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縮小模型鐘之振動模態與發聲機制探討

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摘要

鐘為金屬製之打擊樂器，形狀為上窄下寬之中空碗狀，其音色渾厚莊嚴的特性常用於寺廟或教堂之演奏。本文應用有限元素分析(FEA)和實驗模態分析(EMA)，對縮小模型鐘進行模型驗證及聲音特性與振動模態之關聯性探討。首先，對縮小模型鐘建構有限元素模型，並進行理論模態分析，求得鐘的自然頻率及其對應的模態振型，同時結合實驗模態分析，以衝擊槌為驅動器，加速規為感測器，透過訊號擷取卡擷取訊號做快速傅立葉轉換，可量測求得鐘的頻率響應函數，再經由曲線嵌合軟體擷取實驗的模態參數，透過模型驗證之程序更新分析模型系統參數，當 FEA 及 EMA 所得模態參數相互對應時，可確認有限元素模型等效於實際結構。此外也針對縮小模型鐘進行聲音頻譜量測分析，可由結構振動模態瞭鐘的發聲機制，同時探討不同敲擊棒對鐘聲之差異影響。本文針對縮小模型鐘的聲音與振動探討，所採用的分析與實驗手法及模型驗證理念，可以作為解析其他打擊樂器發聲機制的參考。

關鍵字： 縮小模型鐘、有限元素分析、模型驗證、聲音頻譜

Discussions on Sound Generation Mechanism and Vibration Modes of Miniature Bell

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Abstract

Bell is a kind of metal-made percussion instrument with an empty bowl shape, producing deep and solemn tone sound, and frequently used at temples or churches. This work applies finite element analysis (FEA) and experimental modal analysis (EMA) to perform model verification (MV) on the miniature bell, so as to discuss the correlation of sound and vibration characteristics of the bell. The finite element (FE) model of the miniature bell is constructed and conducted for theoretical modal analysis (TMA) to obtain bell's natural frequencies and corresponding mode shapes. By using the impact hammer as the actuator and the accelerometer as the sensor, the frequency response functions (FRFs) of the bell can be measured and processed to determine experimental modal parameters via curve-fitting software. Through the MV procedure by updating system parameters, the bell FE model can be verified equivalent to the real structure when both modal parameters from FEA and EMA, respectively, agree to each other's. The percussion sound spectrum from the bell is also measured and interpreted by structural vibration modes to realize the sound generation mechanism. The sound effects for different percussion sticks are compared, and the proper stick can be suggested. The analytical and experimental approaches in analyzing and measuring the bell's sound and vibration are presented and can be adopted for other percussion instruments as well.

Keywords: Miniature Bell, Finite Element Analysis (FEA), Experimental Modal Analysis (EMA), Model Verification, Sound Spectrum