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The effect of contact force parameters on the synthesized impact sound properties

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ABSTRACT

One of the essential problems in sound source identification is the extraction of physical-parameter-related sound characteristics. Previous studies mainly extracted the characteristics based on impact sounds since they are broadband and can preserve most of the structural information. Nevertheless, recent studies showed that the structural admittance (system function of the structure) is independent of the external contact force. That means the contact force information in the impact sound will affect the performance of the sound characteristics. In order to make the effects of contact force more clearly, the robustness of sound characteristics against the contact force parameters is carefully studied in this paper. Firstly, the impact sound continua of a cylinder structure are synthesized through a discrete state space and modal expansion based method. Then the effects of Hertz contact parameters (determine the contact force) on the temporal waveforms, spectrums and typical auditory characteristics of the impact sounds are examined respectively. The results show that both the temporal and spectral properties of the impact sound vary with different contact parameters. For subsequent studies, the extraction and selection of physical-attribute-related impact sound characteristics should eliminate the effect of impact force or avoid the characteristics which are sensitive to the contact parameters.

Keywords: Impact Force, Impact Sound, Sound Characteristics
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1. INTRODUCTION

In the study of sound source identification, people were engaged to restore the physical attributes information of the sound source from the radiated impact sounds. Physical

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attributes such as material, size and shape were most involved in previous studies [1–4]. However, the potential effects of the spatial radiation and the impact force are largely ignored in literatures. In some degree, the effects of the receiving positions can be neglected when the sound is received in the far-field. However, the effects of the impact force can not be ignored since it is relevant with both the temporal and spectral properties of the impact sound.

The physical processes of the impact sound production can be clarified by analogy with a signal system. The impact force and impact sound can be treated respectively as the input and the output of the system, and the structure and acoustic transfer path are two successive linear time-invariant sub-systems (black boxes). Since the physical attributes of the sound source and the radiation circumstance are assumed to be invariant, the input signal are independent from the system functions. Thus, the sound source identification task can be redefined as restoring the information of the system functions. In this point of view, the effects of contact force parameters on the impact sounds should be carefully studied and eliminated before starting any subsequence studies.

The synthesized impact sounds have irreplaceable advantages on the elaborate study of relationships between physical attributes and sound features since the physical attributes can be set flexibly. Tian [5] proposed a DSS+MEM based impact sound synthesis method, which consist of the whole processes of the sound production, those are, the Hertz contact process, the structural response process and the sound radiation process. Tian's method is more efficient than weekly coupled transient acoustic response case in Virtual.lab without losing too much accuracy, and it is introduced to obtain the synthesized impact sound corpus in the following text.

In this study, the effects of contact force parameters on the impact sounds properties of a cylinder structure are investigated. Firstly, the impact sound corpus is established through DSS+MEM method by varying different contact force parameters. Then the contributions of contact force parameters on the impact forces, driven-point admittance and impact sounds are analyzed. Finally, the coefficient factors between sound features and contact parameters are calculated and analyzed. The results show that the contact parameters are independent of the inherent physical properties of the structure, but they have broad effects on both impact force properties and impact sound properties.

2. EFFECTS OF CONTACT PARAMETERS ON FORCE AND ADMITTANCE

2.1. Experimental configurations

A simply supported cylinder structure is mainly studied. The larger cylinder as well as its material properties in reference [5] is introduced. Its length, radius and thickness are respectively 1.2 m, 0.4 m and 0.003 m. The initial displacement of the hammer is fixed to -10^{-4} m, and the driven point and the receiving point are respectively located at $x_p(r, \theta, z) = (0.4\ m, 0°, 0.08\ m)$ on the surface of the cylinder and $x_{receive}(r, \theta, z) = (2\ m, 0°, 0.08\ m)$ in the sound field.

The contact parameters are interpolated continuously in Table1 based on the reference configuration. The values of reference configuration are bold in Table1. Each contact parameter is controlled independently for 7 times. Thus, a total number of 36 impact sound samples (including the reference one) are synthesized and analysed.

Table 1: Parameters of the impact system.

