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SOUND DESIGN FOR IMPULSIVE RADIATED SOUND OF MECHANICAL STRUCTURE BASED ON STRUCTURE MODIFICATION

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ABSTRACT
Recent mechanical structure of the same kind of performance is almost the same in terms of making a sound. If the structure is discriminated to generate an ideal sound from other structures, it has an added value furthermore. In this research, impulsive radiated sound like hitting a ball by a golf club is extracted some distinctive frequency peaks in consideration of several amplitude and harmonic balance. The real sound from the original structure can be changed to the ideal sound by modifying the distinctive frequency peaks. An external force to work on the original structure can be estimated using frequency response function and vibration response. A new structure to generate the ideal sound can be predicted based on structural modification by using vibration-sound pressure transfer matrix and the external force. The proposed method is confirmed by a numerical model and a real structure.

1 - INTRODUCTION
In general, sound in our living space is combined by some sinusoidal sounds. There are three elements of the sound, namely, frequency, amplitude and tone quality. The frequency and the amplitude are expressed simply using high-low and big-small respectively, however tone quality is included multi-factor of adjectival meaning, beautiful, clear, pleasant, etc... To generate an ideal sound from a new structure should not define abstract expression using adjective like semantic differential method but concrete frequency characteristic as a spectrum. Structural modification with the intention of generating an ideal sound is named sound design, which does not go through the sequence process of causing a sound from a structure but the reverse process of estimating a design parameter from an ideal sound.

2 - TONE QUALITY OF GOLF CLUB
Impulsive radiated sound from hitting a ball by a golf club made of titanium is shown in figure 1, which has windy noise below 2 kHz and main three peaks of 3 kHz, 6 kHz and 10 kHz. Superior sound of the golf club has almost the same amplitude of the three peaks, otherwise inferior sound has hardly the 6 kHz peak on account of imperfect welding condition. According to jury evaluations, it is confirmed that a peak and adjoined two peaks of both sides prefer almost the same amplitude. Since the ideal sound of the golf club is discriminated, the purpose of tone quality can be created.

3 - THEORETICAL BACKGROUND OF SOUND DESIGN
Flow chart of this research is shown in figure 2. When vibration velocity V on a structure is obtained, vibration induced sound pressure P in the field point can be defined as follows.

$$\{P\} = [Q]\{V\} \tag{1}$$

Here $[Q]$ is vibration-sound pressure transfer matrix calculated by boundary element method [1]. Conversely, ideal vibration velocity $\{\bar{V}\}$ for generating an ideal sound can be estimated by limited number of vibration induced sound pressure $\{\bar{P}\}$ and vibration-sound pressure transfer matrix $[Q]$ as follows.

$$\{\bar{V}\} = \left([Q]^h [\mathrm{Q}]\right)^{-1} [\mathrm{Q}]^{\mathrm{h}} \{\bar{P}\} \tag{2}$$

