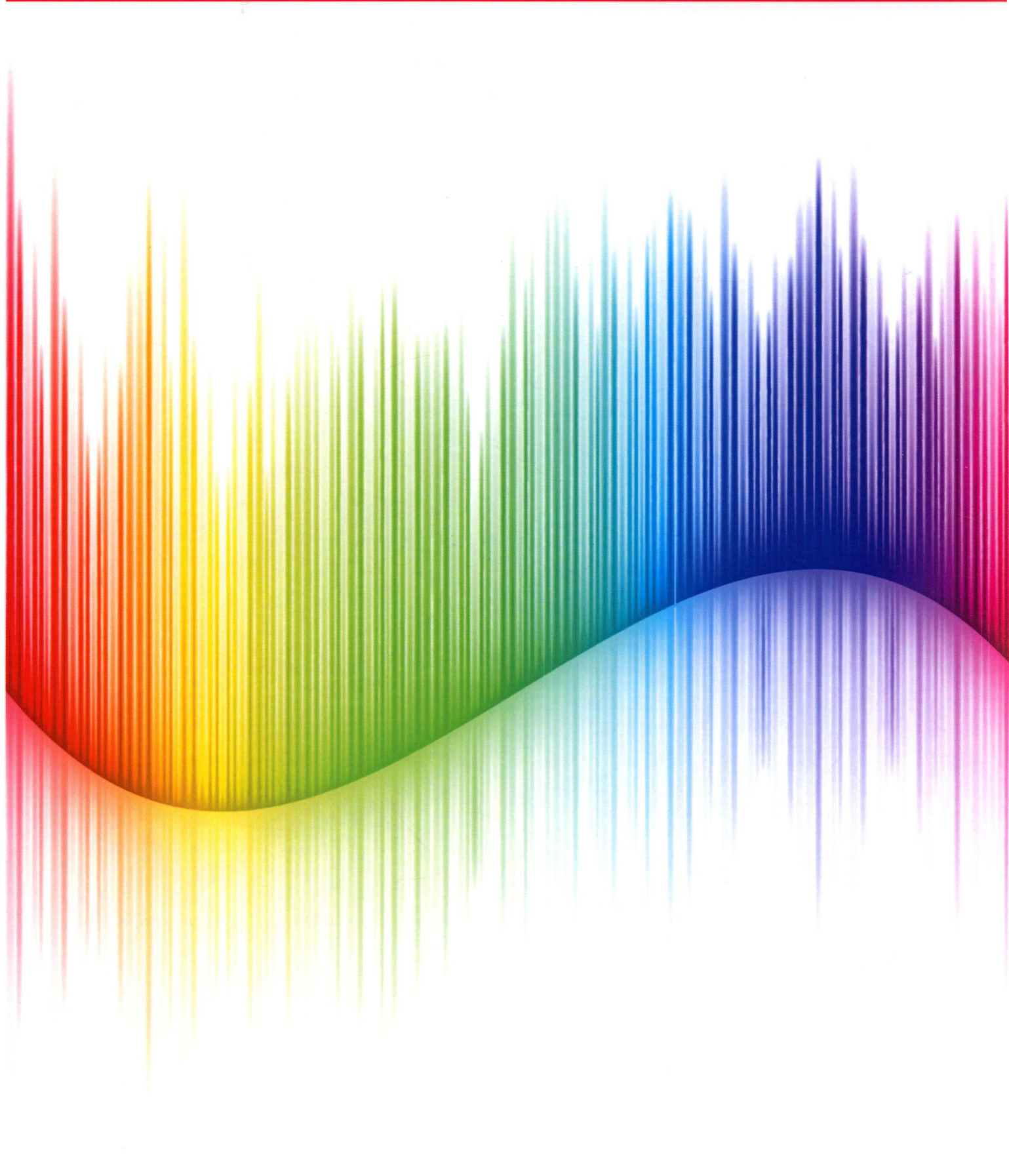


Vibration Spectrum Analysis: A Practical Approach

Contributors: Satoru Goto, Yoshinori Takahashi, et al.