Contact Parameters	*Interpolated Values*								*Unit*
	1	2	3	4	5	6	7	8	
Initial velocity	**2**	4	6	8	10	12	14	16	m/s
Contact elastic modular	**50**	100	200	400	800	1000	1200	1400	GPa
Contact damp factor	0.1	0.2	0.3	0.4	0.5	**0.6**	0.7	0.8	–
Contact index	2.2	2.4	2.6	2.8	3.0	3.2	3.6	**3.8**	–
Hammer mass	**1**	2	4	8	16	32	64	128	g

2.2. Effects on contact force

The spectrums of impact forces, when five contact parameter in Table1 is controlled independently, are shown in Figure 1 (a~e). Where V_0 and mh are the initial velocity and mass of the hammer, kh, $lamda$ and n are the contact elastic modular, contact damp factor and nonlinear index. Another parameter which relevant with the contact process is the driven position. It is investigated as a complementary experiment to shown whether it is relevant with the contact forces properties. Only the axial coordinate of the driven point is considered since the cylinder is axial symmetry. The results of contact forces when driven position is varying are shown in Figure 1 (f). Where Z is the axial coordinate of the driven point.

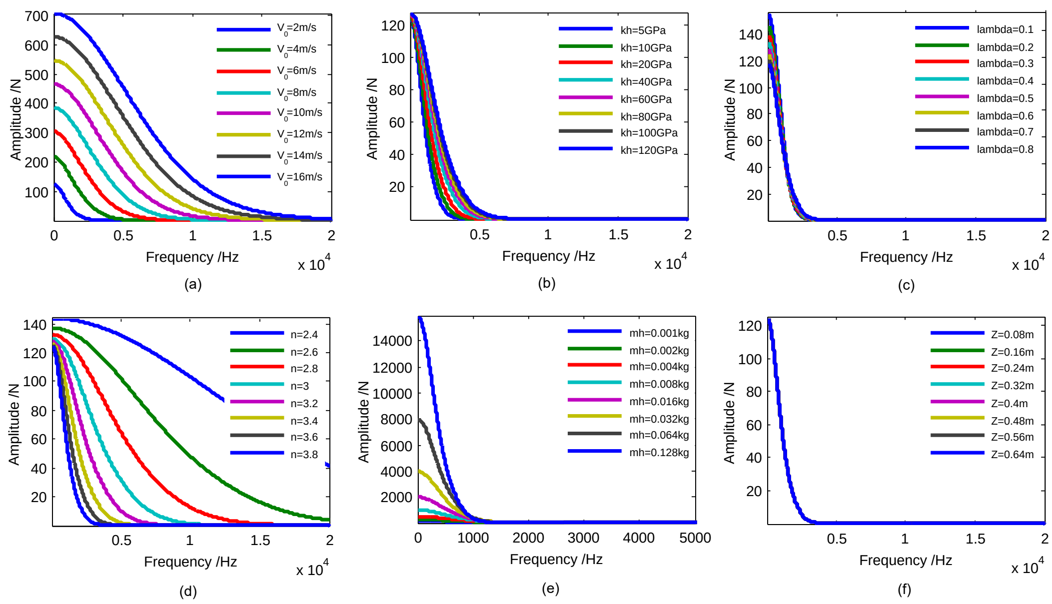

Figure 1: Force responses when each contact parameter is controlled

It can be seen from Figure 1 that the spectrums of the contact forces are in forms of half-Gauss, the spectral amplitudes decrease along the frequency axis, and both the initial value, decay slope of the spectrums are affected by five contact parameters. The contact forces, as external factor of the sound source, are changeable with different contact parameters, which will affect the performance of the sound characteristics in sound source identification tasks. The phenomenon that the contact forces do not change with the driven positions can be explained with the local interaction assumption of Hertz contact theory. This phenomenon implies the independence of contact force from driven point.

2.3. Effects on driven-point admittance

The driven-point admittances under different contact parameter conditions are shown in Figure 2. Even though the changes of five contact parameters, the driven-point admittance responses are coincident with each other. The slightly differences in the high frequency domain can be eliminated by increasing the sampling rate of the contact force when its duration is extremely short. The independence of point admittance (as a linear time-invariant system function) and input force signal, described in the Introduction section, is perfectly proved in Figure 2.

