UNIVERSITI TEKNOLOGI MARA

EXPERIMENTAL IDENTIFICATION OF NONLINEARITY IN BOLTED BEAM STRUCTURE USING FORCE-CONTROLLED STEPPED-SINE TESTING AND RESPONSE-CONTROLLED STEPPED-SINE TESTING

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ABSTRACT

Identifying nonlinearities in structural dynamic is important for complex and advanced engineering structures, particularly slender structures with bolted joints which is very common in various engineering fields such as aerospace, automotive and civil constructions. Nonlinear phenomena such as unstable branches, sub- and super-harmonic often occur in these structures, which linear modal analysis is invalid for the identification of these nonlinear phenomena. These nonlinearities play an important role in affecting the behaviour and stability under various dynamic loads. Therefore, it is very important to understand the nonlinearity in structural analysis using an accurate and effective technique. This study aims to compare the robustness and effectiveness of Force-Controlled Stepped-Sine (FCT) and Response-Controlled Stepped-Sine (RCT) for identifying nonlinear dynamic behaviours in bolted beam structures. The bolted beam structure is excited with two different sets of force and displacements amplitudes to measure the Nonlinear Frequency Response Functions (NLFRFs). The measurements of NLFRFs are initially performed using FCT to identify the unstable branches by performing two directions of sweeping frequencies, which are known as sweeping up and down a specified frequency range. RCT is performed to identify unstable branches in the FRFs using a single sweeping direction as the FRFs extracted from RCT are symmetrical and exhibit no unstable branches. Harmonic Force Surface (HFS) method is applied to map out the NLFRFs, allowing a comprehensive analysis of the bolted beam structure responds to various force and displacement amplitudes. The integration of RCT and HFS effectively identifies the nonlinearity behaviour, which is very similar to the FCT results. However, RCT demonstrate clear superiority over FCT in terms of computation efficiency, approximately four times faster than FCT in measuring FRFs. The use of HFS allows for improved visualisation of the nonlinear response surface, which further facilitates the identification of complex nonlinear behaviour. These advantages of RCT and HFS can provide engineers and researchers with a great technique to accurately and efficiently identify nonlinearities in structures. By comparing the two experimental methods, understanding the strengths and limitations of RCT and FCT can help the industries make informed decisions regarding structural health monitoring, maintenance and design improvement, especially for complex structures.

Keywords: Nonlinear frequency response function; Harmonic Force Surface; Stepped Sine; Response-controlled testing; Force-controlled testing.

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TABLE OF CONTENTS

CHAPTER 1
INTRODUCTION

1.1 Motivation of This Study

Vibration happens all around us, daily and every time. Everything with mass and stiffness [1] tends to vibrate at its natural frequencies. The advantages of vibrations have been taken into consideration of healthcare [2], music [3] and constructions [4]. However, the undesirable effect of vibrations that could lead to the failure of a structure or components [5]. This resonance-induced malfunction can occur in large structures such as airplane, building, bridges and so does to subsystems of a small machine such as bearings, pipelines and joints. Structural failure due to resonance can occur to any area of engineering. Over 500 failures of bridges structures in the United States between 1989 and 2000. Among the case studies, 53% of all bridge failures lead to frequency peak [6]. Earthquakes can cause structural failure to buildings especially during 1985 in Mexico [7], large number of buildings collapsed during the earthquake. These scenarios could seriously take lots of lives.

Most of the dynamic systems can be studied using linear model. However, modern and advanced machineries tend to occur nonlinear vibrations [8]. The machineries usually operate at high operating speeds with lighter element. Gears, bearings and frictions could produce nonlinearity in a mechanical system. The nonlinearity of systems usually happens to helicopter, jetfighter etc. Robinson R44 helicopter commonly face an issue with wear failure of the joint bearing of the main rotor which can affect the manoeuvrability, stability and safety of the helicopter [9]. Several fighter aircraft such as F-16 and F/A-18 have persistent problem with limit cycle oscillations (LCO) [10]. The LCO response is characterized by antisymmetric motion of the wing and a lateral motion of the fuselage and aircrew. Therefore, this study is about experimental techniques in identifying nonlinearity in a bolted beam structure is crucial to minimise serviceability problems and protect human lives. The fundamental motivation for this study is to investigate and validate two identification methods to identify nonlinearity and detect unstable branches in the nonlinear frequency response