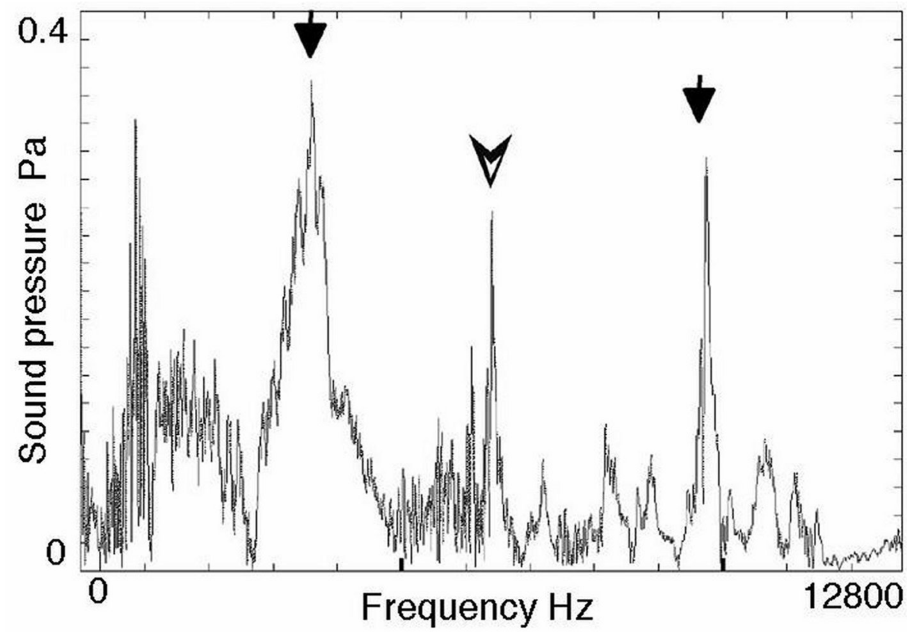

Figure 1: Radiated sound pressure from golf club at the time of hitting a ball.

where h: complex conjugate transpose
As external force can be estimated by original Frequency Response Function (FRF) $[H]$ and vibration response. So sound design FRF $[\overline{H}]$ can be calculated by estimated ideal vibration velocity $[\overline{V}]$ and the external force.
On the other hand, modified FRF H'_{ab} between response point a and reference point b after structural modification of adding mass with Δm at point c is defined using original FRF H_{ab} and other FRFs as follows [2].

$$H'_{ab} = H_{ab} - \frac{H_{ac}H_{cb}}{H_{cc} + \frac{1}{\Delta m}} \tag{3}$$

If modified FRF H'_{ab} is similar to sound design FRF, structural modification of adding mass at point c is a correct point for generating an ideal sound.

4 - APPLICATION TO REAL STRUCTURE

This method is applied to a cantilever plate as shown in figure 3. Impulsive external force by impact hammer, which is nearly constant level of measurement frequency range as shown in figure 4, is input to the cantilever plate at point 7. Original radiated sound pressure from the cantilever plate has three peaks at around 0.5, 1 and 1.5 kHz as shown in solid line of figure 5. Since the peak of 1 kHz is not the same amplitude as other two peaks of both sides, the peak of 1 kHz is made a try to have higher amplitude for ideal sound as shown in dotted line of figure 5. Vibration velocity for ideal sound is calculated using ideal sound pressure of two point and vibration-sound pressure transfer matrix in equation (2). And sound design FRF is identified by the vibration velocity and the external force as shown in solid line of figure 6.
Next, a numerical model of the cantilever plate is built by finite element model, which is in good agreement with real structure. The numerical model is modified by structural modification of adding mass for generating an ideal sound. A coincidental condition between original and sound design FRF is 1) at the same intervals of each peak, 2) at the same tendency of peak amplitude and 3) at the same frequency value of each peak in order.
When a mass of 65.8 gram at point 24 of the numerical model is added as shown in figure 3, the aimed three peaks of FRF are satisfied with the coincidental condition as shown in dotted line of figure 6. Although the frequency value is slightly lower shift of the aimed three peaks because of adding mass modification, the peak balance is almost good agreement. While the numerical model and the real structure is added mass at the point 24, the radiated sound pressure are calculated by boundary element method in dotted line and measured in solid line respectively as shown in figure 7. The aimed three

