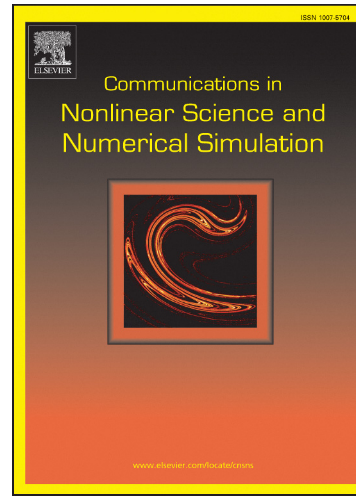

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The effect of nonlinear damping on vibrational resonance and chaotic behavior of a beam fixed at its two ends and prestressed

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This research work is based on the study of the dynamic of one-degree-of freedom nonlinear oscillator representing a built-in clamped-clamped prestressed beam model with a nonlinear damping. First of all, we model this moving structure where we regard the perturbations as a combination of both low-frequency force and high-frequency force. Then, we analyse the occurrence of vibrational resonance, where the response consists of a slow motion and a fast motion respectively with low and high frequencies. Through this, we obtain an approximate analytical expression of the response amplitude and we determine the values of the low frequency and the amplitude of the high-frequency force at which vibrational resonance occurs. The theoretical predictions are found to be in good agreement with numerical results. Moreover, for fixed parameters values of the system, as the nonlinear damping vary, we found appearance and the disappearance of resonance with or without cross-well motion. Secondly, we study the chaotic dynamic of the beam. In this case, critical values of perturbation parameters for the onset of the chaotic motion are specified using Melnikov's method. Hence, the global dynamical changes of the system have been examined by plotting phase portrait, bifurcation diagram and their corresponding Lyapunov exponent.

I. INTRODUCTION

Beams are very significant nowadays so that scientists and engineers developed a science to study them called ”structures calculus”. In its context, we define a beam as a column generated by a plan cross-section which center of gravity belongs to a curve called ”average line” of the solid [1, 2]. They invaded the world of construction in particular in the mega-structures such as bridges, roads, sportive infrastructures, buildings etc... From their exceptional characteristics, they are used everywhere where other structures show their limits.

During their uses, beams are subjected to environmental conditions like wind, earthquake, variations of temperatures, which can put them in movement. It is Leonard Euler and Jacques Bernoulli who emitted the first theory in 1750, while Daniel Bernoulli wrote for the first time, the differential equation for the vibratory analysis of beams [3]. Today, specialists model them by writing equations describing their dynamics [4], and consider natural disturbances as external excitations in order to study some physical phenomena. In this work, we will consider that natural disturbances are combination of a low-frequency force and a high-frequency force. This combination will enable us to study the phenomenon of ”vibrational resonance”. Resonance is a phenomenon which occurs when an oscillating system is excited in permanent mode by a periodic signal, which frequency is equal to the natural frequency of the system. When the system is excited by high and low frequencies periodic signals, the resulting phenomenon is called vibrational resonance [5–7]. The vibrational resonance phenomenon has been found in the double-well Duffing oscillator [6–9]. However, these models were found to exhibit linear damping coefficient. In the model studied in our paper, we consider nonlinear damping resulting from the fact that in the reality, linear damping is an ideal case. The vibrational resonance phenomenon has been also found in spatially extended [10], excitable [11] systems, quintic [12] and over-damped two-coupled anharmonic oscillators [13, 14]. Recently, vibrational resonance has been found in delayed system [15], fractional-order oscillators [16] and neuron population [17]. The effects of noise on vibrational resonance have also been analyzed in certain systems [18–20]. From the practical point of view, it proved its importance in telecommunication [21], neuroscience [22], acoustics [23]. In this work, we will highlight it in structures calculus through the vibrations of beams.

Under extreme conditions, the motion of dynamic systems changes considerably and becomes chaotic. Nevertheless, with the advent of the study of chaotic motion by means of strange attractors, Poincaré maps and fractal basin boundaries, it has become necessary to look for a better understanding of the nonlinear systems. Chaos, nowadays, interposes in several fields like demography [24], the communication [25], automobile technology [26]. In the theory of beams, chaotic motions are undesirable because of their unforeseeable characters which cause sometimes disasters. In order to better control this type of motion, the Melnikov's theory [27] was developed, to determine the limits of disturbances for which it would be necessary to avoid to fall into a chaotic mode. The Melnikov method [28] is an effective approach to detect chaotic dynamics and to analyze near homoclinic or heteroclinic motion with deterministic or random perturbation. The method was first applied in [29] to study a periodically forced Duffing oscillator with negative linear stiffness, and by [30] to investigate the chaotic behavior of a parametrically excited system such as the transverse vibration of a buckled column