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COUPLING FINITE ELEMENT AND EXPERIMENTAL MODAL ANALYSIS FREQUENCY RESPONSE FUNCTIONS OF JOINTED STRUCTURES USING THE FREQUENCY-BASED SUBSTRUCTURING METHOD

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ABSTRACT

Achieving accurate coupling remains a major challenge due to the complexities of boundary conditions and coupling interfaces, especially in bolted structures, where bolted joints are common in aerospace, automotive and civil engineering serve as coupling interfaces. The presence of bolted joints further complicates the coupling process, requiring in-depth and systematic experimental and analytical investigation. To address these challenges, this study proposes a methodology for coupling FE-FRFs with EMA-FRFs, improving the effectiveness of the Frequency-Based Substructuring (FBS) method. The proposed methodology is developed based on the integration of the Finite Element Method (FEM), Experimental Modal Analysis (EMA) and the FBS method for coupling FE and EMA FRFs for the investigation of the dynamic behaviour of a jointed structure. In this study, a Flanged Elbow Pipe (FEP) substructure and a Flanged Pipe (FP) substructure are assembled to form an assembled structure, namely a Bolted Flanged Pipe assembly (BFPA). They are used as a case study for the proposed methodology. The FE model of the FP substructure is carefully constructed to include the coupling interfaces and to calculate the FRFs under free-free boundary conditions. Special jigs are specifically designed and fabricated to measure the FRFs of the coupling interfaces of the FEP substructure using EMA under fixed-free boundary conditions, which are very difficult to represent analytically. The FRFs determined at the coupling interfaces of both substructures are coupled using the FBS method to form the coupled FRFs of BFPA. The accuracy and capability of the proposed coupling methodology is evaluated by comparing the coupled FRFs with the measured FRFs of the physical test BFPA. The comparison shows that the proposed methodology is highly capable of representing the EMA results, achieving 83 percent accuracy for seven modes and 95 percent accuracy in the low-frequency range, which is particularly important for analysing structural dynamics. Moreover, the proposed methodology is able to incorporate substructures such as FP and FEP with complex boundary conditions for which only coupling interfaces are available. The impressive performance of the proposed methodology shows that the proposed methodology has the potential to improve the accuracy and efficiency of predictions for complex structures consisting of a large number of substructures with complex boundary conditions. Furthermore, the proposed methodology can help speed up product manufacturing decisions or improve the performance and safety of products, which will have a positive impact on the industry concerned.

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TABLE OF CONTENTS

CHAPTER 1
INTRODUCTION

1.1 Motivation of the Study

The search for new, more efficient and sustainable solutions for the shipbuilding, automotive and aerospace industries has become very important [1-8]. These industries are constantly striving for new changes, and in order for them to remain competitive, a profound change in their evolutionary tactics is required. Engineers working in these industries almost always have to improve their products and services in the shortest possible time and under constant customer demand to meet new performance requirements resulting from numerous design changes.

For this reason, computational approaches are very important today, as they allow engineers to analyse and solve complicated problems in a cost-effective and efficient way. When developing a product, vibration research and design is carried out with the aim of achieving high performance with low noise and low vibration [9-12]. For vibration analysts, computer modelling and analysis tools enable early analysis of the underlying factors responsible for vibrations and their solutions which could easily be overlooked in initial designs.

In Malaysia, there is a growing demand for the early integration of vibration studies in the preliminary design process of mechanical structures. Unfortunately, in many product development scenarios, vibrations are only considered after the fact, meaning that systems are initially built without a sufficiently constructive approach to design. By taking a proactive, deterministic approach to mechanical vibration during the design of a structure, vibration-related issues can be defined as future problems that can then be easily addressed, even if they occur late in the schedule. Furthermore, vibrations can be utilised positively, e.g. the relative motions between components or the resonance effect can be used to improve system performance.

This important shortcoming of neglecting mechanical vibrations has motivated the author to engage in more complicated advanced research in addition to professional development in the field of structural dynamics, in particular the use of substructuring techniques such as the Frequency Based Substructuring (FBS) method. This method solves the challenge of performing a combined Finite Element Analysis (FEA) and