About the Book

Vibration analysis is not a new technology. The Piezo effect and charge output of certain materials was discovered in 1880 by the Curies. The first accelerometer was built in 1923. Over the last 100 years, this technology has been refined for today's industrial market to provide fast efficient measurements of rotating machinery vibration. The advent of the microprocessor has enormously advanced the process of vibration data acquisition and analysis in recent years. Measurement tasks that took hours only two decades ago can now be completed in minutes and better decisions made because of better data presentation. However, the basic processes of measurement and analysis have remained essentially unchanged, just like the machines from which the vibration is measured. The results of the measurement and data analysis need to be compared with known standards or guidelines and decisions made as to whether the machine is acceptable for service or maintenance should be planned. Vibration analysis is used for condition monitoring of machines in operation. All the machines while operating vibrate more or less, and with most of them the vibrations are unwanted and the effort is to minimize them. Only with some types of machines, vibrations are directly a working principle of the machine and are caused deliberately (e.g. vibrating screeners). Implementing vibration analysis on the machines will improve the reliability of the machines and lead to better machine efficiency and reduced down time eliminating mechanical or electrical failures. Vibration analysis programs are used throughout industry worldwide to identify faults in machinery, plan machinery repairs, and keep machinery functioning for as long as possible without failure.

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**Goto,
Takahashi**

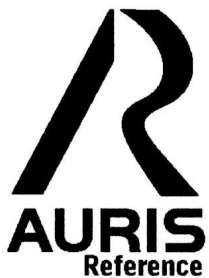
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Preface

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STRUCTURAL VIBRATION MONITORING USING CUMULATIVE SPECTRAL ANALYSIS

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ABSTRACT

This paper describes a resonance decay estimation for structural health monitoring in the presence of non-stationary vibrations. In structural health monitoring, the structure's frequency response and resonant decay characteristics are very important for understanding how the structure changes. Cumulative spectral analysis (CSA) estimates the frequency decay by using the impulse response. However, measuring the impulse response of buildings is impractical due to the need to shake the building itself. In a previous study, we reported on system damping monitoring using cumulative harmonic analysis (CHA), which is based on CSA. The current study describes scale model experiments on estimating the hidden resonance decay under non-stationary noise conditions by using CSA for structural condition monitoring.

INTRODUCTION

Structural health condition diagnostics are needed for ensuring the safety of buildings struck by earthquakes and old buildings. Spectral analysis focuses on the change in the resonant frequency caused by structural degradation, and it yields useful information for health monitoring. However, for structural health monitoring, spectral analysis requires a test signal. Although using a test signal is an easy way to measure structural spectral characteristics, it is impractical to vibrate a structure during every measurement. If the spectral characteristics could be measured using structural vibrations due to wind, ground motion, and so forth, the health of the structure would be able to be

monitored all the time. However, this sort of measurement would require a lot of spectral information about external noise characteristics besides the structural spectral characteristics. For this reason, spectral characteristics analysis for structural health monitoring generally requires the external source characteristics to be known at all times [1, 2].

Hirata proposed the short-interval period (SIP) distribution to analyze the dominant spectral components of a structure subject to an unknown vibration or even non-stationary noise [3]. The SIP distribution represents the shape of the frequency response in poor measuring conditions. Recently, Hirata et al. showed that the SIP distribution can be used to get the gradual time variation of the frequency response of a structure subjected to non-stationary vibrations [4]. On the other hand, the SIP distribution requires a sufficiently long signal because the computational process of the SIP distribution uses information on the dominant frequency components taken from a number of short intervals.