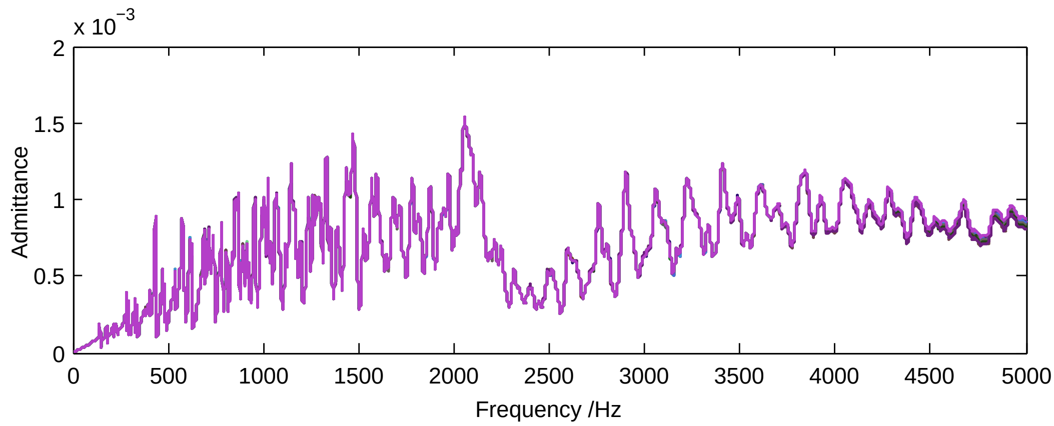

Figure 2: Structural admittance when each contact parameter is controlled

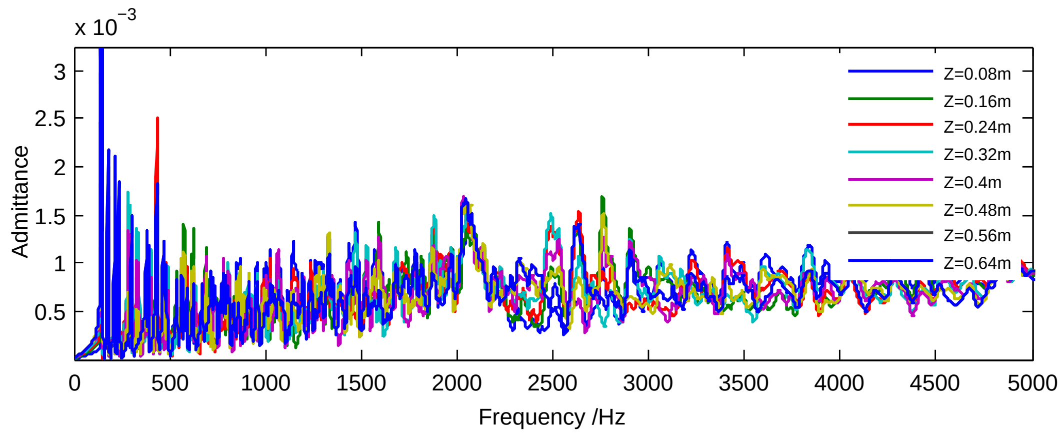

Figure 3: Force responses when the position of driven point changes

The effects of driven position on the point admittance responses are displayed in Figure 3. It can be seen that the driven position has great effects on the modal weights of point admittance responses. Actually, in the modal analysis theory, driven position determines the modal weights but it can't change the inherit modal distribution of the vibrating structures. Even though relevant with the contact process, driven point is independent from contact force and should not be treated as a contact parameter.

3. EFFECTS ON IMPACT SOUNDS

3.1. Effects on impact sound waveform and spectrum

The normalized waveforms and logarithmic spectrums of total 36 impact sounds are shown respectively in Figure 4 and Figure 5. The temporal amplitude and scale change gradually along with each controlled contact parameter. The modes (peaks) of the logarithmic spectrums are preserved the same with each other, nevertheless the decay slopes along the frequency axis are obviously affected by different contact parameters. It is obvious that the effects of contact parameters are mainly reflected on the slow amplitude changes. If the slow amplitude changes can be evaluated and isolated, the contribution of contact force in the impact sound can be eliminated and the extracted sound characters can be more robust against the contact parameters.

