MEASUREMENT OF NATURAL VIBRATION OF ACOUSTIC SPACE BY UNDAMPED VIBRATION USING DECENTRALIZED CONTROL

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Natural vibrations of acoustic space expand noise. To reduce noise based on mechanism, measurements of natural vibration is effective. Acoustic space has many natural vibrations with damping in the noise frequency band. Multi-point excitation is useful for measuring natural vibration, which has mixed modes. Furthermore, it is necessary to cancel the influence of damping to excite the modes individually. In this study, the measurement technique of natural vibrations of acoustic space by multi-point excitation using decentralized control with local feedback control is proposed. An excitation system with local feedback control excites natural vibration without frequency adjustment and cancels damping in acoustic space. Excitation systems with decentralized control can have multi-point excitation without any adjustment of phase and amplitude each other. The acoustic excitation system consists of a speaker, a microphone and a local feedback controller. The controller generates negative damping according to the sound pressure detected by the microphone and feeds it to the speaker. Firstly, it is confirmed that one acoustic excitation system is self-oscillate at resonance frequency and some resonance peak of the transfer function is sharpened by canceling the effect of damping. Secondly, to excite many modes, multi-point excitation using decentralized control is performed using four acoustic excitation systems. All supposed modes are excited without adjustment of the excitation systems according to mode such as amplitude and phase. Finally, it is confirmed that acoustic excitation system has no limitation on the number of installations and has extensibility for higher-order mode excitation.

Keywords: acoustic space, natural vibration, self-excited vibration, local feedback control, decentralized control

1. Introduction

In recent years, customers demands regarding sound quality in cabin room of vehicle (e.g. automobile, railroad car and so on) are increasing. Various interior noises (e.g. engine noise, booming noise, road noise and wind noise) which deteriorate sound quality, occur in the cabin room of a moving vehicle. Interior noise can be modelled as a vibro-acoustic system in which the acoustic system of cabin space and the structural vibration system of vehicle body are coupled [1]. So, measurement of acoustic transfer characteristics are important to reduce interior noises [2].

Numerical analysis such as finite element method (FEM) is performed to understand acoustic transfer characteristics. Numerical analysis before prototyping can reduce the development cost and
time. Various ideas which concern numerical analysis method have been proposed to analyze the actual complex structure [3-4]. Experimental modal analysis which measures the transfer characteristics by excitation of real structure is necessary to verification of numerical analysis result.

Cabin space of vehicle is a three dimension space and has high damping because of vehicle seats and acoustic material as cover material [5]. Therefore, it is difficult to excite natural vibration by one-point excitation and measure transfer characteristics. In the case of measurement of transfer characteristics of system with high damping, the multi-point excitation using many actuator is a must.

Centralized control system is well known as popular multi-point excitation system [6]. In this control system, the sinusoidal wave signals which the amplitude and the phase are adjusted according to the natural vibration mode shape are inputted to all actuators. As the one of this system’s issue, since numerical analysis results are used to adjust the amplitude and the phase of input signal, the measurement result depends on numerical analysis results. Further, there has been an explosive increase in the adjustment time of input signal in association with increase of excitation points.

The authors have developed decentralized control system using local feedback control [7]. In this system, an actuator is excited by self-excited vibration which is generated by local feedback control. Local feedback controller is designed to cancel influence of the structure damping. Furthermore, the amplitude and the phase of each actuators are adjusted according to the natural vibration mode shape because of synchronization of multi self-excited oscillators. Previous study has demonstrated that decentralized control can drive at resonance point of multi-degree-of-freedom system easily.

In this paper, multi-point excitation method using decentralized control for acoustic excitation is developed and measurement method of acoustic natural vibration by developed multi-point excitation is proposed. Firstly, acoustic excitation system to realize local feedback control is developed. Secondly, local feedback controller for acoustic excitation is designed. Furthermore, the experiment by one-point excitation using local feedback control is examined to confirm that natural vibrations can be measured. Finally, the experiment by multi-point excitation using decentralized control is examined to demonstrate that measurement result can be improved.

