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ORIGINAL PAPER

Machine learning and acoustic method applied to leak detection and location in low-pressure gas pipelines

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Abstract
The increase in pipeline safety would prevent incidents that can result in fatalities, environmental disasters, and economic losses. The present work proposes a technique that combines acoustic sensors and machine learning algorithms to identify and locate leakages in low-pressure gas pipelines. The patterns on the sound signal captured by microphones were used to accomplish those two tasks. The technique aims to solve two persistent problems, the detection of small leakages on pipelines operating under low pressures and the reduction of false alarms in the presence of external disturbances. The experimental results showed that the method identified 99.6% of the leakages and achieved a rate of false alarms of 0.3%, while the position of the leakages was estimated with a maximum location error of 4.31%. These results show that the technique proposed is an efficient and reliable alternative to monitor low-pressure pipelines.

Graphic abstract

Keywords Leak detection · Leak location · Low-pressure pipeline · Machine learning

Introduction

Pipelines are the safest and most economically efficient way of transporting and distributing natural gas. Despite their high reliability, these pipelines are a cause for alarm, mainly due to leakages. There are numerous possible causes for leakages, and the main ones are the aging of the pipelines, the operational conditions, and the material of the pipes (Mamlook and Al-Jayyousi 2003). The concerning about leaks is magnified by the presence of pipes both in highly populated and in environmentally sensitive areas. Incidents can result in environmental disasters, economic losses, and even the loss of human lives. According to Jackson et al. (2014), only in the USA, these incidents cause an average of 17 deaths and $133 M in losses every year. Furthermore, it was estimated that almost 2.4% of all the natural gas produced in that country is lost to the atmosphere. Assessments indicate that almost 30% of the more severe accidents in the chemical industry were caused by pipeline leaks (Shariff and Zaini 2013). To prevent these outcomes is essential to find a set of techniques capable of rapidly detecting a leakage, and to determine its location, enabling a corrective measure to be taken.

There are numerous solutions available to approach those two problems, techniques based on soil monitoring, ultrasonic flow meters, digital signal processing, negative

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Acoustic and Biomedical Engineering

Verification of Inverse Image Source Method Applied for Acoustic Field Creation in Open Area

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The paper presents an original method for sound reinforcement in open areas. The method enabled both a regular sound reinforcement and the required spatial impressions of sound to be achieved in the area used for the study. The inverse image source method was used for the disposition of sound sources in order to find the inverse problem solution for determining the configuration of additional sound sources. Simulations demonstrated the improvement of sound impressions in the area in question and the simulations results were verified experimentally. The intended result of the proposed method was the increase of the lateral energy fraction and lateral energy fraction coefficient parameter values by 6 and 8 points, respectively, for the simulation by 5 and 7 points for the experiment. It should be stated that, in both the simulation and the experiment, eligible values for the acoustic parameters were obtained after using the sound system with additional sound sources, the speech intelligibility value parameters remain at an excellent level. In conclusion, it may be claimed that the proposed sound reinforcement system makes the creation of the intended spatial sound impressions in an open area possible.

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1. Introduction

Direct sound predominates in open areas. Propagation of acoustic waves is realized in straight lines, without barriers and diffraction which means that the sound is not reflected, absorbed, diffracted, refracted, scattered and subjected to the resonance effect [1]. Reflected or scattered sound occurs in much more limited extent than in enclosures, which causes that its spaciousness is very limited (in case of classic configurations of electro-acoustic installations). For this reason the most important and preferred acoustic parameter determined for sound system in an open area was the sound pressure level (SPL), the other parameters are determined much more seldom [2, 3].

During a sound reinforcement in open areas by means of so-called wall of sound it is possible to create the acoustic field in two ways: in case of small areas — by means of loudspeaker sets with a large power, located centrally (on stage) and in case of large areas — by means of multi-zone sound reinforcement [4–6]. An alternative method is application of line arrays systems, that comparing with the wall of sound they enable obtaining of more uniform sound field distribution in the area of entire amplified surface [7–14]. In both cases the purpose is to ensure an appropriate SPL in sound amplification area.

