Insights on the dynamics of piecewise-smooth oscillators with continuous representations

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Abstract. Freeplay nonlinearities in mechanical systems are often modeled with fully smooth approximations, but not all approximations may actually be appropriate for use. In this work, several different approximations are used to simulate a forced Duffing oscillator with freeplay and to study its nonlinear performance. These are compared to the exact piecewise-smooth representation to evaluate the accuracy at capturing the correct system physics. The computational costs are also compared for time considerations.

Introduction

Systems with freeplay nonlinearities are often modeled using fully smooth and continuous approximations for the freeplay terms. Common approximations use polynomial, hyperbolic tangent, and absolute-value functions and combinations thereof. However, past research on aeroelastic systems with freeplay [1] indicated that not all approximations can successfully capture all the behavior of a freeplay system. Chaotic responses can be missed and falsely output a periodic response, for example, if a polynomial approximation was used. A hyperbolic-tangent approximation, on the other hand, gave good agreement when compared to the exact freeplay representation. In this work, several different continuous freeplay representations will be investigated for their effectiveness at capturing accurate physics of a freeplay system. Results are compared to the discontinuous representation, obtained using a time integration method employing Matlab® and its Event Location option. The system used is the forced Duffing oscillator studied by deLangre [2]. Approximations include several different polynomial expressions and the hyperbolic-tangent expression used in [1], among others. The usefulness of this work is to determine if any of the approximations can match or exceed the discontinuous Matlab method in terms of both accuracy and computational cost. Also, a particular focus will be paid on the nonlinear dynamics of the system when considering all these representations.

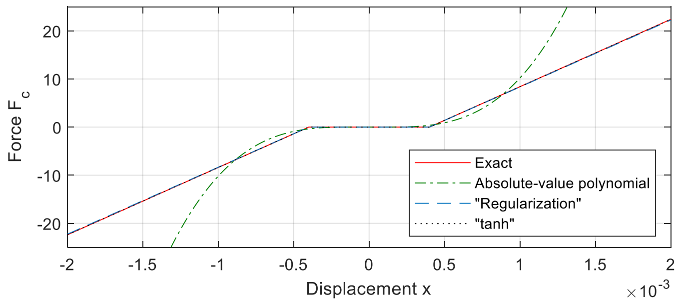

Figure 1: Comparison of various smooth approximations to the exact piecewise-smooth freeplay term (red curve).

Results and discussion

Preliminary results (Figure 1) indicate that some of the polynomial approximations will be unable to accurately represent the exact freeplay and hence no detection of the contact point. Results may be better for small displacements or for high stiffnesses. Particularly, the approximations for which the discontinuous force is not substantially close to zero within the freeplay boundaries may suffer low accuracy. The main benefit from the approximations is the dramatic computational cost reduction over the exact discontinuous representation, which can range from 2 to 10 times faster in some cases. Incorrectly captured physics nevertheless means that some representations may be unacceptable for use. In fact, the resonance region of the system as well as present nonlinear responses may not be captured by these continuous representations.

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References

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