結構噪音傳播之流體互制效應

Fiuld-Structure Interaction Effect to the Structure-Borne Noise Propagation

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一. 摘要

浮體與水接觸之振動現象，與浮體在空氣中振動所造成之聲波，因介質密度差異懸殊，故考慮浮體振動時之輻射互制效應亦有所不同。

本研究即擬探討流體輻射負荷效應，對結構噪音傳遞之影響量。任意振動物體之聲輻射可用一包含格林函數並帶有給定輻射條件的積分方程來表示，希望就克希霍夫-漢姆霍茲積分方程之已有基礎，建立流體與結構表面之偶合效應數值模型，進而瞭解該流體聲輻射效應對結構噪音傳播之影響。

關鍵詞：輻射負荷、克希霍夫-漢姆霍茲積分方程、彎曲波、壓力波

ABSTRACT

The radiation loads of a vibration body in air and in water are of paramount difference. This is mainly due to the big density difference of the media.

The aim of the research project is to discuss the influence of the fluid radiation load to the behaviour of the structure-borne noise propagation. The sound radiation problem can be expressed of the form of integral equation which is in terms of a Green's function and the given radiation condition. It is intended to develop a numerical model based on the Kirchhoff-Helmhotz integral equation to approach the fluid-structure interaction problem of the vibrating stiffened plate structure in the medium frequency range.

Keywords：radiation load, Kirchhoff-Helmhotz integral equation, bending wave, pressure wave.

二. 研究動機及目的

像船舶這樣的浮體結構可儲存縱向壓縮波、彎曲橫波、剪切波及扭轉波等應力波的能量。另一方面，由於流體只能儲存壓縮能量，故僅存在縱向壓縮波於流體介質中。因此結構中之彎曲波是結構噪音傳播中與聲輻射起直接偶合作用之唯一結構波型。

本計畫主持人曾於 100GT 高速艇實測得知：於船台上及下水後主機彈性座之傳遞動性頻譜，顯見在 600Hz 以下水之輻射負荷對彈性墊動性有 10~20dB 之降低效果，此激發好好研究之動機，以探討在中低頻域結構噪音受流體互制效應究竟如何評估。

三. 研究方法及結果

浸在液體中的彈性結構體與聲音介質的互制作用，在結構聲學上是十分重要的問題。對於任意形狀的三度空間彈性結構體，有限元素是一個有效的工具來探討其動態行為。而聲音介質對結構體的作用則以邊界元素法的應用最為廣泛。將有限元素法及邊界元素法結合起來可以處理結構/聲音介質在中低頻方面的交互作用[1-6]。以邊界元素法處理聲音介質對結構作用力的優點是把三度空間的介質動態行為完全的表示成在物體表面上二度空間的問題，並且此等的表示方法自動的滿足了在遠場的輻射邊界條件，亦即 Sommerfeld's radiation condition，如此邊界元素法或是邊界積分方程式所代表的聲場的動態特性滿足了數學上之唯一性[7]。而在高頻範圍內由於結構振動波長愈短，有限元素法無法再細切元素，因此將改採統計能量法（SEA），其詳細的理論可參考[42]，此法是在高頻範圍現可以使用較成熟的方法，在文獻上[43]澳洲的海軍已有成功使用的範例，而本系同仁亦投入此方面研究有 6-7 年之久，因此高頻的部分可使用統計能量法。

船體結構浸於水中，當結構體內之振源如運轉之主機即是，其所造成之結構音傳

播，除了輻射音受聲音介質之影響外，即使結構本身之振動轉換函數亦受流固偶合效應之影響。為探討此問題本研究採用以下方法：

1. 利用結構應力波之四端參數法，建立板與樑元素之力與速度之轉換矩陣方程，簡化結構音傳播問題之複雜性。
2. 利用克希霍夫-漢姆霍茲積分方程，建立流體與結構表面間之輻射偶合關係之數值分析模式。
3. 探討流體聲輻射效應對結構噪音傳播之影響。
4. 對結構模型進行實驗測試與數值結果比對，用以驗證數值模式。