The analysis of acoustic field was performed already in ancient time (graphical method), in 19th century W.C. Sabine has created a statistical theory of acoustic field and in the 20th century development of wave methods and geometrical methods took place. In the last dozens of years primary geometrical methods, ray method and image source methods, have evolved and their modifications make currently possible omitting of some limitations characteristic for geometrical methods in primary form [15–18]. Most common application of geometrical methods is the analysis of acoustic field in real or virtual objects being in the project stage, which enables possible changes in the project and improvement of acoustic properties of objects [19, 20]. Except of the analysis of influence of the shape and features of the object on its acoustic properties, simulation programs based upon geometrical methods enable also analysis of acoustic field distribution depending on location and character of the sound source or sound sources [21–23]. Results of simulation performed on the basis of geometrical methods are reflecting to a high degree the state from real objects [24, 25]. It is necessary to point out that it is still the area of analysis of acoustic field, i.e. at known features of the object and known distribution of sound sources the sound field distribution is determined.

In this elaboration the image source method in an innovative way has been used, i.e. by means of this method the distribution of sound sources creating the acoustic field in an open area has been determined, characterised by such properties that the listener has an impression that he is in a closed object with good acoustic properties. In open areas, as mentioned above, spatial impressions are very limited, so it was very important to create such sound reinforcement system, that could improve impression of spatial sound. To improve this impression, a unique technique has been applied — introducing into area of additional sound sources simulating reflections of sound from walls, the arrangement and parameters of which have been determined by means of inverse image

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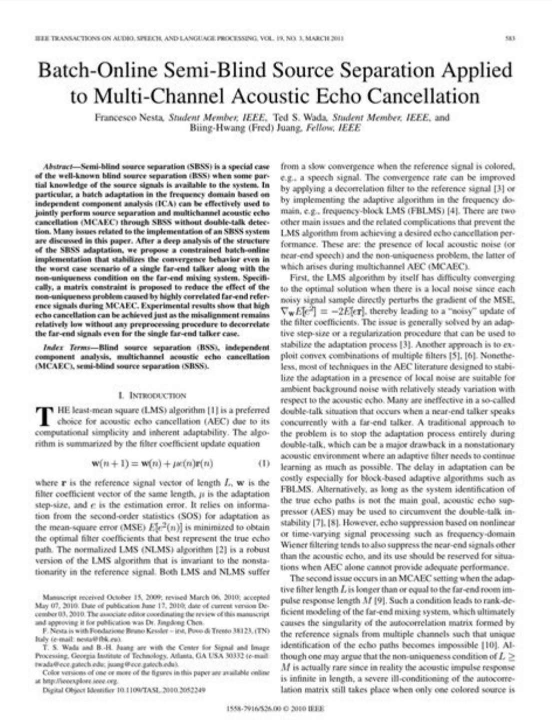

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Batch-Online Semi-Blind Source Separation Applied to Multi-Channel Acoustic Echo Cancellation

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***Abstract*—Semi-blind source separation (SBSS) is a special case of the well-known blind source separation (BSS) when some partial knowledge of the source signals is available to the system. In particular, a batch adaptation in the frequency domain based on independent component analysis (ICA) can be effectively used to jointly perform source separation and multichannel acoustic echo cancellation (MCAEC) through SBSS without double-talk detection. Many issues related to the implementation of an SBSS system are discussed in this paper. After a deep analysis of the structure of the SBSS adaptation, we propose a constrained batch-online implementation that stabilizes the convergence behavior even in the worst case scenario of a single far-end talker along with the non-uniqueness condition on the far-end mixing system. Specifically, a matrix constraint is proposed to reduce the effect of the non-uniqueness problem caused by highly correlated far-end reference signals during MCAEC. Experimental results show that high echo cancellation can be achieved just as the misalignment remains relatively low without any preprocessing procedure to decorrelate the far-end signals even for the single far-end talker case.**

***Index Terms*—Blind source separation (BSS), independent component analysis, multichannel acoustic echo cancellation (MCAEC), semi-blind source separation (SBSS).**

