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# SYSTEMATIZATION OF THE PRINCIPLES OF CLASSIFICATION OF ACTIVE NOISE AND VIBRATION CONTROL METHODS

Andrei V. Vassiliev

Department of Mechanics and Environmental Protection, Togliatti State University Togliatti, 445667, Belorusskaya Str., 14, Russia

NIL9@tltsu.ru

**Abstract**

Active noise and vibration control presently is the important way to decide the problem of low-frequency noise and vibration reduction. Due to the rapid increase of books, papers and patents in this field, it is necessary to systematize the principles of classification of active noise and vibration control methods. Traditional and new approaches are investigated. The author proposes to use an energetic approach, according to which all methods and arrangements of reduction may be classified as completely passive (adaptive and non-adaptive), regenerative, active and hybrid passive-active. Other criteria include consideration of the spatial kind of low-frequency noise and vibration source, completeness of reduction, the type of spectrum, etc. The classification is illustrated by the different constructions of active noise and vibration control devices, mufflers and dampers, some of which are developed by the author.

## 1. INTRODUCTION

Environmental, occupational and domestic noise impact to the population and environment is increasing every year. Inadmissible noise levels affection leads to the population disease growth. For industrial city environment the strong noise impact to the city population is low frequency noise. Analysis of inhabitants' complaints confirms it [9]. An increased sensitivity to annoyance due to energy in the 30-50 Hz region was also found. Low frequency noise is spreading for a long distances without significant absorption. There are also some peculiar characteristics of low frequency noise affection such as the resonance of the human body, the association with natural phenomena etc. Thus, we can determine the zone of the main ecological and psychological discomfort in frequency range of low frequencies.

Another serious problem (partly connected with the above mentioned) is low-frequency vibration reduction. Specific problem is vibration influence to the operators in industry as well as transport vibration impact to the drivers and passengers. Pipeline pulsations cause vibrations may cause fatigue breakdown of pipeline and apparatus junction, disturbance of sealing airproof, decreasing of machine operating characteristics, etc. One of the main vibration sources of piston machine pipelines are low-frequency gas pressure oscillations (pulsations) spreading along pipeline main and appearing during alternating gas suction into the cylinder due to the pressure drop between cylinder recess and abutting pipeline. Of cause, we may also point out non- periodical noise and vibration generation sources.

Active noise and vibration control presently is the important way to decide the problem of low-frequency noise and vibration reduction. Due to the rapid increase of books, papers and patents in this field it is necessary to systematize the principles of classification of active noise and vibration control methods. This paper is devoted to the classification of active noise and vibration control methods.

## 2. GENERALYSATION OF CLASSIFICATION OF LOW FREQUENCY NOISE AND VIBRATION REDUCTION METHODS

Generally the classification of low-frequency noise and vibration reduction may be based on the variety principles. In Table 1 approach to the classification of low-frequency transport noise and vibration reduction methods is shown, proposed by the author of this paper.

Table 1. Systematization of criteria and types of classification of low-frequency noise and vibration reduction methods.

| № | Criteria of classification | Types of classification | Examples |
|---|---|---|---|
| 1. | The general way of low-frequency noise & vibration reduction | Reduction in the source of generation<br><br>Reduction on the ways of propagation<br><br>Individual means of protection | Noise mufflers<br><br>Acoustic barriers<br><br>Electrodynamic anti-noise headphones |
| 2. | The spatial kind of low-frequency noise & vibration source reduction | One-dimensional (ducts);<br><br>Two-dimensional (plane surfaces)<br><br>Three - dimensional<br>- Reduction inside of enclosed volume;<br><br>-Reduction in open space | Compressor pipeline vibration dampers<br>Compensation of noise spreading through the windows inside of buildings<br><br>Compensation inside of automobile passenger compartment<br>Compensation in open space of living territory |
| 3. | Periodicity of low-frequency noise & vibration generation | Periodical<br><br>Non-periodical | ICE intake & exhaust mufflers<br>Noise barriers |
| 4. | Energetic criterion | Passive<br>Active (adaptive and non-adaptive)<br>Hybrid (active-passive) | Engine capsulation<br>Active mufflers<br><br>Hybrid Helmholtz resonator |

| | | | |
|---|---|---|---|
| 5. | Completeness of low-frequency noise & vibration sources reduction | Reduction of single source<br><br>Reduction of several sources<br><br>Complex reduction | Automobile ICE exhaust noise muffling<br><br>Automobile ICE intake & exhaust noise muffling<br><br>Complex automobile low-frequency noise & vibration reduction |
| 6. | The kind of noise & vibration source spectrum | Broadband noise<br><br>Narrowband (tonal) noise<br><br>Broadband vibration<br><br>Narrowband (tonal) vibration | Noise inside of building<br><br>ICE intake & exhaust noise<br><br>Vibration dampers<br><br>Resonators |
| 7. | The kind of noise & vibration source | Airplanes<br><br>Separate automobiles, motorcycles<br><br>Power plants | Reduction of low-frequency noise inside of aircraft<br><br>Noise mufflers, vibration mounts<br><br>Active vibration reduction mounts |