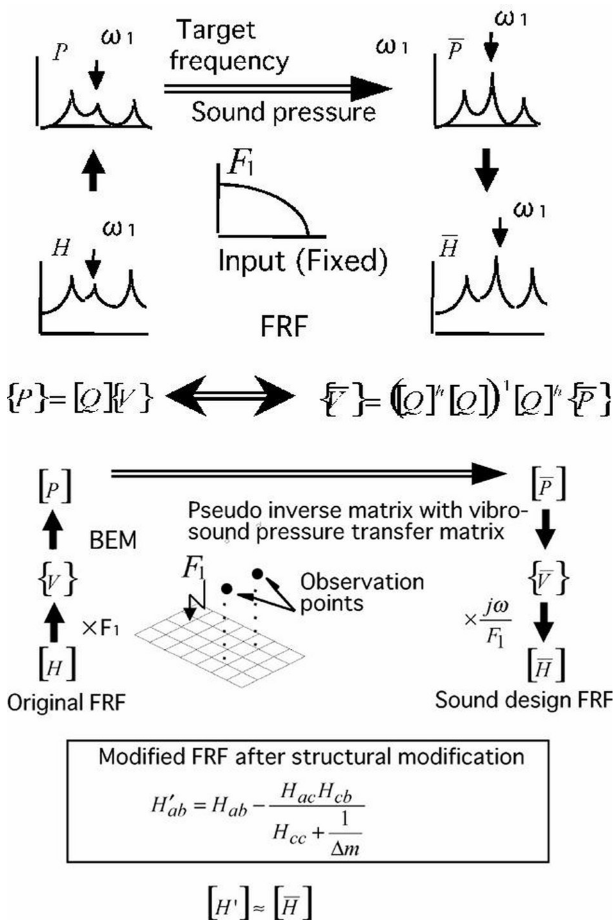

Figure 2: Flow chart of this research.

peaks as shown in figure 7 are the same tendency of the ideal sound as shown in dotted line of figure 5. Moreover ideal sound and modified sound are verified the same tone quality according to jury evaluations.

5 - CONCLUSIONS

- According to jury evaluations, a criterion of an ideal sound from golf club at the time of hitting a ball can be decided and some distinctive frequency peaks can be extracted.
- Vibration velocity of a structure for generating an ideal sound can be identified by limited number of ideal sound pressure and vibration-sound pressure transfer matrix, which is calculated by boundary element method.
- The proposed method is applied to a cantilever plate and verified to generate an ideal sound by sound design with adding mass of structural modification.

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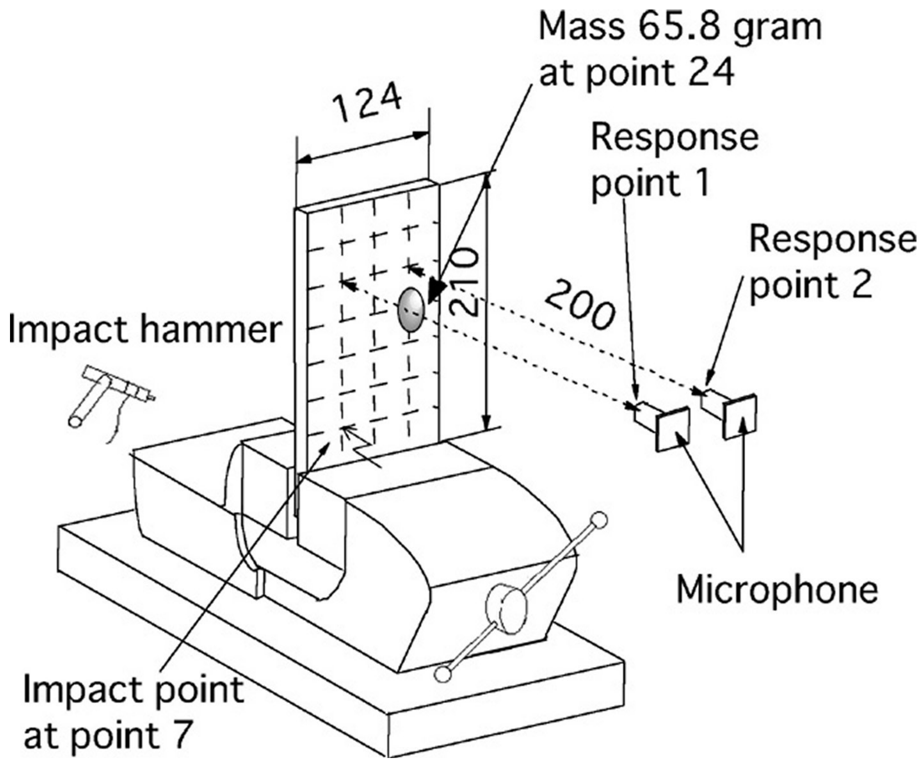

Figure 3: Experimental configuration.

