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AMPLITUDE DEPENDENT STIFFNESS IN THE TWO-DEGREE-OF-FREEDOM SYSTEM WITH CLEARANCES

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ABSTRACT

Nonlinearities due to presence of gaps and clearances exist in a large class of mechanical systems. Vibration of systems with clearances can result in relative motion across the clearance space and impacting between the components. Impacts in the clearance (vibro-impacts) can be separated into three different regimes: a no-impact regime, a single-sided impact and a two-sided impact [1].

The physical effect of the clearance nonlinearity can be viewed as an amplitude dependent stiffness. The amplitude dependent stiffness is the relative amount of time spent in one stiffness stage versus the other. The oscillator is said to be *hardening* if the stiffness increases for increasing amplitudes and *softening* if the stiffness decreases for increasing amplitudes. The hardening or softening effect of the clearance nonlinearity depends on the static deflection and whether the system is undergoing single-or two-sided vibro-impacts (the system is linear for the no-impact case). For single-sided impacts, if the static deflection is in the non-zero stiffness stage, as the amplitude increases the time spent in the backlash region increases, reducing the average stiffness (softening effect). If, however, the static deflection is within the backlash region, the average stiffness increases, as the amplitude increases, for both double – and single-sided impacts leading to a hardening effect. In the dynamical system with two clearances, the hardening and softening effects are coupled; i.e. the behavior of one clearance can be influenced by the other.

The harmonic balance method and the piecewise full decoupling method [3] are used to obtain an approximate analytical and numerical response, respectively, of the two-degree-of-freedom system with two clearances. The system parameters are adopted from [2] where the system with one clearance was studied. The frequency response with regions of different impact regimes is shown in Figure 1.

The stability of piecewise full decoupling solutions is examined by the periodicity of response. If the alternating amplitude coincides with the effective amplitude the solution

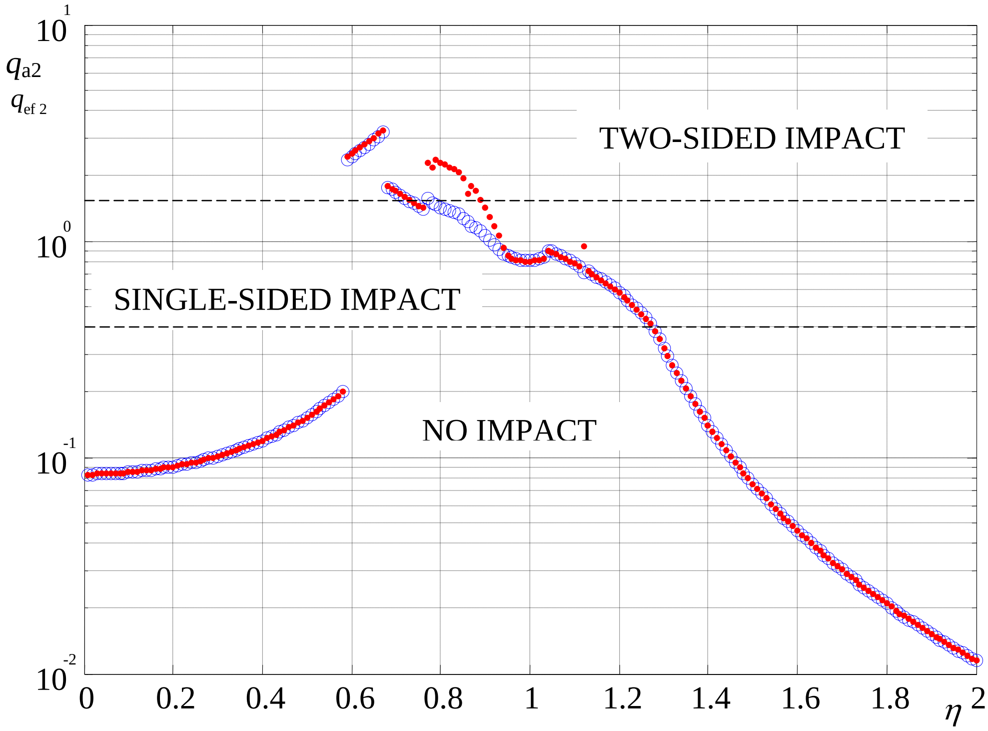

Figure 1. Frequency response of the second displacement with the regions of different impact regimes: ● *alternating amplitude* q_{a2}, **O** *effective amplitude* $q_{ef\,2}$

is periodic; otherwise the solution is nonperiodic. Nonperiodic responses may correspond to a quasiperiodic, transient or chaotic motion. The nonperiodic solutions are indicated in the frequency range $0.77 < \eta < 0.94$, therefore for this range, the type of impact regime cannot be clearly recognized.

For small excitation frequencies, the system operates in the no-impact regime. The magnitude of the alternating amplitudes increases, as the excitation frequency approaches resonance, and along with it, the possibility of impacts. At the resonant frequency $(\eta = 0.57)$ the system jumps in the two-sided impact regime which represents a hardening. As the excitation frequency approaches to $\eta = 0.67$, the first displacement jumps into the no-impact regime while the second displacement continues to operate in the two-sided regime, but in a softening manner. For the other periodic solutions $(\eta > 0.94)$, the system is experienced by the hardening effect. As the softening only occurs in the frequency interval which is in direct contact with the nonperiodic responses, it is reasonable to assume a link between the softening effect and the nonperiodic motions.

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