I. Introduction

THE least-mean square (LMS) algorithm [1] is a preferred choice for acoustic echo cancellation (AEC) due to its computational simplicity and inherent adaptability. The algorithm is summarized by the filter coefficient update equation

$$\mathbf{w}(n+1) = \mathbf{w}(n) + \mu e(n)\mathbf{r}(n) \quad (1)$$

where $\mathbf{r}$ is the reference signal vector of length L, $\mathbf{w}$ is the filter coefficient vector of the same length, μ is the adaptation step-size, and e is the estimation error. It relies on information from the second-order statistics (SOS) for adaptation as the mean-square error (MSE) $E[e^2(n)]$ is minimized to obtain the optimal filter coefficients that best represent the true echo path. The normalized LMS (NLMS) algorithm [2] is a robust version of the LMS algorithm that is invariant to the nonstationarity in the reference signal. Both LMS and NLMS suffer from a slow convergence when the reference signal is colored, e.g., a speech signal. The convergence rate can be improved by applying a decorrelation filter to the reference signal [3] or by implementing the adaptive algorithm in the frequency domain, e.g., frequency-block LMS (FBLMS) [4]. There are two other main issues and the related complications that prevent the LMS algorithm from achieving a desired echo cancellation performance. These are: the presence of local acoustic noise (or near-end speech) and the non-uniqueness problem, the latter of which arises during multichannel AEC (MCAEC).

First, the LMS algorithm by itself has difficulty converging to the optimal solution when there is a local noise since each noisy signal sample directly perturbs the gradient of the MSE, $\nabla_{\mathbf{w}} E[e^2] = -2E[e\mathbf{r}]$, thereby leading to a "noisy" update of the filter coefficients. The issue is generally solved by an adaptive step-size or a regularization procedure that can be used to stabilize the adaptation process [3]. Another approach is to exploit convex combinations of multiple filters [5], [6]. Nonetheless, most of techniques in the AEC literature designed to stabilize the adaptation in a presence of local noise are suitable for ambient background noise with relatively steady variation with respect to the acoustic echo. Many are ineffective in a so-called double-talk situation that occurs when a near-end talker speaks concurrently with a far-end talker. A traditional approach to the problem is to stop the adaptation process entirely during double-talk, which can be a major drawback in a nonstationary acoustic environment where an adaptive filter needs to continue learning as much as possible. The delay in adaptation can be costly especially for block-based adaptive algorithms such as FBLMS. Alternatively, as long as the system identification of the true echo paths is not the main goal, acoustic echo suppressor (AES) may be used to circumvent the double-talk instability [7], [8]. However, echo suppression based on nonlinear or time-varying signal processing such as frequency-domain Wiener filtering tends to also suppress the near-end signals other than the acoustic echo, and its use should be reserved for situations when AEC alone cannot provide adequate performance.

The second issue occurs in an MCAEC setting when the adaptive filter length L is longer than or equal to the far-end room impulse response length M [9]. Such a condition leads to rank-deficient modeling of the far-end mixing system, which ultimately causes the singularity of the autocorrelation matrix formed by the reference signals from multiple channels such that unique identification of the echo paths becomes impossible [10]. Although one may argue that the non-uniqueness condition of $L \geq M$ is actually rare since in reality the acoustic impulse response is infinite in length, a severe ill-conditioning of the autocorrelation matrix still takes place when only one colored source is

