made up of the fundamental frequency and its harmonics, and the low frequency noise components are the major source of annoyance [1]. The outdoor type transformer is the main complaint and building sound barriers around it is a common way to control the transformer noise. It is well known that the noise attenuation performance of the sound barrier is weak in low frequency range, due to the sound diffraction at the top of the barrier. This is against the noise control of the rich low frequency component of the transformer noise. Although the noise level is better than the national standard limit by an enough high barrier, people still complain that they suffer from the low frequency tonal noise of the transformer.

Since the technique of ANC is very effective for controlling the low frequency noise, its application to transformer noise control has been the subject of many researchers [2-9]. Several strategies have been studied according to different application scenarios. As a structural-acoustic system, the hum of the transformer is caused by its tank vibration. As a result that active structural acoustic control has been introduced to control the transformer noise. Li used 8 inertial shakers as vibration control sources to minimize the sound field radiated from a small transformer tank, which was excited by an inertial shaker at 100 Hz in an anechoic room [2]. Global control was achieved from experimental results, with 15.8 dB average sound pressure reduction at 528 monitor points on a frame surrounding the transformer. The application of loudspeaker type control sources were studied

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by more researchers. Multiple loudspeakers were arranged in linear array or planar array to reduce the transformer noise in some direction, however, the noise level increased in other direction [3-5]. Global control can be realized by large amount loudspeakers and optimal locations of control sources and error microphones [2, 6-9]. On a particular occasion, the transformer is located inside a building with one opening, a virtual sound barrier formed by loudspeaker array and microphone array was developed to “block” the noise. Wang et al reported that 15-channel virtual sound barrier system was mounted at the opening of about 1.58×3.21 m^2 to control the noise generated by a loudspeaker inside the room, and the experiment results showed that noise reduction of 15 dB for 100 Hz and 8 dB for 200 Hz in the far field was achieved [10]. In many cases, due to the existing traditional barrier, ANB which includes ANC system and the barrier should be more economical and practical.

ANB has been studied since 1990s, and research results have shown that the application of ANC systems can enhance the insertion loss of passive noise barrier in low frequency [11-12]. Most of the previous studies are concerned with the physical system design for the ANB, which includes: (1) the arrangement of the ANC physical elements, i.e. the locations of control sources and error sensors [11-14]; (2) the optimization of the physical system, such as the comparison of different cost functions and the optimization of control sources directivity [15-16]. To analyze the ultimate performance of the ANB systems, the feedforward centralized control system is often selected in academic studies, with the ideal reference signal coming from the signal generator which feeds the signal to the primary source. Therefore, it isn’t suited for in application field due to its complexity and expensive cost. Instead, the decentralized feedback control system was applied in some previous works, due to its compactness and easy implementation [17-19], and the most practical ANB system also used feedback control system, which is called Product-type Active Soft Edge (ASE) Noise Barrier [17]. However, the performance of feedback control is limited due to its strict stability requirements and the waterbed effect [20].

The ANB with decentralized feedforward control system was proposed and its feasibility was verified by simulations and experiments [21]. In this paper, a product-type ANB using decentralized feedforward ANC system was developed and applied to a practical case. Physical system of the ANB was designed in first. Then a decentralized feedforward ANC system composed of the cascaded ANC units was developed. Finally, the experiments were carried out on the rooftop of a five-floor building. The practical application in Hunan is underway, in which the noise reduction of the 110kV power transformers was needed.

