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Quantification of parametric uncertainties induced by irregular soil loading in orchard tower sprayer nonlinear dynamics

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ABSTRACT

This paper deals with the nonlinear stochastic dynamics of an orchard tower sprayer subjected to random excitations due to soil irregularities. A consistent stochastic model of uncertainties is constructed to describe random loadings and to predict variabilities in mechanical system response. The dynamics is addressed in time and frequency domains. Monte Carlo method is employed to compute the propagation of uncertainties through the stochastic model. Numerical simulations reveals a very rich dynamics, which is able to produce chaos. This numerical study also indicates that lateral vibrations follow a direct energy cascade law. A probabilistic analysis reveals the possibility of large lateral vibrations during the equipment operation.

1. Introduction

The proliferation of pests in agricultural industry can be harmful to consumers and producers, since it can cause problems such as a reduction in the products quality, partial/total loss of the plantation, etc. Thus, the process of agricultural spraying for pest control is of great importance in orchards, vegetable gardens, etc. In general, the spraying of orchards is done with the aid of an equipment called *tower sprayer*, that consists of a reservoir and several fans mounted on an articulated tower, which is supported by a vehicle suspension [1]. Due to soil irregularities this equipment is subjected to loads of random nature, which may hamper the fluid spraying proper dispersion.

Primary studies on this topic are presented in [1–3], using a mathematical model that considers an inverted pendulum mounted on a moving base to emulate the equipment. These works perform deterministic analyzes to investigate the influence of certain parameters (stiffness, torsional damping, etc) in the model response. In addition, references [2] and [3] present a detailed study of the associated linear dynamics. In all cases, the observed behavior is physically reasonable, but also the analyzes are limited to simple situations, once the model does not take into account the system dynamics

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underlying uncertainties. In fact, system parameters have uncertainties due to a series of factors such as variabilities intrinsic to the manufacturing process, materials and geometric imperfections, etc [4,5]. Taking such uncertainties into account is essential for making robust predictions, but also, it has been becoming a common practice in engineering [6–10].

In this sense, this paper aims to construct a consistent stochastic model to describe the nonlinear dynamics of an orchard tower sprayer, taking parametric uncertainties into account. In a first analysis, the authors concentrate their efforts in tires excitation uncertainties, induced by soil irregularities, once these loads are extremely complex and have great influence in the system dynamics. For this purpose, it is more realistic to describe the system dynamics by means of a probabilistic model of uncertainties, since in this type of approach uncertainties are naturally characterized [4]. Some initiatives in this direction were presented by the authors in two conference papers [11,12], where a harmonic random process was used to emulate the aleatory loadings. But now, they intend to construct the random excitations using Karhunen-Loève (KL) decomposition, seeking a better characterization of the loads. This work also intends to deeply investigate in depth the effects of random excitation in the tower sprayer response, and compute the probability of undesirable operating events, such as large lateral vibrations.

The rest of this paper is organized as follows. In Section 2, it is presented a deterministic model to describe the sprayer nonlinear dynamics. A stochastic model to take into account the uncertainties associated with the soil induced loading is shown in Section 3. The results of the numerical experiments conducted in this work are presented and discussed in Section 4. Finally, in Section 5, the main conclusions are highlighted, and some paths for future works are indicated.

2. Deterministic modeling

2.1. Physical system definition

The mechanical system of interest here is the tower sprayer schematically represented in Fig.1. It consists of a reservoir tank, used to store a spraying fluid, which is mounted onto a vehicular suspension. In this suspension, there is a support tower where sixteen fans are arranged in columns, eight on the right and eight pointing to left. These fans are used to pulverize an orchard. As this equipment moves through a rough terrain, vertical and horizontal vibrations may be observed.

2.2. Physical system parameterization

For modeling purposes the orchard sprayer tower is considered as the multibody system illustrated in Fig. 2, such as proposed by [1,2]. Suspension chassis and reservoir tank are emulated by a rigid trailer with mass m_1. The vertical tower and funs are modeled by an inverted rigid pendulum of mass m_2. Their moments of inertia, with respect to their center of gravity, are respectively denoted by I_1 and I_2. The point of articulation between the trailer and tower, denoted by P, has torsional stiffness k_T and damping torsional coefficient c_T. Its distance to the trailer center of gravity is L_1 and the pendulum arm length is dubbed L_2. The left wheel of the vehicle suspension, located at a distance B_1 from trailer center line, is represented by a pair spring/damper with constants k_1 and c_1, respectively, and it is subject to a vertical displacement y_{e1}. Similarly, the right wheel is represented by a pair spring/damper characterized by k_2 and c_2, it is B_2 away from the trailer center line, and it displaces vertically y_{e2}. For simplicity, the sprayer translational velocity is supposed to be a constant v. The acceleration of gravity is denoted by g.

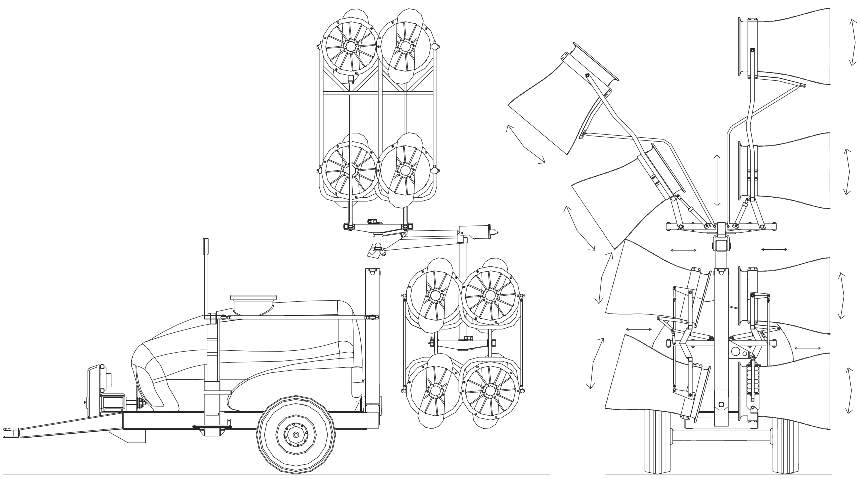

Fig. 1. Schematic representation of the tower sprayer. Adapted from [2] and courtesy of Máquinas Agrícolas Jacto S/A.