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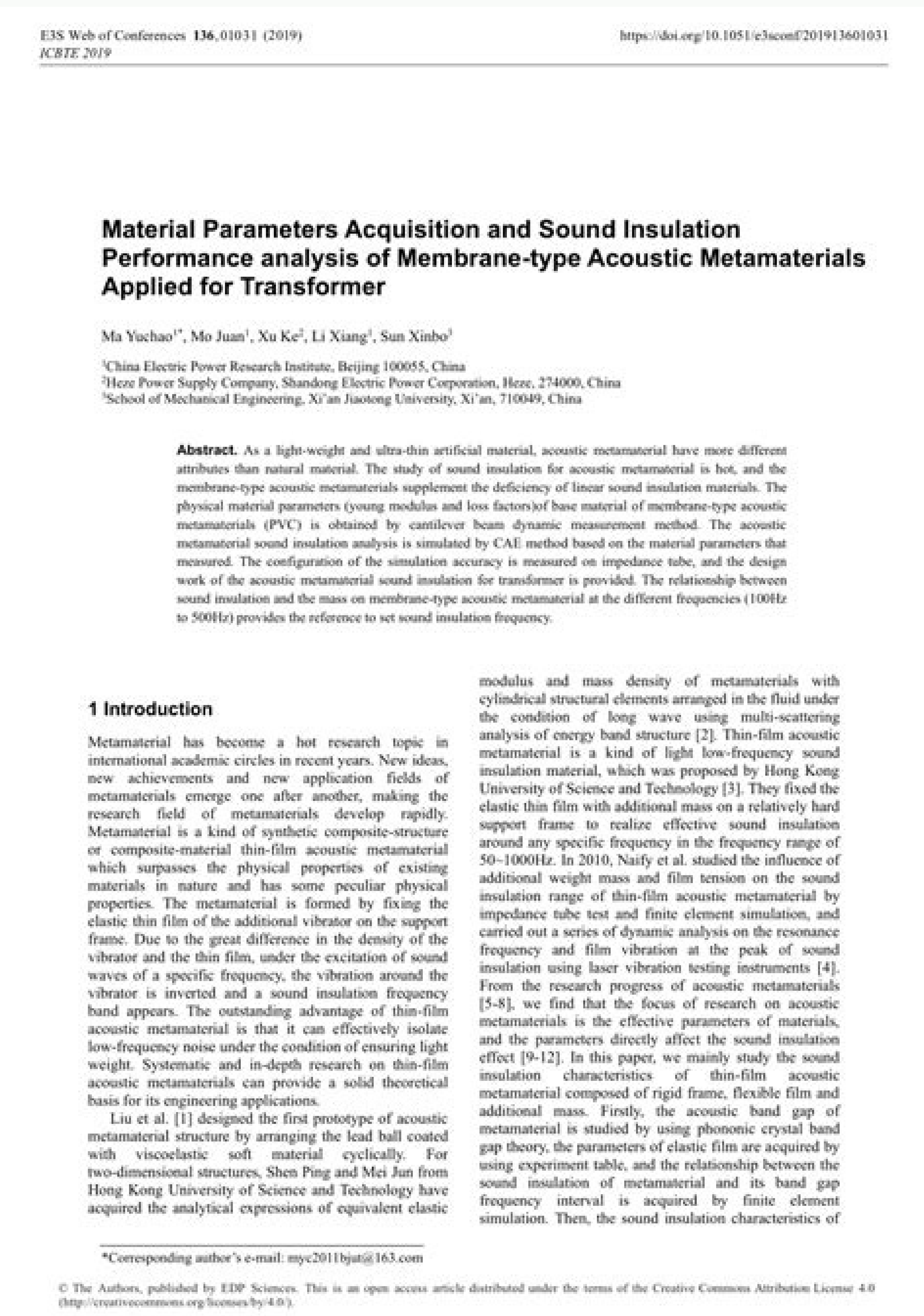

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Material Parameters Acquisition and Sound Insulation Performance analysis of Membrane-type Acoustic Metamaterials Applied for Transformer

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Abstract. As a light-weight and ultra-thin artificial material, acoustic metamaterial have more different attributes than natural material. The study of sound insulation for acoustic metamaterial is hot, and the membrane-type acoustic metamaterials supplement the deficiency of linear sound insulation materials. The physical material parameters (young modulus and loss factors)of base material of membrane-type acoustic metamaterials (PVC) is obtained by cantilever beam dynamic measurement method. The acoustic metamaterial sound insulation analysis is simulated by CAE method based on the material parameters that measured. The configuration of the simulation accuracy is measured on impedance tube, and the design work of the acoustic metamaterial sound insulation for transformer is provided. The relationship between sound insulation and the mass on membrane-type acoustic metamaterial at the different frequencies (100Hz to 500Hz) provides the reference to set sound insulation frequency.