Let us consider more detailed some criteria of classification.

### 2.1 The general way of low frequency noise & vibration reduction

The classical approach is to subdivide the methods and means of noise and vibration reduction on the general way (in the source of generation and on the ways of propagation) and on the meaning of reduction methods (collective and individual protection). As collective methods of protection acoustic barriers may be considered, as individual - electronic headphones.

### 2.2 The spatial kind low frequency noise & vibration source reduction

The spatial distribution of low-frequency noise & vibration source has a great significance when choosing the way of reduction. Now it is generally accepted that low-frequency noise in ventilation ducts (one-dimensional spatial distribution) may be efficiently cancelled by active noise control. For example, "Topexpress" company (England) have implemented the system allowing to reduce noise on 13 dB for the basic frequency of ventilator operation (270 Hz). Two-dimensional vibration e.g. we may find in the case of vibrating surface.

Three-dimensional noise & vibration sources are in automobile passenger compartment (the case of enclosed space) or transport noise from the several highways (the case of open space). The most complicated case is three-dimensional broadband noise & vibration cancellation. Especially difficult to reduce noise in enclosed spaces due to the modal performance of internal sound field.

### 2.3 Periodicity of low frequency noise & vibration generation

In fact the main low-frequency noise and vibration source radiate periodical sound. E.g., intake or exhaust noise of automobile internal combustion engine is caused by piston periodic operation and acoustic waves propagating in intake or exhaust ducts due to flow pulsations, so it has the periodical mechanism of generation. One of the main vibration sources of piston compressors pipelines are low-frequency gas pressure oscillations (pulsations) spreading along pipeline main and appearing during alternating gas suction into the cylinder due to the pressure drop between cylinder recess and abutting pipeline.

### 2.4 The type of low frequency noise & vibration spectrum

The spectra of noise or vibration may be very different for different kind of sources. For example, the peculiarity of intake or exhaust noise of automobile internal combustion engine is the presence of one or several maximal tonal harmonics of engine crankshaft rotation frequency [10]. So, in order to reduce significantly external engine noise it is enough often to reduce noise only for one or two harmonics.

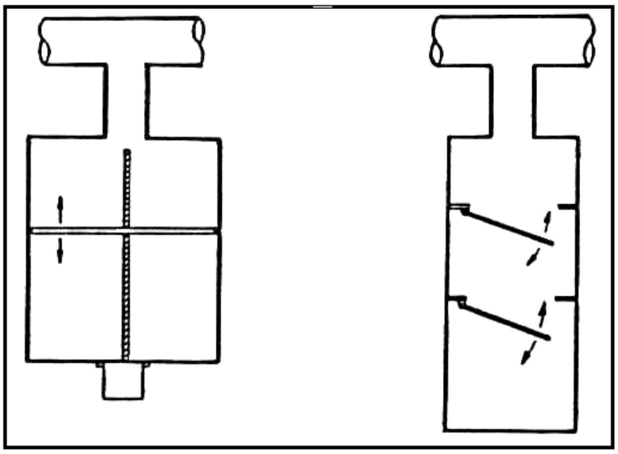
## 3. ENERGETIC APPROACH TO CLASSIFICATION

At "Inter-Noise 92" Congress Bernhard et al. [1] proposed four classifications of noise and vibration control devices: active systems, passive systems, adaptive-passive systems and hybrid active-passive systems. The progress in techniques have made it possible to implement more widely the concept of active noise and vibration control. However, there are still numerous applications where existing active or passive solutions are not effective. In this case hybrid (active-passive) solutions are promising to use.