Takahashi et al. proposed a health monitoring method that focuses on damping using cumulative harmonic analysis (CHA) to reveal the spectral peaks of hidden structural resonances in short signals [5]. In a recent report, the authors estimated the temporal damping changes in the presence of unknown non-stationary vibrations by using the interpolated power spectrum of CHA [6]. Damping is an important factor in structural diagnostics, and it is related to the resonant decay of transient information in the time domain. For instance, if a pillar has a crack, any resonance decay will be short lived. This means that a way of estimating transient information such as resonant decay would be of value to structural diagnostics. CHA is an extension of cumulative spectral analysis (CSA) proposed by Berman and Fincham [7], and CSA determines the transient characteristics of loudspeaker systems. In terms of the relationship between transient information and CHA, Takahashi et al. predicted the howling frequency by using a histogram of CHA power spectrum peaks of the transient decaying portion [8]. Thus, in acoustic systems, spectral analysis with a stepwise time window can accurately detect resonance peaks under the unknown signals and possibly predict the hidden frequency change from the transient decaying portions of the histogram of the CHA peaks in a simple feedback system. Consequently, when using a stepwise time window spectral analysis, we assume that acoustical techniques could be applied to structural analysis in order to reveal the resonance decay characteristics for structural diagnostics under non-stationary noise.

In this paper, we discuss a hidden resonance decay estimation for structural health monitoring that does not need the frequency characteristics of the external noise. We also describe experiments on scale models subjected to simulated non-stationary noise that assessed the effectiveness of resonance decay estimation focused on the transient decay portion.

Section 2 describes the measurement of the scale model's impulse response. Section 3 explains the CSA analysis and impulse response analysis. Section 4 describes the experiments in ideal cases of resonance decay analysis on the decay portions of the spectra. Section 5 discusses the results of the simulation experiment. Section 6 discusses the possibility of quantitative structural diagnostics using experimental CSA results.

SCALE MODEL AND IMPULSE RESPONSES FOR A SIMULATION EXPERIMENT

We made two scale models and measured their impulse responses. Each scale model was a wooden framework (18 cm (W) * 21 cm (D) * 38 cm (H)) of a three-story building. The scale model had four pillars, and each pillar comprised 1 cm square lumber. Impulse responses were recorded at an F_s of 6 kHz using a piezoelectric accelerometer (PV-90B, RION) with an impulsive hammer. Figure 1 shows the scale-model experimental conditions and the linear interpolated impulse response waveforms and magnitude responses. As the upper illustration of Figure 1 shows, we prepared two scale models for condition 1 and condition 4. Conditions 2 and 3 simulated structurally degraded conditions by linear interpolation between the impulse response waveforms of conditions 1 and 4. The lower panels show the impulse response waveforms and magnitude spectra. From these panels, we can see that the magnitude spectra characteristics gradually change from condition 1 to condition 4.

