Teaching Active Sound and Vibration Control in Manufacturing Oriented Engineering Education

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Abstract *- The course in vibroacoustics at the bachelor's and master's level in the College of Engineering at Southern Illinois University-Carbondale focuses on a modern technology of vibration and noise control. This course will be offered for students as a technical elective either in their senior year or during graduate studies. Students will have an opportunity to learn in the classroom as well as in the laboratory techniques and methods of vibration and noise control, diagnostics of machines and machine components, and principles of design of these components for minimum vibration and sound emission. Some of the main topics and experiments are related to active noise and vibration control (ANVC).*

Active noise and vibration control technique is the best tool to reduce an unwanted vibration or an acoustical signal level, especially at low frequencies when passive control methods become inefficient. The manufacturers of cars, home appliances, etc., adjust the design of their products in order to reduce acoustic signal and vibration level. Experiments have shown that this is a difficult task mainly in the frequency range from 40 to 200 Hz. Passive methods do not work well in this frequency range. Researchers and manufacturers are striving to develop low cost and effective active noise and vibration control components and techniques. The general idea is based on the superposition principle and is to produce by electro-dynamic devices, an opposite image of the vibration or acoustical signal, so it is possible to fade unwanted vibration or noise. In practice, a control system has to generate from a reference signal measured usually by an accelerometer (or microphone), the desired opposite image of the primary (reference) signal.

This paper describes the development of a classroom topics and laboratory experiments related to ANVC. The implementation of active noise and vibration controller is based on digital signal processor (DSP) kit of Arbor Scientific in order to cancel the narrowband noise or vibration unwanted signal. Therefore, our students will be better prepared to face new technologies, modern design and manufacturing problems.

Introduction

The structure of the "Vibroacoustic" course and associated laboratory experiments is presented in "Vibroacoustics in Manufacturing-Oriented Engineering Education"[1]. That paper outlines a designed course that includes class and laboratory sessions that emphasize the principles and concepts of noise and vibration phenomena. Presented paper underlines important part of the course related to the ANVC only.

Students enrolled in vibroacoustics will be required to have completed calculus and the equivalent of eight semester hours of mechanical or electrical courses. The knowledge in feedback and control systems and in digital signal processing fields is very desirable. At the beginning of the semester, students are introduced to the fundamentals of the vibration and acoustics. In the class as well as in the laboratory they are learning relationships between nature of sound field and vibrating surfaces acting as a generator. They are also learning about time and frequency domains and how to measure frequency, sound pressure, speed of sound, acceleration of vibrating systems and flow of unwanted energy in acoustical or vibrating systems.

In the control of sound and vibration topics, students learn about damping of the vibrating system, sound transmission loss and sound absorption. These topics are presented to them as two groups of topics. The first group is described as a "passive noise and vibration control" and the second one as an "active noise and vibration control." Passive noise and vibration control reduce the level of vibration or sound by altering the physical properties by adding dampers, enclosures or barriers [7.8.9]. Active noise and vibration control reduces unwanted level of vibration or sound by adding an additional out of phase force to the vibrating system or out of phase acoustic field to the existing unwanted sound field.

The topics include:

a) Placement of the control source (electro-dynamic, piezo devices or loudspeaker)

b) The vibrating system or sound field characteristics (harmonics vs. random signal)
c) Group delays (DSP based controller)
d) Error sensor (accelerator or microphone) placement in self-tuning or adaptive control system.

Two cases that need to be discussed in a class as well as in the laboratory. The first case is the reduction of power output of both primary and control sources. The second one discusses the energy flow into the control source and the reduction of ambient levels of vibration or sound signal, while the energy flow from the primary source is roughly the same.

Arbor Scientific ANVC Kit and System Requirements

The Arbor Scientific ANVC kit includes a board with 16-bit stereo audio I/O capability, assembler, linker and simulation software, PC host software, DSP algorithm source code and accessories [2,3]. Accessories comprise two full audio frequency range speakers with build in amplifiers, two microphones (which can be substituted by proper accelerometers) and cables.

Stereo audio I/O is provided by the on-board AD 1847 JP code which has the added flexibility of programmable gain and programmable sample rates from 5.5 to 48 kHz. The kit's board integrates 32 k words of RAM, DMA parts and power management circuitry on chip. The digital signal processor ADSP-2181 is a fixed point DSP of the ADSP-2100 family. The board is shipped with an on-board EPROM containing a monitor program which allows uses to run demonstrations and upload/download programs from a PC. A socketed EPROM and PROM splitter utility give the opportunity to replace the factory-installed EPROM with an EPROM containing code developed by the operator for specific (and different than factory provided) applications. The board accommodates an EPROM size of 1 Mbyte by 8-bit. Developed custom EPROM and two rows of expansion connectors allow operator to design DSP based application for specific purposes. Included in the kit instruction level simulator allows the operator to inspect all ADSP-2181 operations on cycle-by-cycle basis. A user configurable windowed interface provides a visibility into all registers in memory. This same simulator allows to set breakpoints single step, and perform functions such as plotting data memory. According to the manual, by Scott D. Snyder [2,.3] which is supplied with the kit, the minimum system requirements are as follows:

Windows 3.1 (and later)