### 3.1. Passive methods

Passive methods are traditional and admit that passive elements do not add energy to the system. They may absorb energy or change the impedance of the source such that undesirable energy is not created. Classical passive noise control example – sound absorption and sound isolation. The application of passive control is very old and we may find many efficient and low cost passive solutions. Presently there are significant efforts to increase efficiency of passive control elements. We may either use new materials, or use existing materials in more effective ways (e. g. to absorb energy more effectively). But the negative feature is that passive methods do not sufficiently reduce noise and vibration in low frequency range. In general passive methods may be subdivided to completely passive and adaptive-passive. Bernhard [2] proposed also the concept of semi-active control. Completely passive methods are the most oldest and traditional. For example, it could be using of absorbing materials or noise barriers.

Adaptive-passive methods utilize passive elements which can be tuned such that performance can be optimized over some specified range of conditions. But in this case, passive elements again cannot add energy to the system. Adaptive-passive solutions are the most efficient for narrowband applications. For example, the adaptive Helmholtz resonators described by Lamancusa [6] and shown in Figure 1 would be used for control of narrowband sound at several running speeds.



a). b).

Figure 1. Adaptive-passive side-branch resonators (from Lamancusa [6]).

Dampers with pliable walls may be considered as adaptive-passive constructions, for example, intake manifold oscillations damper of internal combustion engine, which bottom and cover are made of elastically deforming material (e.g. rubber). However this construction cannot provide maximal efficiency of oscillations attenuation. In paper [8], an adaptive-passive low-frequency pulsations damper in piston machine pipeline is presented. At least one of the damper walls is pliable. Capacity is formed by space frame fixed on rigid walls and covered with soft non-elastic casing (e.g. fabric) sagging between frame elements so as capacity volumetric change value is more than the piston machine cylinder capacity value. Such construction achieves effective pressure impulses compensation in the intake system due to exclusion of casing elastic characteristics. Another damper construction with pliable capacity is membrane-spring damper, where connection between the main and the damper is achieved through the light movable hermetically suspended membrane jointed with elastic high-pliable element, for example, soft spring. Effective pressure impulses attenuation in abutting pipeline occurs due to membrane and spring oscillation and by means of resilient characteristics of spring.

As the example of broadband adaptive-passive applications an engine mount of Graf et al. [3] could be considered, see Figure 2. All vibration excitation above the rotation speed of the engine is controlled for this application.

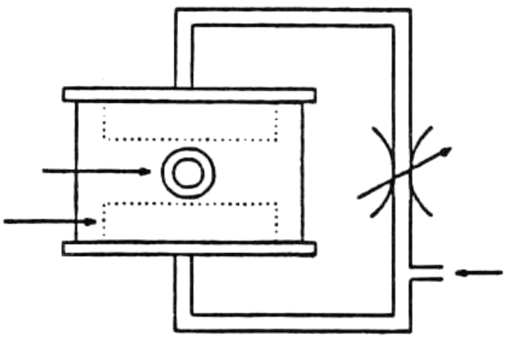


Figure 2. Adaptive-Passive Engine Mount (from Graf et al. [3]).

Special subclass of adaptive-passive schemes is the so-called semi-active control system [2]. These systems are built up of passive components with adaptive parameters. However, for semi-active systems the parameters are changed at the same rate as the excitation. The resulting control system is more capable and sophisticated that the control systems for typical adaptive-passive applications which change only at the rate that the environment changes. The semi-active system cannot add energy to the system, thus it will not cause instability. The performance of these devices can be made quite close to the performance of active systems for applications where an active system would require very little external energy.

### 3.2 Active methods

Active noise control systems are capable of putting energy into a system. Classically, these systems use loudspeakers to generate an acoustic wave interfering with the disturbance wave and are making stable system unstable. Design strategy suggests that active control and other alternatives be considered only if passive methods are inadequate. Active systems are generally relatively complicated compared to passive methods and require a source of power.

Recent years have brought a significant progress in active noise and vibration control systems developments for different kinds of transport noise reduction. Presently the world-wide companies - automobile manufacturers ("General Motors", "Ford", "Lotus Engineering", "Volkswagen", "BMW", "AUDI", "Peugeot", "Nissan" etc., specialized consulting companies ("Sound Attenuators Ltd.", "Nelson Industries", "Topexpress Ltd", "Noise Cancellation Technologies, Inc.", "Active Noise and Vibration Technologies, Inc" etc., research & development institutions and universities (National Research Development (Great Britain), Müller BBM GmbH (Germany), Fraunhofer-Gesellschaft (Germany), acoustic Institute named by N. N. Andreev of Russian Academy of Science, Togliatti State University (Russia) etc., and also such well-known companies as (Matsushita, Hitachi, Toshiba, Philips, Sharp, Lockheed etc have developed a numerous number of active silencers.