2. DESIGN OF THE ANB SYSTEM

2.1 Physical system

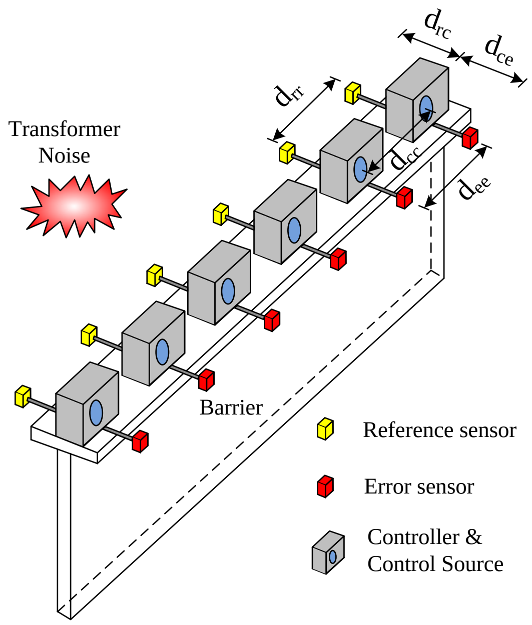

Figure 1 – Configuration of the ANB system

The configuration of the ANB is shown in Figure 1. The decentralized feedforward ANC system is on the top of the barrier, which is formed by multiple single-channel ANC systems. Each ANC system consists of a control source, a reference sensor, an error sensor, and a single channel controller. The single-channel systems are equally spaced in lines, so the spacing between the control sources d_{cc}, the spacing between the reference sensors d_{rr} and the spacing between the error sensors d_{ee} are equal. The reference sensor, control source and error sensor of a single-channel system are separated by d_{rc} and d_{ce} respectively.

It has been demonstrated by Omoto's work that the control is stable and effective when the interval between the error sensors is less than a half-wavelength of the noise signal [11-12]. Therefore, this interval is chosen according to the expression, $d_{cc} < c / f_H / 2$, where c is the speed of sound in the air and f_H is the maximal frequency concerned. f_H is set at 400 Hz for the noise of the first four harmonic frequencies of the transformer noise is dominated. As a result, d_{cc} is no larger than 0.43 m.

The noise reduction in the target region is maximal when error sensors of the ANC system are located at the certain locations in the target region. However, with the ANB system, this sort of arrangement results in inconvenience by locating the error sensors in the far field and reducing the robustness [21]. Near field error sensor locations were selected, where the interval between the error sensor and the control source d_{ce} was 0.2 m. This interval cannot be very small, or else the poor performance will be obtained due to the small control effort of the control sources [21].

To guarantee the causality of the ANC system, the location of the reference sensor should meet the constraint of $d_{ne} > d_{nr} + d_{ce}$, where d_{ne} and d_{nr} are the distances from the transformer to the error sensor and the reference sensor, respectively. In view of the latency time t_0 of the controller and the circuits, the above formula should be modified to $[d_{ne} - (d_{nr} + d_{ce})] / c > t_0$. When the primary source is far enough away from the barrier, we can write the above equation as $d_{rc} / c > t_0$. With the controller used here, t_0 is about 0.5 ms, so d_{rc} is no less than 0.17 m.