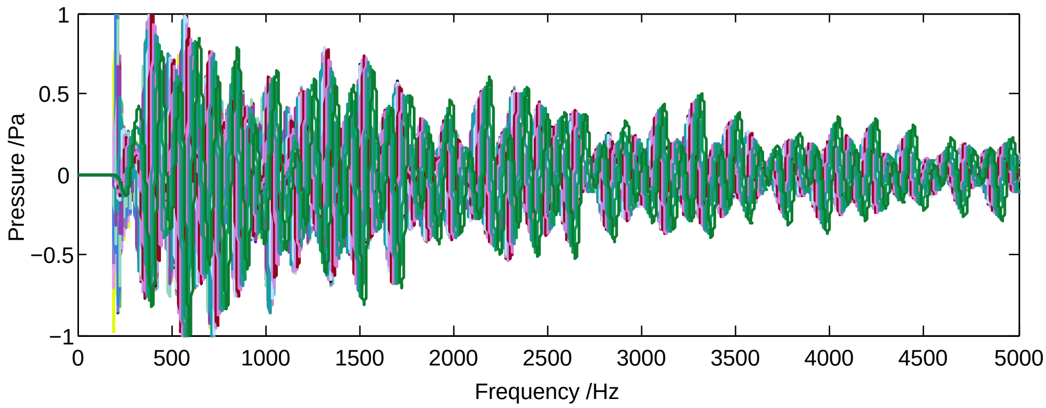

Figure 4: Normalized impact sound waveforms

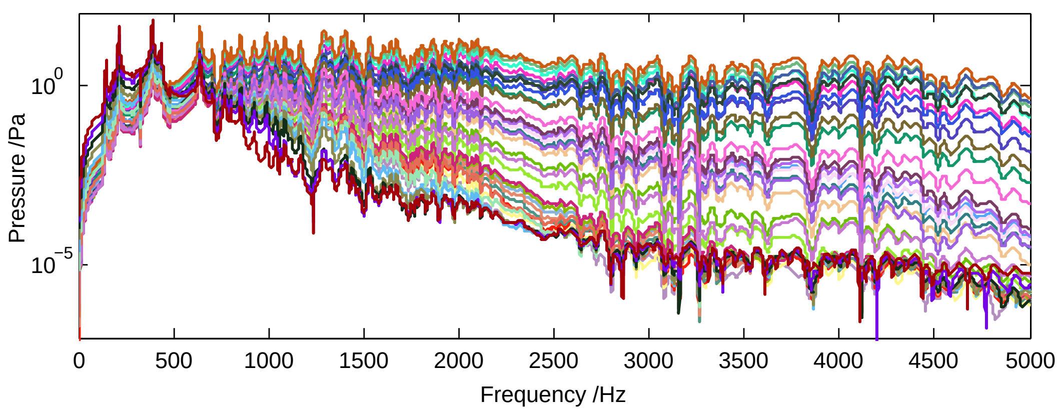

Figure 5: Impact sound spectrums

3.2. Effects on timbre features representation

In order to clarify the effects of contact parameters on the timbre features. The Pearson correlation analysis has been conducted. The timbre features are extracted from Matlab Timbre Toolbox 1.4 [6]. A total number of 164 timbre features, extracted from temporal energy envelope (feature 1~38), STFT magnitude and power (feature 39~82), harmonic sinusoidal modeling representation (feature 83~120) and ERB representation (feature121~164), are considered in this study.

The coefficient factors of the contact parameters and timbre features are displayed in Figure 6. It can be seen from the figure that most of the timbre features are strongly relevant with different contact parameters. Such result implies that timbre features will not be robust in an impact sound source identification task when the contact force is unknown or arbitrary.