- MS-DOS, version 3.1 or later
- Microsoft Windows version 3.1 or later
- A personal computer with *at least* a 25 MHz 80386 or higher microprocessor (preferably a 33 MHz 80486 or higher)
- A VGA resolution or higher video adapter
- A 600 x 800 pixel monitor or higher
- A math co-processor
- A minimum of 4 Mbytes RAM
- A minimum of 4 Mbytes of hard disk space

Windows 95/NT

- Microsoft Windows 95, or Windows NT version 3.51 or later
- A personal computer with at least a 33 MHz 8048 or high microprocessor
- A VGA resolution or higher video adapter
- A 600 x 800 pixel monitor or higher
- A minimum of 8 Mbytes RAM
- A minimum of 6 Mbytes of hard disk space

Applications

Active noise and vibration control techniques are the best tool to reduce the acoustic noise or vibration levels at low frequencies. The development of adaptive digital signal processing and later availability of digital signal processors makes this technology applicable in practice.

Generally two schematics of ANVC are dominating field applications and students learn about them in a class as well as in the laboratory. The first schematic is a feedback and the second one is a feedforward active control system.

The block diagram of the basic active noise (or vibration) control is shown in figure 1.

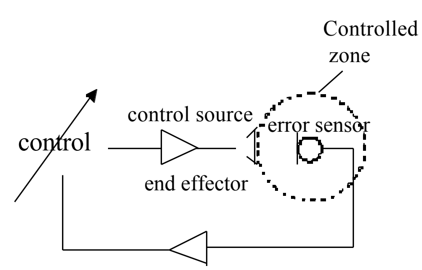

Figure 1. Block diagram of the basic ANVC system

The reference signal from primary source field (unwanted noise or vibration) can be obtained with a microphone or accelerometer. Often this sensor is located directly on the vibrating part or in a case of noise control in a space occupied by unwanted noise. The electrical signal from this sensor is supplied into DSP based controller and an adaptive algorithm implemented on it processes the signal. The processed signal (often called canceling signal or out of phase signal) is amplified and converted into acoustic pressure waves by a speaker (or end-effector force in the case of vibration) located in the space where sound or vibration level reduction is required. When the reference signal is periodic in nature like for example, an electrical transformer noise, a motor noise, etc., an external reference branch is not required. The external reference signal can be estimated from an error signal. That new configuration of ANVC system shown in Figure 2 is bearing the name of "feedback active noise (or vibration) control."

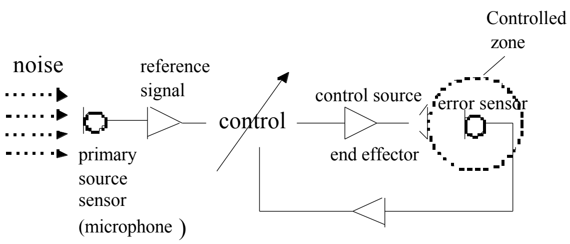

Figure 2. Black diagram of the Feedback ANVC System

In a feedback control system, the controller predicts a phase and an amplitude of the signal to be added at the error sensor position to reduce unwanted sound or vibration level. The amplitude and phase predictions are calculated with a delay. The signal period is determining maximum delay. The delay introduces an increasing phase shift with increasing frequency. This phase shift can produce an instability in the control system loop at a given frequency. Different filters are used to compensate the phase shift to overcome the instability problem. Students will learn that feedback ANVC can be used only when the unwanted signal is periodic in it's nature.

The second technique in ANVC applications is the implementation of adaptive feedforward controller. The adaptive feedforward controller is shown in Figure 3.

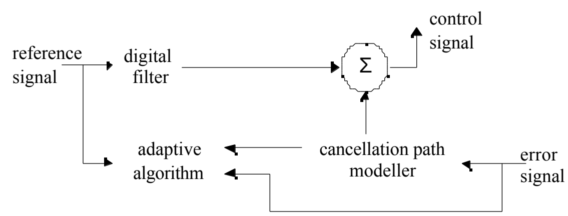

Figure 3. The components of the Adaptive Feedforward Controller

The digital filter is modifying the amplitude and phase of the reference signal frequency components to produce a control signal.

The adaptive algorithm performs the function of tuning the digital control filter so as to achieve the best performance for a given physical arrangement [3, 4, 5]. The function of cancellation path modeller is to model "what happens" to the control signal as it passes from the digital filter, out the electronics, through an amplifier, out a loudspeaker, through the acoustic environment, into the error microphone, and back into the microprocessor [2, 3, 4, 5]. Knowledge of this path, quantified as a transfer function, is required for a stable operation of the adaptive algorithm.

Conclusions

Students in an undergraduate and graduate program were provided with the content of the "Vibroacoustic" lecture and laboratory and were asked to rate the topics and experiments on a scale from "exciting" through "average," to "uninteresting." Results of the informal evaluation are shown in the table below.

Table: Preliminary Rating of the "Vibroacoustic" Course

	Exciting	Average	Uninteresting
Undergraduate Students	75	15	10
Graduate Students	80	10	10

The results indicate that this class can successfully teach new technology, add an enthusiasm to engineering education at both undergraduate and graduate levels.

Students often have asked to have a guided tour of the Acoustics Laboratory facility.

The College of Engineering at Southern Illinois University at Carbondale has the potential to supplement existing classes and laboratories with a new course that can enhance enthusiasm for engineering and increase retention of students.

References

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