實驗模型如圖 1，係以軟繩四點懸吊於固定架上，其有限元素模型如圖 2。當一有偏心質量之馬達置於該模型中，以模擬振源，並配置各式彈性基座，如圖 3，將該實驗模型分別吊於空氣中及浮於水池中，用以

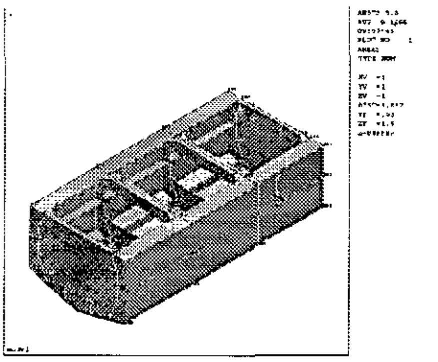

圖 1 實驗船體之模型幾何

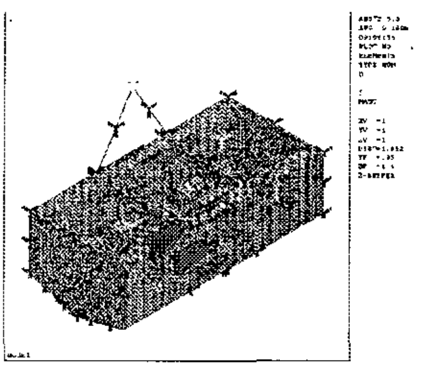

圖 2 實驗船體之有限元素網格劃分、邊界條件與主自由度模型

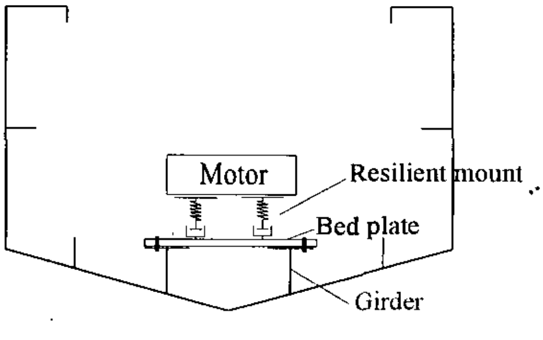

圖 3 馬達-彈性墊-底座結構串聯系統

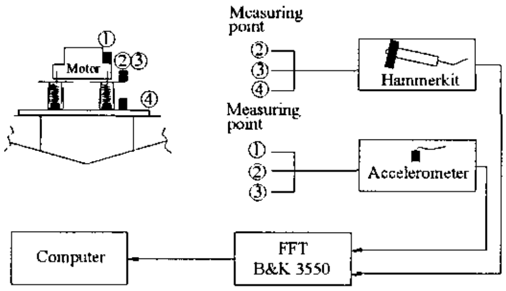

圖 4 動性量測測點及儀器佈置

量測圖 4 中由①點傳至④點之傳遞動性函數 M_{41}，其量測之實驗佈置亦示於圖 4 中。

數值分析按以上 1，2 之步驟，求得模型結構浮於水中之傳遞動性 M_{41}。模型結構吊於空氣中傳遞動性 M_{41} 則直接以 ANSYS 程式分析求得。將數值解分別與實驗值比較，其結果如下：

圖 5 為模型結構點動性 M_{44} 之數值解與實測值比較，作為相互驗證之用。似乎在 600Hz 以下甚為吻合，600Hz 以上，則 M_{44} 之峰值漸漸偏移了。其原因主要是 ANSYS 中元素性質對應力波描述本質上之誤差，頻率愈高，誤差會愈大。圖 6 與圖 7 分別比較模型吊於空氣中不加彈性墊與加彈性墊之 M_{41} 分析值與量測值比較，結果甚吻合。圖 8 與圖 9 則分別比較模型浮於水池中不加彈性墊與加彈性墊之 M_{41} 分析與量測值，其結果之誤差則較於空氣中略為增加一些，但趨勢仍很一致。考其原因應是在數值分析之模式中，僅處理結構四周為半無限域流體，並未計及水中聲波之反射，然在實驗量測中，仍存在有槽壁反射效應之故。