2. Multi-point excitation using decentralized control

In this section, the multi-point excitation method using decentralized control which is proposed in this paper is introduced. The proposed excitation method uses the actuators controlled by local feedback control [7]. Undamped vibration is generated when controller is designed to cancel the structure damping. When structure is excited using some actuators controlled by local feedback control, the multi-point excitation using decentralized control can be implemented.

At first, the principle of undamped vibration generated by local feedback control is explained. The local feedback control proposed by authors uses vibration characteristics of multi-degrees-of-freedom system. Fig. 1 shows multi-degrees-of-freedom system and the transfer function of this system. The phase lag of the transfer function from actuator force to displacement is 90° for all natural frequencies in the condition of collocation which means that both actuator and sensor are same position. The controller is designed to delay the phase by 90°, the control force which direction is set reverse to the direction of the damping force is generated. When the gain of controller is adjusted to equilibrate control force with damping force, the undamped vibration can be implemented.

Next, the mechanism of multi-point excitation using decentralized control is expressed. When the excitation signal is inputted to the actuator controlled by local feedback control, the actuator becomes the self-excited oscillator. In the condition that some self-excited oscillators are set on the excitation object, the oscillators excites with synchronization of each oscillators through the natural vibration mode shape of the object. Furthermore, the amplitude and the phase of oscillators are adjusted according to the natural vibration mode shape because of synchronization of multi self-excited oscillators.
3. Experimental apparatus

In this study, the experiment using the simplest three-dimensional acoustic space is done to examine the basic performance of the proposed measurement method. Enclosed rectangular acoustic space was manufactured as shown in Fig. 2. The size of enclosed acoustic space which consists of aluminium plates is 1200mm × 1000mm × 900mm. Three sides of acoustic space have respectively 8 × 7 holes for microphones to measure mode shapes. This acoustic space has 25 modes in the frequency range from 100Hz to 500Hz theoretically. Modal diagrams of acoustic space are shown in Fig. 3. This acoustic space have some natural vibrations in the narrow band frequency range.

Next, the acoustic excitation system for local feedback control shown in Fig. 4(a) is developed. The speaker and the microphone on the enclosure are placed to become the distance as close as possible. The positions of acoustic excitation systems in the three dimensional acoustic space are four corners of bottom face shown in Fig. 4(b) because of the concept that there is not node between the speaker and the microphone on the enclosure.

Finally, the local feedback controller for acoustic excitation is introduced shown in Fig. 5(a). The
(a) 142Hz (1,0,0) mode.  
(b) 170Hz (0,1,0) mode.  
(c) 189Hz (0,0,1) mode.  
(d) 221Hz (1,1,0) mode.  
(e) 236Hz (1,0,1) mode.  
(f) 254Hz (0,1,1) mode.  
(g) 283Hz (2,0,0) mode.  
(h) 291Hz (1,1,1) mode.  
(i) 330Hz (2,1,0) mode.  
(j) 340Hz (0,2,0) mode.  
(k) 341Hz (2,0,1) mode.  
(l) 368Hz (1,2,0) mode.  
(m) 378Hz (3,0,0) mode.  
(n) 381Hz (1,1,2) mode.  
(o) 389Hz (2,2,0) mode.  
(p) 403Hz (3,1,0) mode.  
(q) 414Hz (3,0,1) mode.  
(r) 414Hz (2,0,2) mode.  
(s) 425Hz (3,0,0) mode.  
(t) 438Hz (1,1,2) mode.  
(u) 443Hz (2,2,0) mode.  
(v) 458Hz (3,1,0) mode.  
(w) 465Hz (3,0,1) mode.  
(x) 472Hz (2,0,2) mode.  
(y) 481Hz (2,2,1) mode.