2.2 Controller

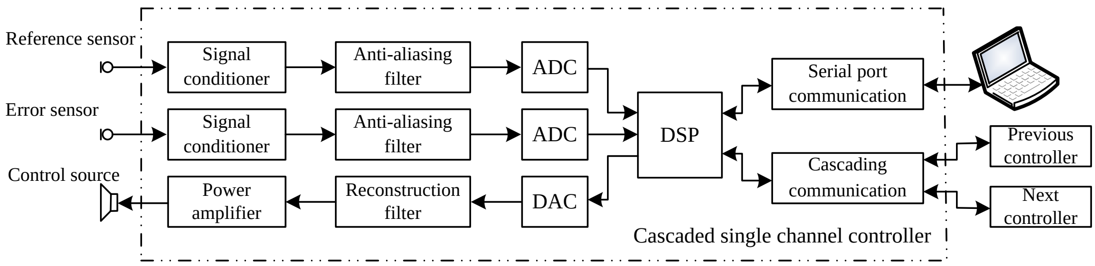

Figure 2 – Block diagram of cascaded single channel ANC unit

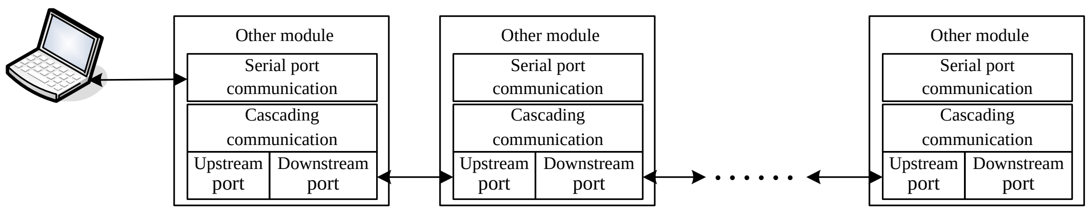

Figure 3 – Block diagram of a decentralized ANC system

A digital controller was designed for each single channel control system, which is made up of digital signal processing module, anti-aliasing and reconstruction filters, analogue-to-digital (ADC) and digital-to-analogue (DAC) converters, signal conditioners, power amplifier, serial port communication module and cascading communication module, as shown in Figure 2. The cascading communication module of each controller has an upstream port and a downstream port, and many controllers connected in sequence can form a decentralized ANC system. Only the first one needs to be connected with a computer through the serial port communication module. As shown in the Figure 3, to operate the whole system, one can input operational commands and monitor the status of the controllers by the user interface on the computer, since the relevant information can be transferred by cascading modules and serial port communication modules of the controllers. Being basic knowledge, the functions of other modules of the controller is not described in details in this study.

The TMS320VC5502 processor was used as the core of the controller, which is a fixed point DSP with a clock rate of 300 MHz, and the peak performance can be up to 600 MMACS [22]. The AD73322L was selected as the ADC and DAC converters, since it includes two16-bit A/D conversion channels and two 16-bit D/A conversion channels, with high signal-to-noise ratio and low group delay characteristic [23].The software in DSP is composed of the single channel ANC control algorithm and extra function modules, i.e., operation maintenance module and data communication module. The signed algorithm with sparse updating is using due to its low computational cost [24-25]. Low pass filter was used with cutoff frequency of 450 Hz. The user interface on computer was programmed by NI LabWindows/CVI, by which status of 16 channel controllers can be displayed simultaneously.

2.3 Control source and sensors

Weather proof solution for control sources and sensors is required due to the outdoor application. A waterproof box covered with glass fiber reinforced plastics was developed, which is divided into three spaces, as shown in Figure 4. The largest space is an enclosure of about 20×20×19 cm^3 with a waterproof 4 inches loudspeaker mounted, and the resonance frequency F0 of the loudspeaker is lower than 90 Hz. Beside the loudspeaker enclosure is a space with a downward opening, in which the controller is installed. The flat space below these two enclosures is designed for arrangement of the wires, such as electric wire, cascade lines and signal wires of the sensors and control source. Each sensor covered with a windscreen is fixed in an iron cage, of which the top and the back surfaces are sealed and the perforating ratio in other surfaces is large enough not to influence the sound transmission. In addition, inner surfaces of the cage are covered with the waterproof sheet. The error sensor is an omnidirectional electret microphone with the sensitivity about -42 dB, and the reference sensor is a unidirectional electret microphone with the sensitivity about -45 dB.

