Strategies for Active and Passive Noise Control

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1.0 Introduction

The solution of noise control problems tends to involve three steps, the diagnosis of the problem, the analysis and design of various elements of the problem, and the application of the appropriate solution. Good practice in each of these areas tends to involve a thoughtful and careful approach. In this paper, observations of good practice in each of these areas will be discussed.

2.0 Problem Diagnosis

Favorite success stories of practicing engineers in the noise control engineering field often lead to the same conclusion, the key to resolving a particularly difficult problem is understanding it. To paraphrase these engineers, "*95% of solving the problem was understanding it, after that the solution was simple*."

Getting to the root of a particular problem seems to be particularly difficult for noise control engineering applications. Typical noise control problems have the following characteristics repetitive and synchronous sources which are indistinguishable using traditional signal processing, reverberation and reflection which make the spatial location of the source hard to identify, and operational characteristics which make disconnect and wrapping studies difficult to apply while keeping the machinery operating under normal conditions. The key to successful diagnostics is having the correct tools and making a thoughtful and comprehensive effort to understand the problem.

The tools for diagnostics are numerous. Their presentation to the community is a bit disjointed and an attempt will be made here to put these methods in some perspective. Diagnostic approaches tend to use either signal characteristics or spatial characteristics.

Digital signal processing methods permit the study of signals measured during operation for characteristics that might indicate the source and/or path. The most straightforward signal characteristics to observe are coherence and transfer functions. However, for traditional signal processing the signal must be broadband, independent, and random signals. Repetitive sources are not random or broadband, synchronous sources are not independent, and reverberant environments mask any random characteristics that do exist with coherent reflections. Thus, traditional signal processing techniques have limited value for noise control applications when applied in a traditional manner.

More advanced signal processing and better application can overcome some of these limitations. As an example, Kompella investigated using multiple operating conditions where different sources would reveal themselves [1,2]. Roggenkamp investigated the application of inverse methods to forces at locations where measurements can not be made directly [3]. Both approaches adapt existing signal processing techniques to the particular features of noise control applications for better diagnostic information.

Acoustical intensity measurements allow the identification of net sound energy flux. Intensity measurement is helpful for identifying source locations under conditions where sound energy flow is reasonably simple and reverberation is low. Often acoustical intensity can be used instead of disconnect studies to identify a source. Acoustical intensity measurement methods should be available in the noise control engineer's toolbox of diagnostic methods.

Disconnect and wrapping studies are laborious and must be done with great care to keep machinery noise characteristics unchanged. In many cases this is the only option for diagnostics studies. Proper laboratory facilities and hardware are very important.

The diagnostic phase of a project is critically important. As experienced engineers have found, once the problem is well understood, the solution is often straightforward.

3.0 Analysis and Design

In his defense of research studies and analytical models, a colleague, Werner Soedel, says, "*There is nothing as practical as a good theory*" [4]. A model that is simple to exercise and explains the essential behavior of the machine saves trial and error design iteration and helps all participants of a design team understand the behavior of the system. Thus, simple models such as the mass law and room acoustics equations give the designer great intuition about design compromises and a good understanding of the behavior of the system.

However, not all systems are amenable to analytical models. Numerical methods, such as the finite element (FEM) or boundary element (BEM) methods, have made it possible to build very complete models of the behavior of machines. However, complex models conceal the essential behavior of a system. Simple numerical methods can be constructed to model just the essential behavior of the system. Such models are often very useful at the concept design phase of the design process. If simple models are constructed such that they can be exercised to give design insight, they can be used when analytical theories are unavailable for the same type of "good theory" understanding of a particular application. Parametric model definition techniques, improved postprocessing, and faster computers make it increasingly possible to implement a process where the behavior of systems and design trade-offs can be determined using numerical models.

Statistical energy analysis (SEA) is a more conceptually simple analysis procedure than the finite or boundary element methods. For many high frequency applications where the assumptions of SEA capture the essential behavior of the system, SEA models can be exercised to create "good theory". In some cases however SEA is not able to capture the essential dominant behavior of a system. For these cases, a more sophisticated but efficient prediction scheme is needed.