Figure 3: Theoretical modal diagrams of three dimensional acoustic space expressing sound pressure (100Hz to 500Hz). Dash lines mean node line.

controller consists of phase reversal element, derivative element and integral element. The speaker is used in the frequency range which is higher than mechanical resonance frequency differing from the mechanical actuator. Consequently, the phase reversal element is necessary for local feedback controller of acoustic excitation because of phase reversal caused mechanical resonance. PID control is used to delay the phase by $90^{\circ}$ shown in Fig. 5(b). This control is designed by MATLAB/Simulink and provided by DSP (dSPACE Inc.).

4. Acoustic excitation test

The acoustic excitation tests to evaluate the basic performance of the proposed method are conducted. At first, the influence of undamped vibration generated by local feedback control on measurement results of natural vibration is evaluated by the experiment which a developed acoustic excitation system is used for acoustic excitation. Furthermore, it is indicated that the multi-point excitation using decentralized control can be implemented as easy as excitation at one point.

Here, the testing method to evaluate the performance and parameter of controller are expressed.
The forced excitation and self-excitation as one point excitation is done to measure transfer function. Furthermore, the multi-point excitation which is used four acoustic excitation systems controlled by
local feedback control and a one system is inputted excitation signal is done. Controller gain of local feedback control is set to cancel 80\% of damping effect. Transfer functions from speaker to microphone on the acoustic excitation system are measured.

Fig. 6 shows the transfer functions which are measured by forced excitation, self-excitation and multi-point excitation. Firstly, all natural vibrations in the low frequency range can be measured from black line of Fig. 6(a). Additionally, the natural vibrations are scattered in the wideband frequency range. In the other hand, the independent peaks of natural vibration in the high frequency range can not be measured from Fig. 6(b) because of crowing of natural vibration in narrow frequency range. Moreover, it is confirmed that some natural vibrations can measure only 20 modes out of 25 modes shown in Fig. 3. It is considered that this cause is the enclosure size. The natural vibrations of (0,2,0), (1,2,0), (0,2,1), (1,2,1) and (2,2,0) mode in Fig. 3 have node in the vicinity of the enclosure face which is setting speaker and microphone.

Secondly, self-excitation indicates that most of the peaks of natural frequencies peaked upright by cancelling damping effect from comparison of forced excitation (black line) and self-excitation (blue line) shown in Fig. 6. The difference of cancelling level between each natural frequencies is confirmed that the modes of the peaked upright strikingly have anti-node in the vicinity of the enclosure face which is setting speaker and microphone. From this result, the developed acoustic excitation system should be set in the neighborhood of anti-node so that natural vibrations are able to measure becase of cancelling effect of the damping caused by local feedback control.

Thirdly, muti-point excitation using decentralized control (red line) is more effective of cancelling damping than self-excitation at one point, for example set of 407Hz, 416Hz and 421Hz or 458Hz, 465Hz and 473Hz. It is confirmed that the local damping is effective for natural vibration of high frequency and multiple excitation can cancel the local damping in the vicinity of excitation point.

At last, the mode shapes measured by each excitation methods are shown in Fig. 7～Fig. 9. It is confirmed that the same mode shape can be measured irrespective of excitation method. This measurement used only sound pressure of microphones for mode measurement. To consider cancelling damping effect will lead to an improved result of measuring mode shape. From this result, the multi-point excitation using decentralized control can be implemented as easy as excitation at one point.

5. Conclusion

In this study, the multi-point excitation using decentralized control for acoustic system was proposed. We obtained the following results:

- The acoustic excitation system for local feedback control is developed.
- The acoustic excitation by undamped vibration using decentralized control was implement.
- The measurement of natural vibration by multi-point excitation using decentralized control was implemented.

Fig. 6: Tranfer functions measured by forced excitation at one point (black line), self-excitation (blue line) at one point and multi-point excitation (red line).
Figure 7: Modal diagram measured by forced excitation at one point.

Figure 8: Modal diagram measured by self excitation at one point.
Figure 9: Modal diagram measured by multi excitation at four point.

successfully as easy as excitation at one point.

In the future work, the acoustic excitation test of high damping system and the development of the method to measure mode shape clearly will be done.

REFERENCES