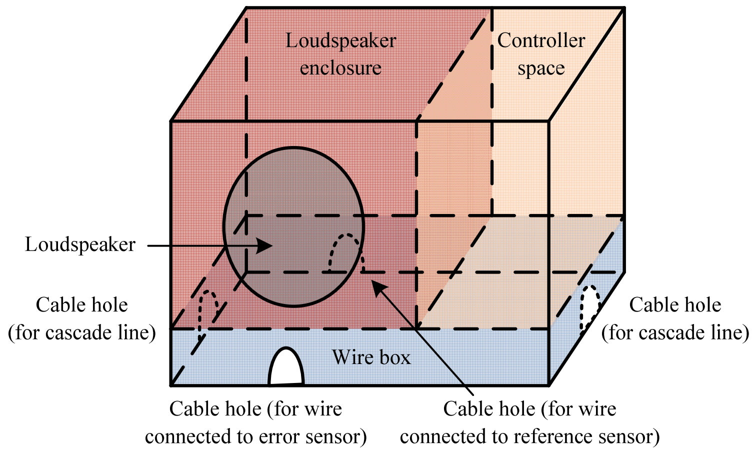

Figure 4 – The box integrated the control source and the controller

3. EXPERIMENTS

Experiments were carried out on the rooftop of a five-floor building of Nanjing University, where is close to a semi-free field. The 2 m high and 8.5 m long barrier was made of acrylic plate with 10 mm thickness, and the surface density of the barrier is about 12 kg/m^2. The noise reduction factor of the plate is about 21.0 dB above 125 Hz, so transmission sound through the barrier can be ignored, compared to the diffracted sound. A decentralized ANC system with 12 single-channel feedforward control units was placed on the top of the barrier, as described in Section 2, with d_{ce} = 0.2 m, d_{rc} = 0.5 m, d_{cc} = 0.4 m. A loudspeaker located on the floor as a primary noise, is 3 m to the barrier. Four measurement positions (P1 to P4) were on the center vertical plane of the barrier, with the distance to the barrier and the height of each position being (2 m, 1.5 m), (2 m, 2 m), (5m, 1.5 m) and (5 m, 2m), respectively. Figure 5 is a photo of the experimental setup.

Four tonal noise signals were controlled by the system in the experiment with the frequencies of 100 Hz, 200 Hz, 300 Hz and 400 Hz. It is demonstrated that the noise reduction in each error sensor location was larger than 15 dB. The control performance at measurement locations is shown in Figure 6, in which it can be seen that the tonal noise reduction was achieved in most frequencies. However, the noise level at measurement locations increased in some frequencies, especially in 100 Hz. On the one hand, the sound diffraction cannot be effectively reduced by the limited ANC channels. On the other hand, the control performance was affected by the sound reflection of the objects on the rooftop, including a glass house and the roof parapet close to the measurement locations. It is shown by the experimental results in our previous work that the system was effective to write noise as well [21].

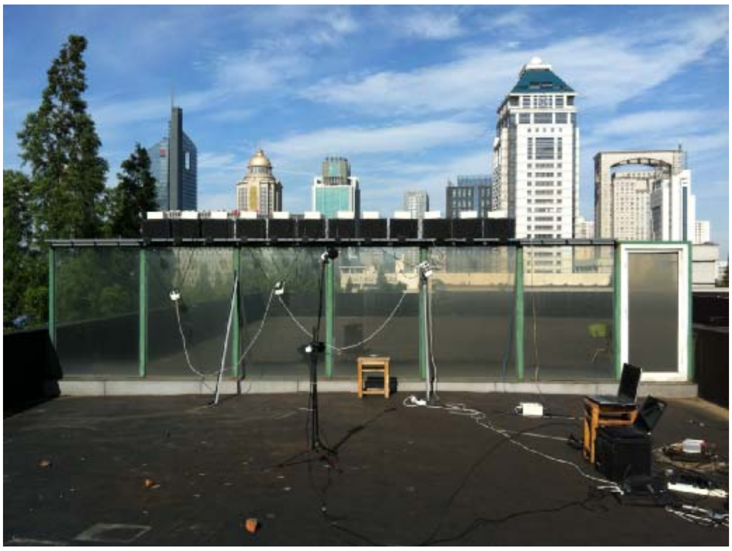

Figure 5 – Photo of the experimental setup

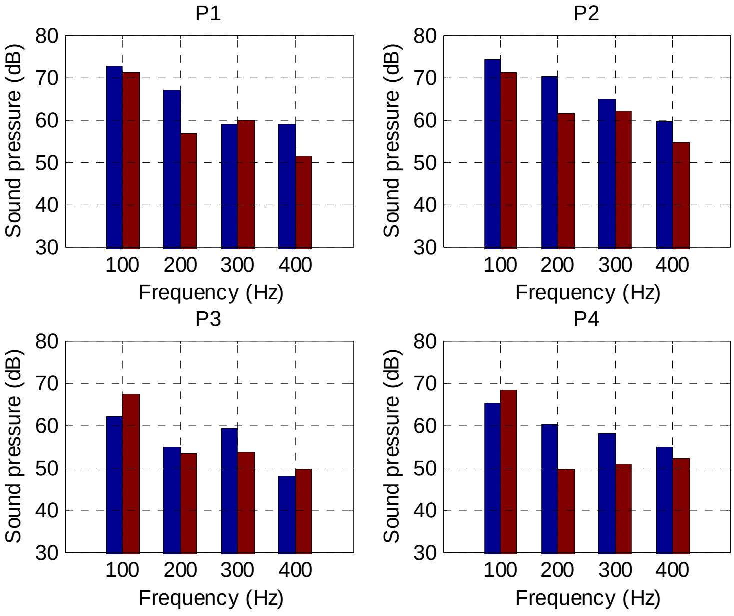

Figure 6 – Sound pressure at measurement locations, blue bar: anc off, red bar: anc on

