MECHANICAL ENGINEERING STUDENT SEMINAR

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Stabilization of self-excited oscillations and chimera states in multibody mechanical networks

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Self-excited synchronous oscillations in multibody dynamical systems have been documented since the middle of the seventeenth century with the amazing observation of Huygens that two pendulum clocks hanging from a common flexible support swung together periodically approaching and receding in opposite motions. During the last two decades there has been a growing interest in the stability and robustness of continuous and intermittent synchronization of periodic and nonstationary oscillations which have been observed in controlled experiments of mechanical networks. Of particular interest are the chimera states in which the symmetry of an oscillator population is broken into a synchronous part and an asynchronous part. Numerical analysis of a phenomenological escarpment model for two coupled metronome populations revealed a narrow chimera state transition between in-phase and anti-phase synchronized solutions. However, this approximate phenomenological model did not reveal any coexisting bi-stable solutions documented experimentally or accurately predict the transition stability thresholds.

We thus examine the complexity of coexisting synchronous and asynchronous self-excited oscillations in coupled arrays of three planar pendula augmented with rotating inertia wheels governed by a linear feedback mechanism. This dynamical system exhibits asymptotically stable equilibria, periodic limit cycle oscillations, and non-stationary rotations. We investigate the synchronous dynamics and the emergence of chimera states within the system by consistently modeling the coupled array of inertia wheel pendula. A combined analytical and numerical approach is employed to investigate the dynamical system bifurcation structure. An asymptotic multiple-scales analysis yields conditions for existence of synchronous solutions in a weakly nonlinear configuration, and a numerical analysis reveals synchronous, decoherent, and chimera states in both periodic and rotational regimes for a strongly nonlinear configuration. The significance of the research is twofold. First, the combined analytical and numerical methodologies enable identification of stability thresholds for both weakly and strongly nonlinear ranges of operation. Second, the combined methodologies enable construction of a comprehensive nonlinear bifurcation structure that shed light on emergence of chimera states, synchronization and decoherence in a multibody mechanical network, where inertia wheel feedback does not require the use of phenomenological modeling governing the self-excited dynamics.

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