Journal of Sound and Vibration 380 (2016) 78–89

Contents lists available at ScienceDirect

Journal of Sound and Vibration

journal homepage: www.elsevier.com/locate/jsvi

Modeling of autoresonant control of a parametrically excited screen machine

S. Abolfazl Zahedi [a,*], Vladimir Babitsky [b]

[a] School of Mechanical, Aerospace and Civil Engineering, The University of Manchester, Manchester M13 9PL, UK
[b] Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University, Loughborough LE11 3TU, UK

ARTICLE INFO

Article history:
Received 12 December 2015
Received in revised form
28 April 2016
Accepted 10 June 2016
Handling Editor: D.J. Wagg
Available online 22 June 2016

Keywords:
Parametric resonance
Screen oscillation
Autoresonant control

ABSTRACT

Modelling of nonlinear dynamic response of a screen machine described by the nonlinear coupled differential equations and excited by the system of autoresonant control is presented. The displacement signal of the screen is fed to the screen excitation directly by means of positive feedback. Negative feedback is used to fix the level of screen amplitude response within the expected range. The screen is anticipated to vibrate with a parametric resonance and the excitation, stabilization and control response of the system are studied in the stable mode. Autoresonant control is thoroughly investigated and output tracking is reported. The control developed provides the possibility of self-tuning and self-adaptation mechanisms that allow the screen machine to maintain a parametric resonant mode of oscillation under a wide range of uncertainty of mass and viscosity.

1. Introduction

Vibratory machines and structures are used in many industrial applications, either as components or individual pieces of equipment [1–3]. The vibrating screen is an example of a vibratory machine used to separate bulk materials from a mixture of particles of different sizes. These machines can perform simple safety screening as well as accurately grade powders or granules. For example, sand, gravel, river rock, crushed rock and other aggregates are often separated by size using vibrating screens. To increase the intensity and energy efficiency, resonant modes will be effective for vibratory screen machines. In addition to giving a high-efficiency performance, operating a system in a resonant mode also provides the additional advantages of being able to separate large particles from fine, and dry from wet. However, the practical use of resonant modes is hindered by difficulty of the resonant tuning under the variable processing loads.

In general, two types of resonant response can be distinguished in mechanical systems, forced resonance and parametric resonance (PR). If the frequency of an external periodic excitation is close to the natural frequency of a system, the system will experience forced resonance. Parametric oscillations occur in systems having time-varying (periodic) parameters. In PR the amplitude of the response grows exponentially, and linear damping elements do not help to saturate this growth. In contrast, forced resonance is caused by an additive driving force. Compared with the forced resonance response, PR is characterized by a much higher intensity within a broad range of frequencies. This type of oscillation occurs in a wide variety of engineering applications and when the excitation term appears as the time dependence parameter in the governing equations of motion [4].

---

[*] Corresponding author.
E-mail addresses: Abolfazl.Zahedi@manchester.ac.uk (S. Abolfazl Zahedi), V.I.Babitsky@lboro.ac.uk (V. Babitsky).

http://dx.doi.org/10.1016/j.jsv.2016.06.011
0022-460X/© 2016 Elsevier Ltd. All rights reserved.

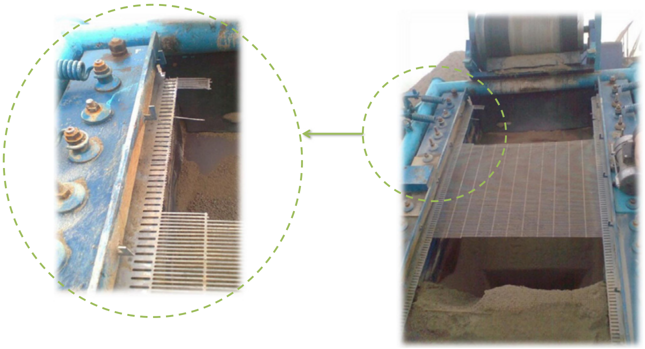

Fig. 1. Screen failure due to high-amplitude oscillations.

The PR condition can display various behaviors including periodic, quasi-periodic, non-periodic and chaotic behaviors [5]. Moreover, resonance often occurs along with saturation phenomena. In particular, when the secondary system enters into PR it functions as an energy absorber by draining energy from the external excitation through the primary system. This entails a large increase in the amplitude of the displacements of the secondary system, whereas the oscillation amplitude of the primary system is maintained as almost constant.

The idea of applying PR to drive screen motion was patented in 2009 [6]. The new generation of machines using PR have some advantages over conventional machines, in which the transverse oscillations are excited directly. PR-based machines have been demonstrated to have large amplitudes of high-frequency oscillations with a high rate of energy transfer, wide resonant-frequency region, low sensitivity to damping, in-plane coupling properties, lateral oscillations and convenient vibration insulation. This type of oscillation has been used in screen machines for the transportation and separation of granular media, which are characterized by larger amplitude values and insensitivity to the dissipation level across a rather wide range of viscosities [7].

PR demonstrates large amplitudes of high-frequency lateral oscillations, robust vibration operation, and the ability to process naturally wet, fine granular material. Although implementation of the PR regime is generally the most efficient method to drive the screen machine, its maintenance is subject to difficulties, especially in systems with high Q-factors and varying parameters and loads [8]. Dangerous high-amplitude oscillations may arise in the system, potentially leading to catastrophic failures (Fig. 1). This is due to the strong sensitivity of resonant tuning to parameters and structural deviations. The problem of managing a finely tuned resonance control is drastically complicated when nonlinear factors, unpredictable variable loads, or limited excitation forces produced by the energy source occur.

In most resonance-related research, the motivation is to develop techniques to avoid or minimize the damaging effects of PR on the structure operating within the expected range of excitation frequencies and forces [9,10]. Few potential methods have been tried in the past to make the amplitude elevate to the desired level, and make the PR oscillations well-ordered, to create a stable regime. Okuma et al. [11] and Yabuno et al. [12] researched the nonlinear characteristics of PR induced in a cantilever beam by a linear feedback control, based on the passive pendulum control method. The study by Oueini and Nayfeh [13] showed that PR-induced high amplitude vibrations cannot be fully prevented by linear or quadratic feedback control. Chen et al. [14] implemented combined linear and nonlinear-velocity feedback control to suppress the principal PR in a flexible cantilever beam structure. These studies were mainly dedicated to the use of lumped-parameter vibration absorbers to suppress the principal PR in structures, however, implementation of such absorbers is subject to limitations for large flexible structures like vibrating screens. It is noteworthy, that due to geometrical and non-linear oscillations in the screen drive motion, the system follows several possible regimes of vibration when the same frequency control is applied. Therefore, the actual steady-state response of the system under frequency control is determined by the history of the control and limited by the use of frequency control to achieve steady performance of the screen system.

The central problem in PR applications is to control the oscillation instability with the aim of keeping the amplitude at a desired level, and making the PR oscillations well-ordered to create a stable response. The autoresonance method is used in the current research for screen systems to control the system response due to its ability to deal with nonlinearity and its robustness when confronting systems with a wide range of uncertainties. This method is well established for machining applications [1,15–20].

The paper is organized as follows: in Section 2, the dynamic model of the screen is described in detail; the principle of autoresonant control is introduced in Section 3; and in Section 4, features of the tuning system are explained, followed by two case studies of mass and viscosity uncertainties.

2. Dynamic model of the screen

The PR-based vibrating screen machine manufactured by Loginov and Partner Mining Company (Kiev, Ukraine) is presented in Fig. 2(a). The machine includes: the vibrator (1), the base (2), the beams fastening the sieve (3), the side springs