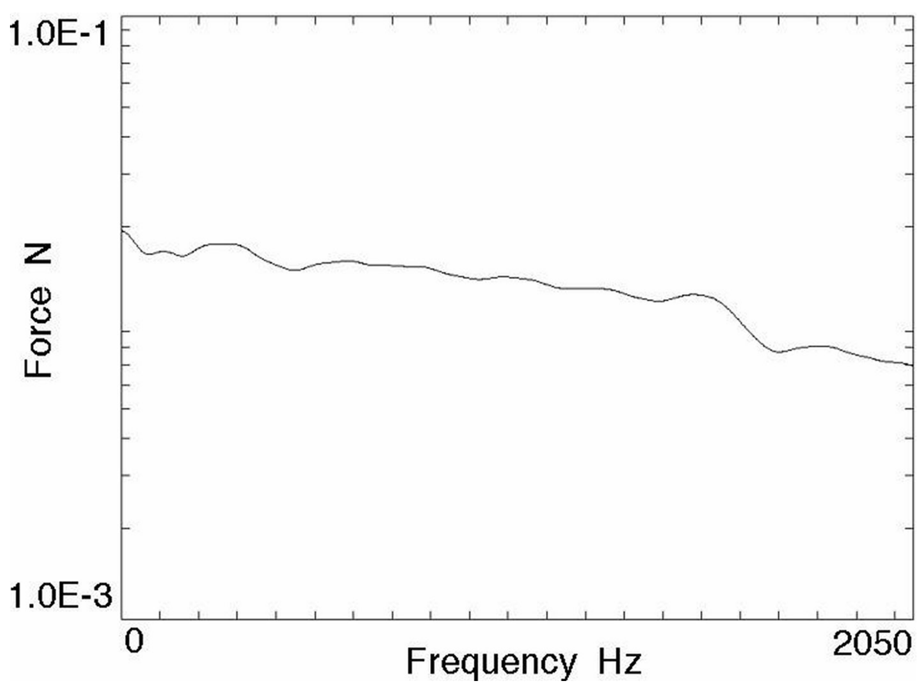

Figure 4: External force.

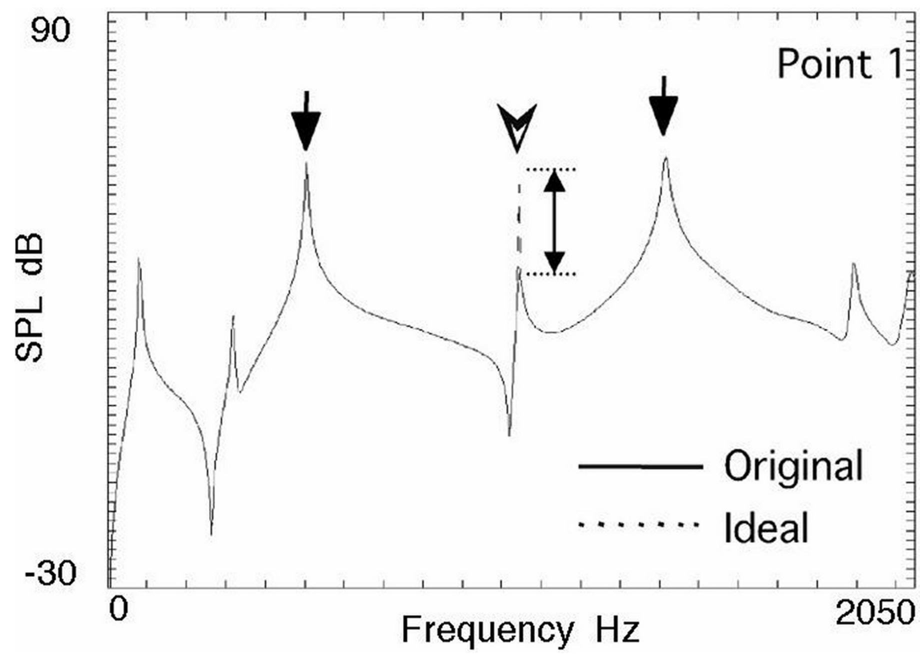

Figure 5: Ideal radiated sound pressure.