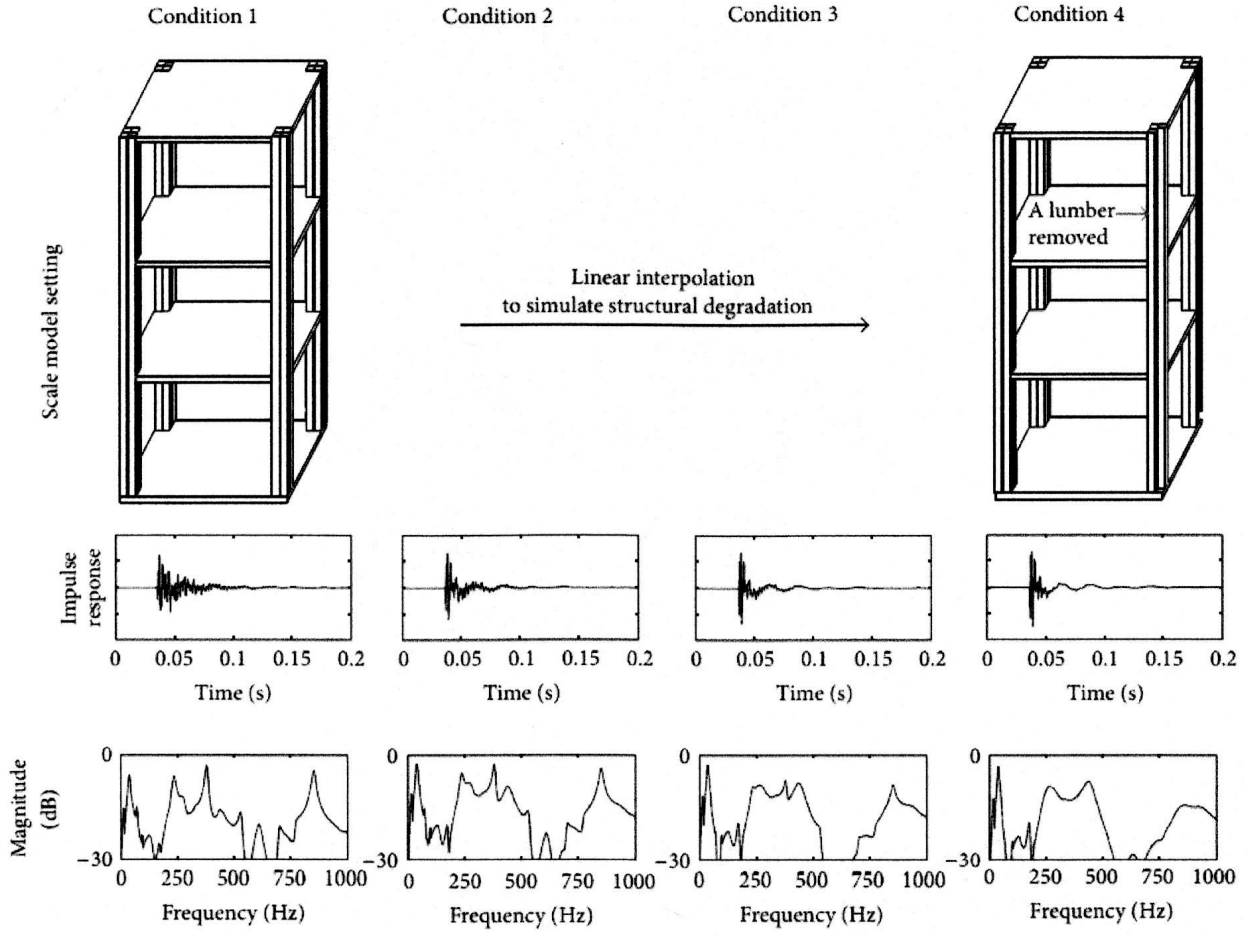


Figure 1: Scale models and corresponding measured and interpolated impulse responses and magnitude spectra.

SPECTRAL ANALYSIS WITH STEPWISE TIME WINDOW

We used stepwise time window spectral analysis to make the resonance decay estimation. The cumulative spectral analysis (CSA) of a framed input signal (n) is formulated as

$$CSA(n, k) = \sum_{m=n}^{N-1} u(m) x(m) e^{j(2\pi k/N)m} \quad 0 \leq n \leq N-1. \quad (1)$$

Here, (n) is a unit-step function corresponding to input signal conditions such as

$$u(n) = \begin{cases} 1, & 0 \leq n \\ 0, & n < 0. \end{cases} \quad (2)$$

We set N to include zero padding of 10 times the frequency interpolation of F_s .

Figure 2 shows the CSAs of the impulse responses corresponding to the different structural conditions. We calculated the CSAs by using a 60 ms frame to extract the impulse response decay portion. The left panel shows the magnitude spectrum of the impulse responses in the steady state, whereas the right panel illustrates the results of CSA. This figure shows that the spectral peaks in the magnitude spectra are the same as those in the CSA results. In addition, if there is a peak on the time axis, the changes in the decay of the resonant frequency can be read in the CSAs across conditions. Moreover, the fundamental frequency of 45 Hz does not decay in any of the plots. This is because the structure profile of the scale model did not change in these experiments. Therefore, the fundamental frequency did not decrease much compared with the higher resonances. The effect of CSA can be seen by comparing the peaks above 250 Hz. As for the peak at 850 Hz, it lasts for 40 ms under condition 1. Moreover, the time period of the peak gradually decreases to under 5 ms in going from condition 1 to condition 4. From these results, we supposed that CSA can estimate resonance peaks and their decays even when the decay portion is shorter than the impulse response.

