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Nonlinear damping identification in rotors using wavelet transform

N. Harish Chandra, A.S. Sekhar*

Department of Mechanical Engineering,Indian Institute of Technology Madras,Chennai600036, India

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ABSTRACT

Estimation of nonlinear damping in rotor bearing systems using continuous wavelet transform based approach is proposed. Krylov–Bogobliubov method is used to obtain the approximate analytical solution for the nonlinear equation of motion of the rotor-bearing system. The envelope of the free vibration signal is extracted using the wavelet based approach to identify the nonlinearities in damping. Two different nonlinear damping models are studied using the proposed approach. Two examples are illustrated as coupled and uncoupled versions of equation of motion of a rotor-bearing system including nonlinear viscous external and internal damping. The performance of the method is tested on signals acquired from experiments and found successful.

1. Introduction

When compared to stationary structures, identification of rotating structures involves different challenges. Nonlinear effects are notable when the vibration amplitude levels are high [1]. Major difficulties associated with modal analysis (linear system identification) of rotor bearing systems are discussed by Bucher and Ewins [1]. A detailed review on nonlinear system identification is presented by Kerschen et.al. [2]. Many techniques are available in literature for identification of nonlinear damping effects [3]. Using these approaches the estimated damping characteristics present a wide range of scatter since damping force models cannot be analytically determined. Identification of nonlinearities in rotor bearing systems can be a parametric study or a non-parametric study. Peeter et al.[4] and [5] reported simulated and experimental study on non-parametric identification of rotor-bearing systems in a frequency domain. To perform a non-parametric identification one has to collect displacement, velocity and acceleration data at an instant. But, a parametric identification procedure requires any one data among displacement, velocity and acceleration. A discrete Fourier Transform representation of a signal is a nonparametric representation.

The analysis of free vibration response of a structure serves as one of the easiest ways to estimate the natural frequency and damping of rotor bearing systems. In the case of SDOF rotor systems, identification of natural frequency and damping can be done using Hilbert transforms [6] or logarithmic decrement method or least squares decay curve fit approach. But, in the case of MDOF rotor systems it is necessary to uncouple the response obtained from the system with respect to the corresponding modes. For linear SDOF and MDOF rotor bearing systems, Cloud et al. [7] reported different damping estimation techniques. They discussed the effect of destabilizing forces like shaft stiffness asymmetry on the stability performance of linearity assumed

* Corresponding author.
E-mail addresses: 97mechari@gmail.com (N. Chandra), as_sekhar@iitm.ac.in (A. Sekhar).

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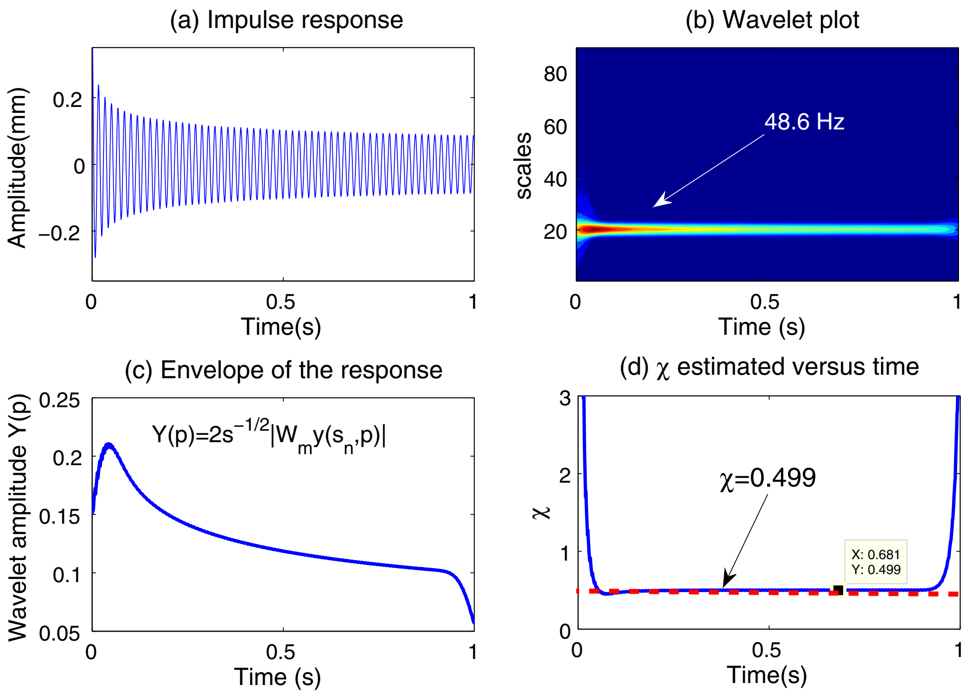

Fig. 1. Nonlinear damping estimation using wavelet transform.

rotor bearing systems. But, in most of the real cases the response of the rotor is nonlinear since the damping and stiffness forces are nonlinear. It is well accepted that these nonlinear damping characteristics depend on the amplitude of vibration and the operating speed of the rotor bearing system [1]. In addition, due to low signal to noise ratio and closely separated modes, it becomes difficult to identify the damping parameters of a rotor. Rotating structures are non-self adjoint and yield non-symmetric or coupled equation of motion. Thus, using time-frequency techniques such as continuous wavelet transform which serve as filters for signal decomposition, it is possible to extract information corresponding to individual mode.

For linear stationary structures Staszewski [8] introduced the wavelet based approach for damping estimation. It is proved [8] that for linear vibrating systems a linear relationship exists between the logarithm magnitude of the wavelet transform and the time translation parameter of wavelet at scales corresponding to the natural frequency of the system. Ruzzene et al. [9] also analyzed the impulse response obtained from a linear time invariant system and presented a method based on wavelet transform to estimate the natural frequencies and the damping ratio of a multi-degree of freedom system. Xu et al.[10] introduced a time varying modal parameter estimation based on linear time frequency representation and using Hilbert transform.

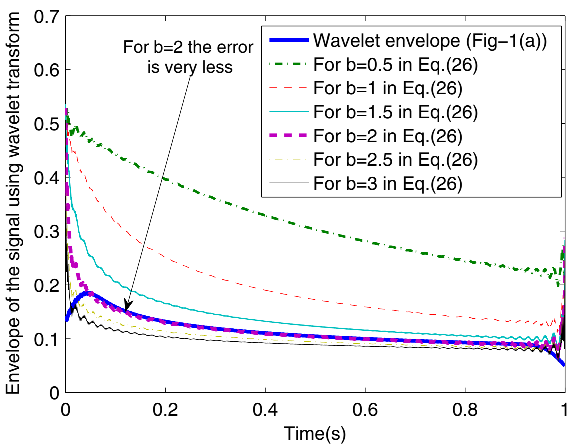

Fig. 2. Envelope of signal using wavelet transform.