Unveiling bifurcation mechanisms of quasiperiodic partial rub oscillations in a piecewise smooth rotor-stator system

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Abstract. An approach combining the methods of multi-grid Point Mapping under Cell Reference (mPMUCR) and Stagger-and-step is first developed in order to efficiently determine both attractors and unstable saddle-type invariant sets in high-dimensional nonlinear dynamical systems. Then, the mechanism behind catastrophic bifurcations of the quasiperiodic partial rub oscillations in a piecewise smooth rotor-stator system are unveiled from the point view of global analysis.

Introduction

Rotary machinery is an important facility widely used in various fields, while Rotor-stator rubbing is a key issue affecting the mechanical efficiency and reliability of the rotor machinery. Many contact- and friction-related dynamical phenomena in rotor-stator rubbing systems are summarized recently in [1] and [2]. Quasiperiodic partial rub oscillations are an important type of non-smooth responses in the rotor-stator rubbing systems. Although, the bifurcation into the quasiperiodic partial rub oscillations may be determined in some cases, for instance, through Hopf bifurcation of the synchronous full annular rub motions for the emergence of the quasiperiodic partial rub oscillation in [3]. The bifurcations around emergence and disappearance of the quasiperiodic partial rub oscillations in the range of small contact friction but high rotating speeds are not well understood until now, due to the difficulty in capturing unstable invariant tori.

For global analysis of general nonlinear dynamical systems, numerical methods are the only workable tools. mPMUCR [4] is developed to take the advantages of methods in point scale and cell scale to efficiently capture attractors in point scale but unstable invariant sets as cell coverings in high-dimensional state space. In order to improve the resolution of the rough cell coverings of unstable invariant sets, Stagger-and-step method, which is devised to find chaotic saddles (chaotic transient) efficiently in dynamical systems [5], is also employed. The rough cell coverings of unstable invariant sets provide useful and targeted initial points for the Stagger-and-step method so that a fine depiction of multiple torus saddles can be also efficiently and accurately determined, which is shown in Figure 1 (a) and (b).

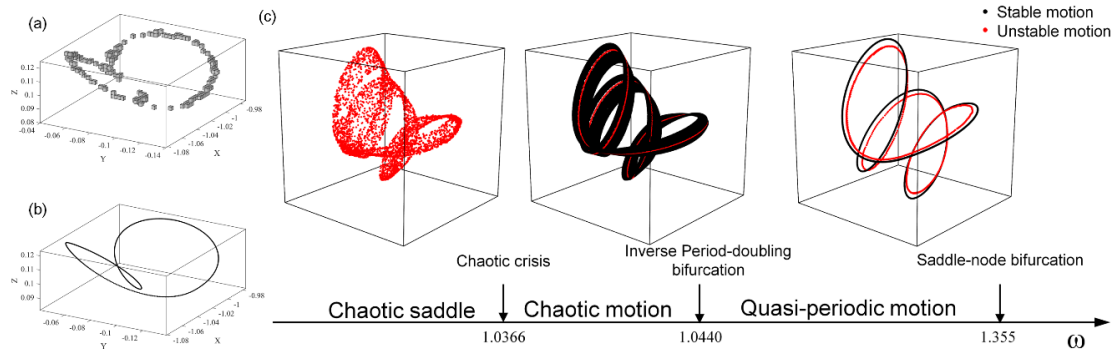

Figure 1: (a) Cell coverings of a torus saddle by mPMUCR in a three dimensional projection of Poincare section. (b) The torus saddle in point scale by Stagger-and-step method with the initial points from mPMUCR. (c) Sketch of the bifurcation process of aperiodic rubbing oscillations in a three dimensional projection of Poincare section.

Blue-sky catastrophic bifurcations in the quasiperiodic partial rub oscillations

Using the proposed computational methods, the bifurcations behind emergence and disappearance of the quasiperiodic partial rub oscillations in a piecewise smooth rotor-stator rubbing system are uncovered. It is found that the quasiperiodic partial rub oscillations emerges through an inverse doubling of torus from a chaotic attractor, which is produced from a chaotic saddle after chaotic crisis. The quasiperiodic partial rub oscillation disappears through a collision between the stable and the unstable tori in Figure 1(c).

References

[1] Jacquet-Richardet, G, et al. (2013) Rotor to stator contacts in turbomachines. Review and application. *Mech. Syst. Signal Proc* **40**:401–420.

[2] Prabith, K., et al. (2020) The numerical modeling of rotor–stator rubbing in rotating machinery: a comprehensive review. *Nonlinear Dyn.* **101**:1317–1363.

[3] Jiang, J. et al. (2001) Stability analysis of sliding whirl in a nonlinear Jeffcott rotor with cross-coupling stiffness coefficients. *Nonlinear Dyn* **24**:269–283.

[4] Jiang, J. et al. (1998) An iterative method of point mapping under cell reference for the global analysis: theory and a multiscale reference technique *Nonlinear Dyn* **15**, 103–114.

[5] Sweet, D. (2001) Stagger-and-step method: Detecting and computing chaotic saddles in higher dimensions *Phys. Rev. Lett.* **86**, 2261