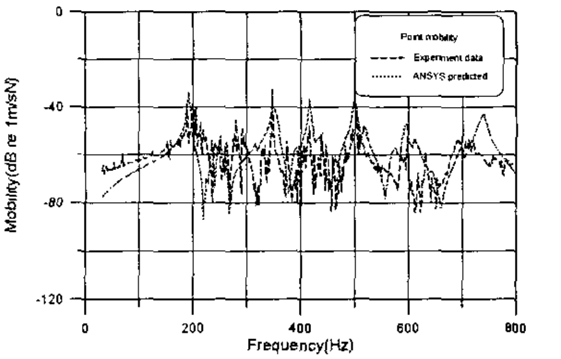

圖 5 在空氣中實驗船體點動性M_{44}量測值與有限元素法分析值之頻譜分析比較

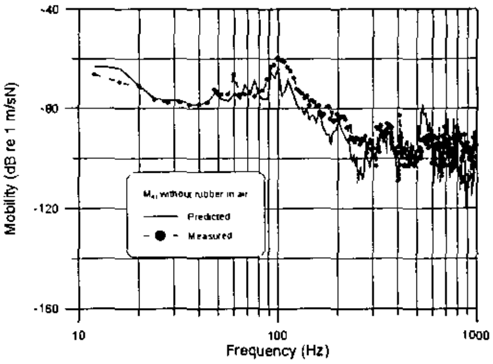

圖 6 在空氣中不加彈性墊實驗與預測值之傳遞動性M_{41}比較

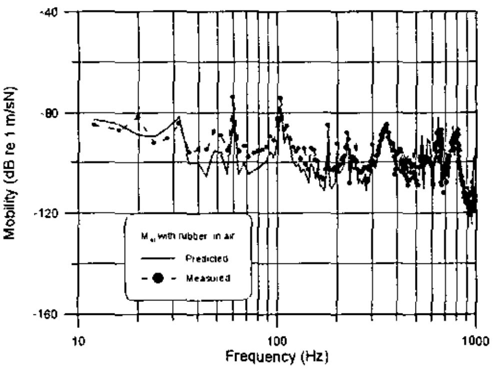

圖 7 在空氣中加彈性墊實驗與預測值之傳遞動性M_{41}比較

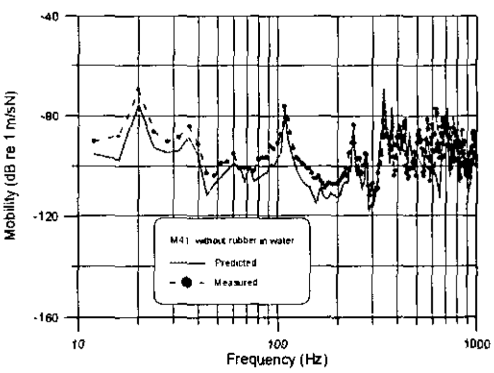

圖 8 在水中不加彈性墊實驗與預測值之傳遞動性M_{41}比較

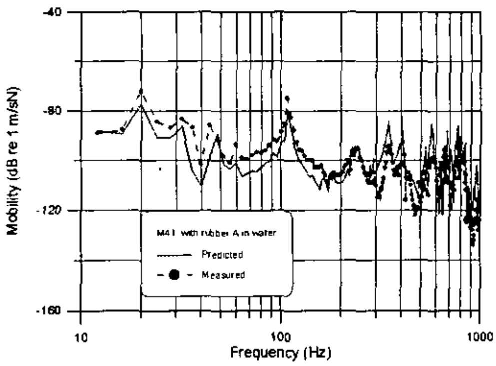

圖 9 在水中加彈性墊實驗與預測值之傳遞動性M_{41}比較

四. 結論與建議

由本研究之成果，可歸納出以下結論：

1. 對中低頻域船體結構噪音傳播，建立了一個考慮流固互制作用之不錯模式。
2. 由本研究中之模型結構分析及實測，流體之輻射負荷對機械彈性墊動性確有10~20dB之降低效果。
3. 待海大造船系大型水中無響室建設竣工後，即可於實驗中消除槽壁之反射效應，屆時對本項理論之驗證可更正確地掌握。

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