A NOVEL REDUCTION TECHNIQUE FOR BLISKS WITH CONTACT INTERFACES IN MICROSLIP

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Abstract: Reduced order models obtained from finite element (FE) models of bladed disks (blisks) are an important design tool. The dynamic behavior of blisks is often complicated by the presence of non-linearities manifested as microslip in contacting substructures. While methods exist to reduce the number of degrees of freedom (DoFs) of linear models and simplify their simulation in the time domains, they do not address the reduction of the non-linear contact DoFs. We present a novel method to obtain a set of reduction basis functions for all the DoFs of the model including the contact interface DoFs. The reduction basis applied to a baseline model generated from a full scale FE model is shown to accurately predict the blisk response, while offering significant savings in computational effort.

Keywords: *vibrations, microslip contact, reduced order model, non-linear dynamics, turbomachinery*

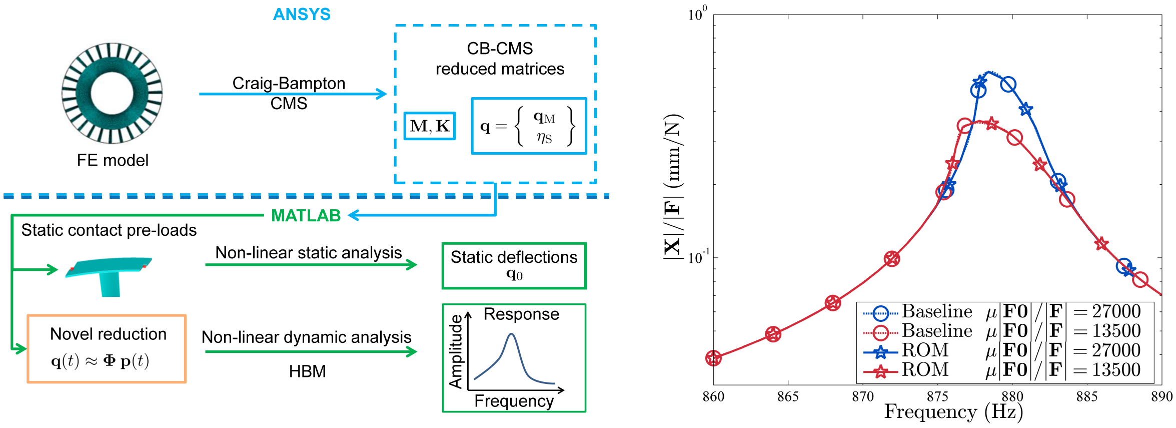
1 Introduction

The ineluctable element of uncertainty in modern blisk design have made probabilistic analyses an integral part of the design process. Innately, such simulations involve a large number of simulations with different parametric variations and place a premium on the size of the model used. Hence, fast and accurate reduced order models (ROMs) are sought for this purpose (Kielb et al., 2006)(Hong et al., 2013). Model reduction is often complicated by non-linearities in the blisk dynamics. Particularly challenging cases are blisks with friction damping introduced by localized non-linearities across the structure. This is seen in blisks with shroud-shroud contact or under-platform dampers. Such blisks exhibit complex microslip phenomena, which are characterized by spatially and temporally varying stick-slip interactions at the contact interfaces (Firrone et al., 2011). In the past, the harmonic balance method (HBM) has been employed to reduce temporal complexity of such problems (Cardona et al., 1994). In addition, the DoFs of the blisk model which are not directly involved in the contact dynamics may be reduced by well-known techniques such as Craig-Bampton component mode synthesis (CB-CMS), first described in Craig et al. (1968). However, this still leaves a large number of non-linear equations for the interface DoFs which must be solved in full. We postulate that due to the existence of spatial correlations in the responses of the non-linear contact DoFs (Saito et al., 2011)(Zucca et al., 2014)(Jung et al., 2014), it is possible to formulate a projection/reduction basis to further reduce the blisk model.

2 Procedure

In this study, we consider a shrouded blisk with 27 blades as shown in Figure 1a. HBM and CB-CMS are employed to generate baseline models of the blisk with system mass ($\mathbf{M}$) and stiffness ($\mathbf{K}$) matrices, which retain all DoFs at contact but reduce other non-contact (linear) DoFs using a set of slave modes (Firrone et al., 2011). The static solution is calculated separately.

A novel method is then used to predict the spatial correlations at the contact interfaces and form a reduction basis for the system. The method is based on analyzing a set of linear systems with specifically chosen boundary conditions corresponding to various slip-stick conditions on the contact interface. First, the modes of the fully stuck linear system (where all contact nodes are in stick) near the frequency range of evaluation are considered. Then, a hypothetical situation is considered where the system is displaced along these stuck modes by various modal amplitudes. The contact conditions based on normal and tangential contact forces generated due to the hypothetical displacement are calculated for each case. As the hypothetical modal amplitude is increased, the contact conditions generated by this method transition from full stick toward gross slip (where all contact nodes are in slip). In the interval between these two cases, several distinct boundary conditions are generated where some nodes are in stick and some in slip. It is postulated that the modes of the linear systems with boundary conditions corresponding to these contact conditions capture the intricate spatial correlations which are observed during microslip. The modes of these systems which lie in the frequency range of interest are collectively used to form the reduction basis, which is used to obtain the set of reduced co-ordinates. Hence, this method uses only linear procedures to generate the reduction basis. Non-linear calculations are still carried out in the reduced space using HBM, but take much less computational time because of the reduction.



(a) Summary of procedures

(b) Responses of ROM vs baseline for EO1 excitation

Figure 1: Reduction technique and sample results

Simulated frequency responses of both the baseline models and ROMs are obtained using HBM at various engine orders (EOs) and under varying degrees of microslip. The responses for the baseline model and ROMs to an EO1 excitation are shown in Figure 1b. The dimensionless quantity $\mu|\mathbf{F0}|/|\mathbf{F}|$ indicates the level of microslip, with its value decreasing as the system transitions from full stick to gross slip. The error at peak response frequency for the ROM responses shown is lower than 1.5%. The ROMs were approximately 5-10 times faster than the baseline simulation for most cases.

3 Conclusions

We have developed a novel method for reducing linear and non-linear DoFs of dynamic systems with friction contacts in the microslip regime. Building these ROMs primarily involves linear analyses and holds a significant advantage in terms of computational savings over other methods involving non-linear solutions, while maintaining good accuracy. This reduction procedure is also relatively flexible and can be easily applied to any general dynamical system with Coulomb friction contacts. The method was demonstrated for a blisk with 27 blades and shrouds with contact non-linearities.

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