There are three outdoor transformers in Shi Lingtang 110 KV substation, located at Changsha, Hunan Province, China. The rated loads of the transformers are 50 MVA, 31.5 MVA and 50 MVA, respectively. People lives in the buildings surrounding the substation suffered from the transformer noise that exceeds relative standards. The noise level at south boundary of the substation exceeded 50 dBA, as shown in Figure 7. To reduce the noise, a 12 m height barrier will be built with the length of 51 m in the east, 16 m in the north and in the south. Only 6 m height barrier will be built in the west, with the length of 3 m in both sides for safety requirements. However, it is likely that the noise level in the south boundary cannot meet the standard, due to the sound diffraction of the low frequency noise in the west. A decentralized ANC system of about 30 channels will be installed on the top and at the north vertical edge of the south 3 m height barrier, to reduce the diffraction. The work is ongoing and some results will be obtained in several months.

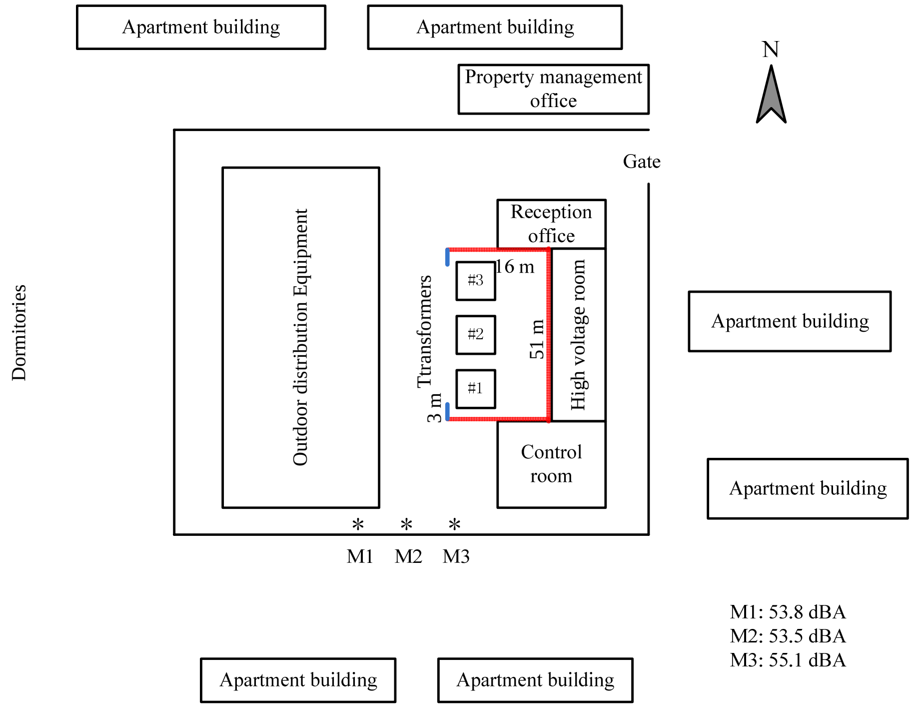

Figure 7 – Sketch map of the substation

4. CONCLUSIONS

To reduce the transformer noise, a product-type active noise barrier using decentralized feedforward ANC system was developed. Physical system of the ANB was designed according to the noise characteristics, limitation of the system time latency and easy installation. A decentralized feedforward ANC system composed of the cascaded ANC units was developed, and one can input operational commands and monitor the status of the controllers by the user interface on a computer. A waterproof box was developed to protect the control source and the controller, and the sensors ware installed in another waterproof structure, either. The experiments were carried out on the rooftop of a five-floor building, which showed the harmonics below 400 Hz should be reduced effectively. The practical application of the ANB in Hunan is underway, in which the noise reduction of the 110kV power transformers was needed.

ACKNOWLEDGEMENTS

This work was supported under Projects 11204130 and 11304152 by National Nature Science Foundation of China.

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