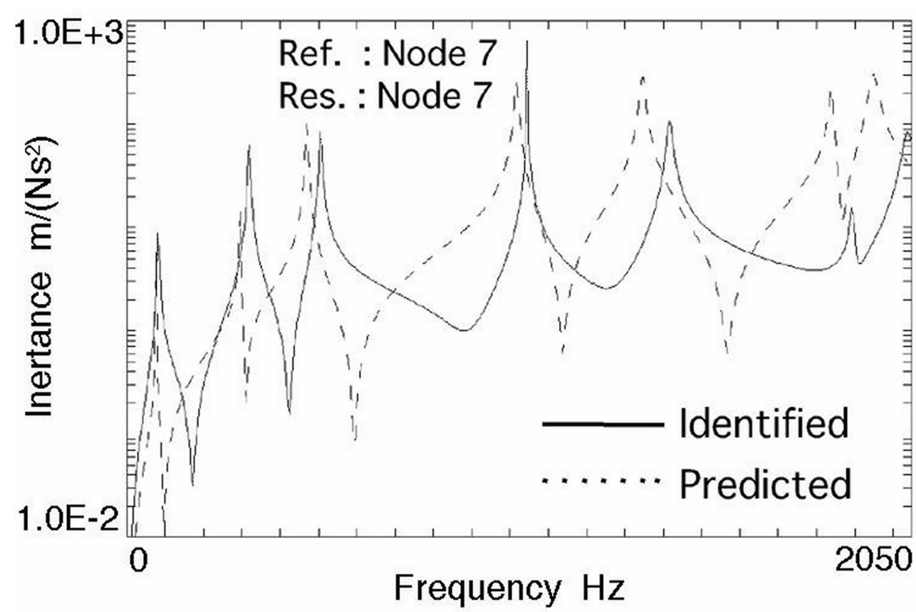

Figure 6: Identified and Predicted FRF.

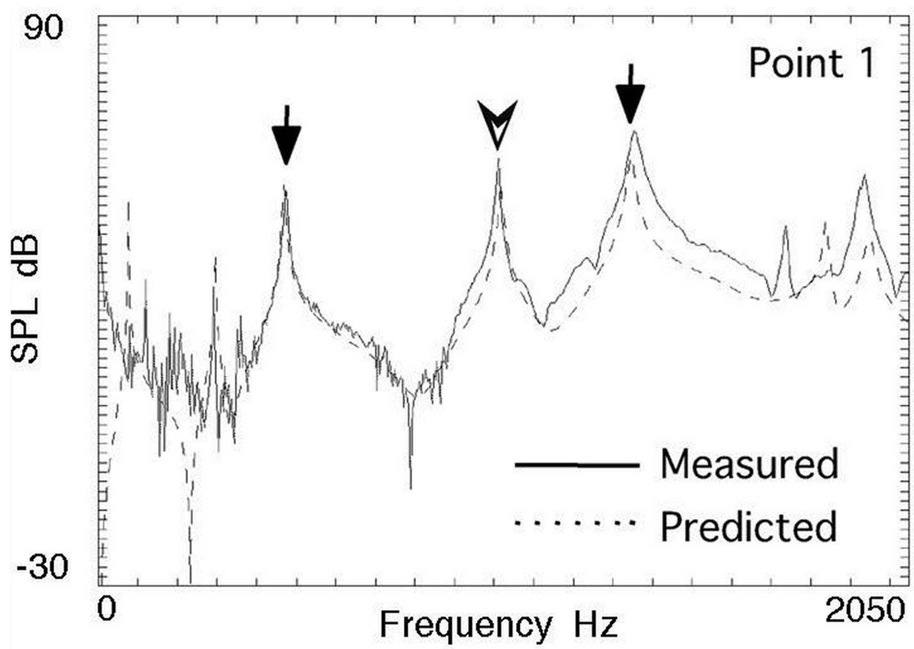

Figure 7: Radiated sound pressure after structural modification.