1 Introduction

Metamaterial has become a hot research topic in international academic circles in recent years. New ideas, new achievements and new application fields of metamaterials emerge one after another, making the research field of metamaterials develop rapidly. Metamaterial is a kind of synthetic composite-structure or composite-material thin-film acoustic metamaterial which surpasses the physical properties of existing materials in nature and has some peculiar physical properties. The metamaterial is formed by fixing the elastic thin film of the additional vibrator on the support frame. Due to the great difference in the density of the vibrator and the thin film, under the excitation of sound waves of a specific frequency, the vibration around the vibrator is inverted and a sound insulation frequency band appears. The outstanding advantage of thin-film acoustic metamaterial is that it can effectively isolate low-frequency noise under the condition of ensuring light weight. Systematic and in-depth research on thin-film acoustic metamaterials can provide a solid theoretical basis for its engineering applications.

Liu et al. [1] designed the first prototype of acoustic metamaterial structure by arranging the lead ball coated with viscoelastic soft material cyclically. For two-dimensional structures, Shen Ping and Mei Jun from Hong Kong University of Science and Technology have acquired the analytical expressions of equivalent elastic modulus and mass density of metamaterials with cylindrical structural elements arranged in the fluid under the condition of long wave using multi-scattering analysis of energy band structure [2]. Thin-film acoustic metamaterial is a kind of light low-frequency sound insulation material, which was proposed by Hong Kong University of Science and Technology [3]. They fixed the elastic thin film with additional mass on a relatively hard support frame to realize effective sound insulation around any specific frequency in the frequency range of 50~1000Hz. In 2010, Naify et al. studied the influence of additional weight mass and film tension on the sound insulation range of thin-film acoustic metamaterial by impedance tube test and finite element simulation, and carried out a series of dynamic analysis on the resonance frequency and film vibration at the peak of sound insulation using laser vibration testing instruments [4]. From the research progress of acoustic metamaterials [5-8], we find that the focus of research on acoustic metamaterials is the effective parameters of materials, and the parameters directly affect the sound insulation effect [9-12]. In this paper, we mainly study the sound insulation characteristics of thin-film acoustic metamaterial composed of rigid frame, flexible film and additional mass. Firstly, the acoustic band gap of metamaterial is studied by using phononic crystal band gap theory, the parameters of elastic film are acquired by using experiment table, and the relationship between the sound insulation of metamaterial and its band gap frequency interval is acquired by finite element simulation. Then, the sound insulation characteristics of

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Chapter 20

Acoustics and Vibro-Acoustics Applied in Space Industry

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Gustavo Paulinelli Guimarães and Luiz Carlos Sandoval Góes

Additional information is available at the end of the chapter

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1. Introduction

During flight, Expandable Launch Vehicles (ELV) are excited by severe acoustic loads in three phases of flight: lift off, transonic flight and maximum dynamic pressure instant [1]. As such, principles to make onboard equipment compatible with the mission environments must be adopted. At lift off, the highly intense acoustic loads occur; and these levels are usually adopted to qualify payloads and equipments. However, during the transonic flight and maximum dynamic pressure phase, acoustic excitation is also present and such characteristics are also significant for performance evaluation as well as for specific system dynamic qualification/acceptance programs. In this way, noise control treatments (NCT) shall be adopted to alleviate internal vibro-acoustic environments, in view of decreasing costs and developments.

The hostile in-flight environments can damage sensors/conditioners as well as make measurements unreliable. In this way, installation adapters must be designed to protect the sensors. The acoustics of such protective cavities influence the measured sound pressure level (SPL) As such, the cavities must be analyzed and their amplitude-frequency characteristics evaluated. Finally, the measurement corrections, necessary to obtain the actual external SPL, are determined.

Concerning the internal environment found during flights, important launcher subsystems as payload fairing (PLF) and equipment bays shall be investigated and vibro-acoustic analysis can be done, as pointed by [2], [3] and [4]. The PLF is the structural compartment of a launcher where the payload is placed during the flight mission. PLF inner acoustics and its attenuation designs, using virtual prototypes are analyzed using deterministic and statistic techniques. However, when in-flight loading are not characterized, the accounted external air-borne excitation can be those described in [5]. In a similar way, SPL along the launcher structure at

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