Along with capturing the essential behavior of the system, "good theory" for noise control applications must also represent the inherent variability of these applications. At frequencies of interest, typical systems are highly sensitive to normal environmental and manufacturing variations. Typical examples of the variation of manufactured products for a sport utility vehicle and light truck were reported by Kompella and Bernhard [5]. Particularly for harmonic sources, the response variation can be very significant from day-to-day or from vehicle-to-vehicle. At high frequencies with broad band sources, the sensitivity does not cause significant variation since all of the important modes tend to be excited. These characteristics of machinery must be accounted for in design. Efficient methods for predicting this behavior are not readily available yet for all applications.

4.0 Noise Control Solutions

For noise control applications it is important to have a full "toolbox" of potential solutions. A "hammer" is not a solution to every problem. Potential noise control solutions include active and passive alternatives and range from acoustical materials to ear defenders to electronic devices. Different solutions fit different problems and the best solution is often determined by performance requirements unrelated to noise or cost constraints.

At times, active control methods have seemed to be the answer to a large percentage of problems because of the potential flexibility of the approach. However, as with most solutions, a particular active control solution is cost effective and performs well only for certain applications.

For example, most active control solutions presented in the literature are adaptive, feedforward configurations. For feedforward approaches, a reference sensor is placed near the source. The adaptation process is achieved using a signal from an "error" transducer placed in the region where control is desired. The signal from the reference sensor is filtered using the digital filter and is input to the control actuator. This type of controller tends to operate in either a "system identification" mode or a "signal identification" mode.

In the system identification mode, the reference signal and the error transducer signal are used to generate a model of the system between these transducers [6]. This approach is particularly efficient when the system that is to be identified is simple. In an acoustical duct application, the system can be modeled as a simple time delay. Feedforward, adaptive active control systems have been very effective for such applications regardless of the complexity of the excitation source.

For signal identification applications, the adaptive filter uses the error transducer signal to adjust the amplitude and phase of the reference signal to generate a signal that drives the control actuator. This type of controller is particularly effective for stationary, harmonic signals where only a relatively few digital filter coefficients are needed to model the signal. Many of the original active controllers were based on this principle.

For some applications, feedback control is more desirable than feedforward control. Feedback control is particular efficient in a collocated regulator configuration. The delay time that occurs when a feedback sensor and the control actuator are not collocated tends to be significant in most noise and vibration control applications and limits the bandwidth of feedback control. This type of control was used recently for effective control of the radiating modes of a panel driven by turbulent boundary layer excitation, an application where it is impossible to locate an appropriate reference transducer for a feedforward application [7].

There is also promise of better control solutions based on combining active and passive control principles. These might be classified as "smart" passive devices that adapt to the environment and operating conditions and maintain a high level of performance despite being primarily passive systems. One example is the adaptive tuned vibration absorber (ATVA) [8]. For this device, a variable spring is constructed from shape memory alloy wire. The natural frequency of the tuned absorber can be made to track the excitation frequency of the system by controlling the current through the wire. This is a very simple and efficient device that can be made very effective for certain applications.

The potential of active and hybrid active-passive solutions has not yet been fully realized. With the development of MEM's devices and continued improvement of electronics and "smart materials", more novel solutions can be expected that span the range of simple to complex and passive to active.

5.0 Conclusions

In a world where noise is increasingly important as a competitive feature of machines and where environmental concerns are becoming more important, it is crucial to have available the correct tools and resources to;

diagnose and understand a noise or vibration problem,

predict the behavior of a system and pick an optimal design, and

apply the best technology possible.

To accomplish this, noise control must be a primary issue for design and construction and the proper tools must be available. To improve the "toolbox" practicing engineers and researchers need to form partnerships to bring all of the technology available to bear on the correct problem. The industrialist and consultant are needed to define the need for technology and the constraints. Researchers are needed to unlock the technology required to address these problems. In a small community, this should be possible.

6.0 References

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