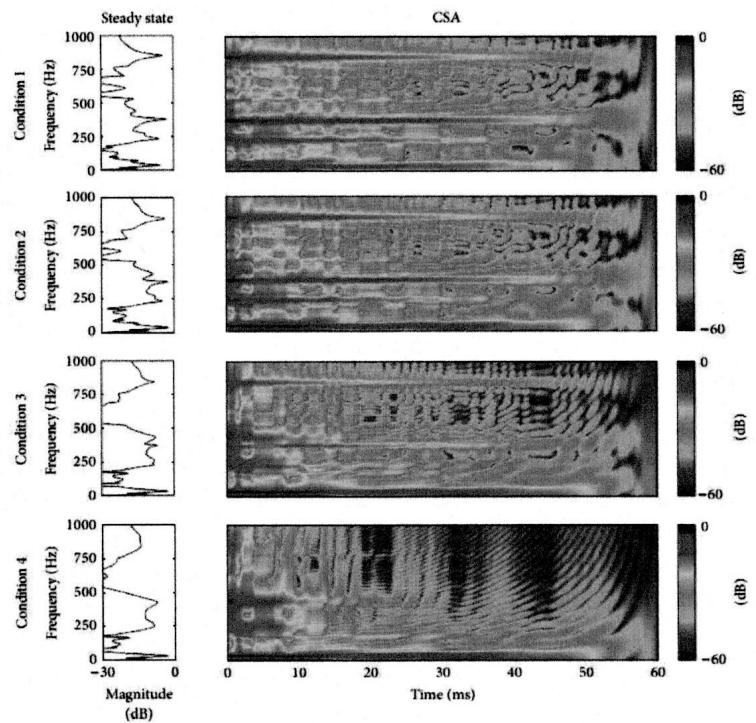


Figure 2: CSA of impulse responses.

RANDOM BURST NOISE ANALYSIS FOR THE IDEAL CASE OF RESONANCE DECAY

When a vibration stops, a transient decay arises through the system’s transfer function. This transient decay includes the effect of the system’s impulse response. To simulate this transient decay under ideal circumstances, we prepared random burst white noise having random durations, intervals, and magnitudes.

Figure 3 shows a random burst noise waveform convolved with the impulse response measured under condition 1 and the CSAs of different extracted portions. The upper panel illustrates the random burst noise and highlights of the extracted waveform for different portions. The decay portion on the left side is just after the random noise stopped. The onset portion in the middle is the onset of the convolved random noise. The continuous portion on the right side is the mixture of the decay of the signal and the beginning of the next random noise. The corresponding waveforms are in the second top panels. CSA at the bottom reveals different resonance decays between the decay portion and the other portions. The CSA of the decay portion has similar characteristics to those of the CSA of condition 1’s impulse response in Figure 2. This means that the frequency characteristics including spectral decay can be estimated by using CSA on the decaying signal portion. On the other hand, the CSAs of the onset and continuous portions do not have spectral decays. This is because in the onset and continuous portions, the input signal was continuous and an increase in the resonance continued. This means that if the signal is found in the decay potion, CSA will reveal a hidden resonance decay.

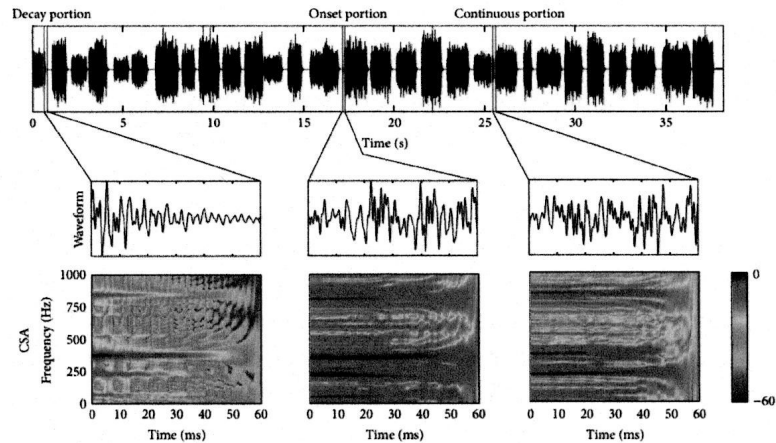


Figure 3: Random burst noise and CSA of different three portions.