### 3.3 Hybrid (active-passive) methods

Taking to account the practical reasons, it is not the most efficient to implement purely active noise and vibration control systems. In fact most so called active systems are a combination of an active system and passive system, or active-passive hybrid. For instance, an active noise control system for a duct application will utilize enclosed loudspeakers where the enclosure has been optimized in order that the power required of the electronic system is minimized. The enclosure acts as a passive element in parallel with the active system [7]. Active mounts also usually consist of active and passive elements. Often the so-called active mount is a near-optimal passive system with an active system added to overcome the limitations of the passive system. Hybrid systems can make an otherwise stable system unstable. The system used by Westland to control helicopter vibration is a hybrid system [5]. Hybrid systems can also be used for acoustical applications. Example is shown in Figure 3.

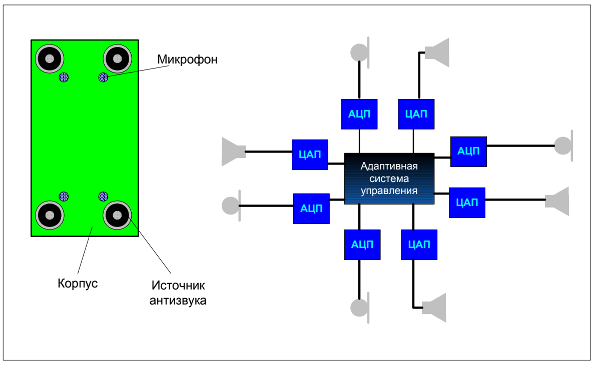



Figure 3. Construction of hybrid noise barrier.

## 3. PECULIARITIES OF ACTIVE NOISE AND VIBRATION CONTROL SYSTEMS CLASSIFICATION

Let us consider active noise and vibration control systems classification more detailed. Together with traditional principles of classification (periodicity of noise & vibration source signal, the spatial kind etc., see table 1), classification of active noise and vibration control systems has some features. First of all, the type of compensating signal is very important. We may point out different types of compensating signals: monopole source (or the set of sources), dipole source, tripole source, combinations of different types of sources etc.

According to construction type active control systems may be subdivided to adaptive, regenerative and non-adaptive. All modern systems are adaptive. Adaptive noise and vibration control systems may be subdivided to feedback, feedforward and combined feedback-feedforward.

Non-adaptive active control systems operating according to pre-tuned constant parameters have been used widely in early years of active noise and vibration control systems concept development.

Example of regenerative active vibration control system is described in [4]. The regenerative active control system consists of an actuator, a controller, a storage device and an energy management device. The energy management system directs energy to storage when excess energy available and directs stored energy to the actuator when needed. The regenerative system is only possible when the excess energy available is greater than the energy needed for an active control system. The regenerative active control system is an attractive idea because the performance of an active controller can be achieved without an external power source. Thus, it is possible that these systems can be made to perform at relatively high levels while completely self-contained and self-powered.

Of course, we may find some other approaches to classification according to construction type active noise and vibration control systems. E.g., active system may be defined as a set of individual components acting together as a whole. For such approach the system may be divided to three broad categories: acoustic, structural and structural/acoustic.

According to the type of compensating source it is possible to subdivide traditional and alternative active sources, sensors and other elements. The most traditional noise source is a loudspeaker. But using of loudspeakers have some drawbacks. The  limitations requires the development of alternative anti-noise sources capable of generating high level pressure at low frequencies and more resistant than loudspeakers. One or such sources is horn. Horn sources may prove advantageous in some situations requiring large reductions in tonal noise. The second example is using of oscillating valve or flap. Such actuator can consequently be used with high temperature gases or heavy fluids.

The main sound sensors used in active control are microphones. There are different kinds of them. The two most common types of omni-directional microphones are the prepolarized condenser (or electret) microphone and the piezoelectric microphone.

According to the type of input and output signals active systems are subdivided to single input - single output (SISO) and multiple input – multiple output (MIMO) systems.

According to the dimension of compensation effect we may point out one-dimensional, plane and three-dimensional active systems.

## 6. CONCLUSIONS

Approach to systematization of the principles of classification of low frequency (especially active) noise and vibration control methods is suggested. Sure, classification presented here is not the matter is settled and complete. The author's aim was only to try to point out and to generalize some features of noise & vibration reduction using active compensation method.

## ACKNOWLEDGEMENT

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