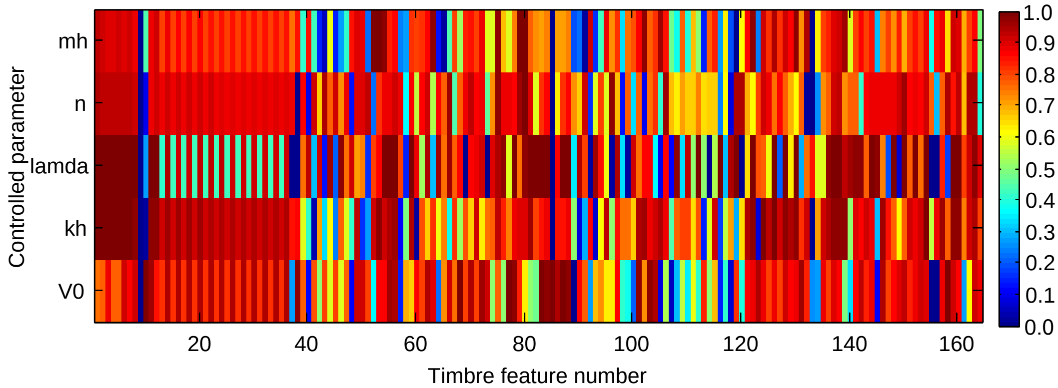

Figure 6: Coefficient factors of each contact parameter and corresponding timber features

3.3. Effects on typical auditory perception features

Typical auditory perception descriptors, such as roughness, fluctuation, brightness, spectral entropy and spectral irregularity, are commonly used in sound source identification studies. Thus investigating the effects of contact parameters on the statistic features of auditory descriptors are very valuable. A total number of 22 statistic auditory perception features are extracted and analyzed (displayed in Table 2). These auditory perception features can be calculated through the Matlab MIRToolbox [7].

Table 2: Auditory features and feature numbers corresponding to Figure 7.

Auditory descriptor	*Statistic feature*	*Feature number*
Fluctuation	*PeakPosMean, PeakMagMean;*	1~2
Brightness	*Mean, Std, Slope, PeriodEntropyy;*	3~6
Spectral entropy	*Mean, Std, Slope, PeriodEntropy;*	7~10
Roughness	*Mean, Std, Slope, PeriodFreq PeriodAmp, PeriodEntropy;*	11~16
Irregularity	*Mean, Std, Slope, PeriodFreq, PeriodAmp, PeriodEntropy;*	17~22

The coefficient factors between contact parameters and auditory perception features are shown in Figure 7. It can be concluded from Figure 7 that most of the auditory perception features are strongly relevant with the contact parameters.

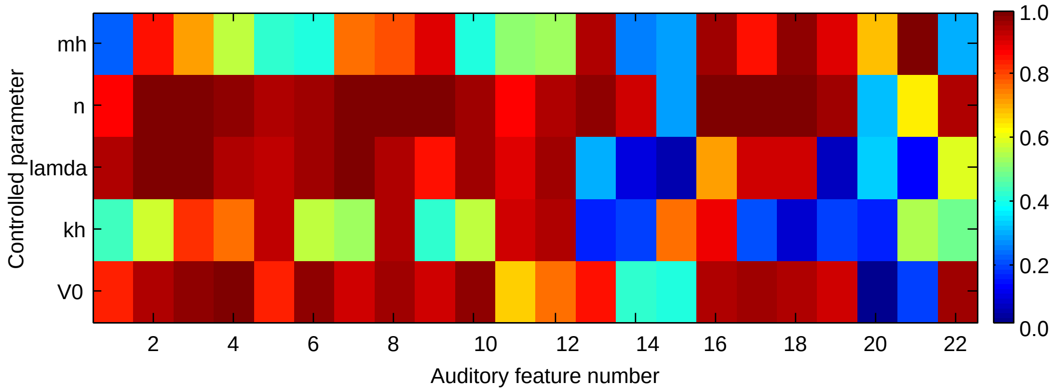

Figure 7: Coefficient factors of the contact parameters and auditory features

4. CONCLUSIONS

In this study, the effects of contact force parameters on the contact force, the driven-point admittance and the synthesized impact sounds properties of a cylinder structure are investigated. The results are as follows

(1) The contact parameters are independent of the driven-point admittance, which represents the independence of contact parameters on the inherent physical properties of the structure.

(2) Both the temporal and spectral properties of contact force and impact sound can be affected by contact parameters.

(3) Most of the timbre features and auditory features can be affected by contact parameters. Those features sensitive to the contact parameters would not be robust unless the weights of contact parameters are proved to be very low compared with those of other physical attributes.

(4) For subsequent sound source identification studies, the possibility of evaluate and eliminate the contribution of the impact force should be investigated as a premise.

5. ACKNOWLEDGEMENTS

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