Effect of wear on the dynamics of structures with friction contacts

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A typical aeroengine is made of many assemblies such as multiple stages of turbine and compressor blades, combustor section, fan section to name a few. These assemblies have many components connected by mechanical joints. These joints create interfaces which are subjected to various static and dynamic loads causing vibration during operation. In the turbomachinery field, the components are designed pushing structural envelopes for performance and efficiency. Hence, during the design phase, accurate prediction of operational vibration levels is critical. The cyclic and rotational nature of the components lead to high modal density and avoiding the resonances in the operating frequency range is next to impossible. Hence, the ideal option is to control the peak vibration levels. The crucial contacts such as bladed disk shroud contacts, blade-root joints and under-platform dampers are designed carefully to provide friction damping by allowing micro-sliding at these contacts. However, the contact interfaces introduce nonlinearity due to friction and inturn affect the dynamic response. The current linear solvers are not sufficient any more, as the results lead to great simplification and do not reflect realistic scenarios. Hence, robust nonlinear solvers considering friction contacts are necessary.

The micro-sliding at the contacts naturally leads to fretting wear. Fretting wear over a large number of cycles leads to high cycle fatigue (HCF), which is a dominant failure mode of turbomachinery components during operation. In addition, the partial or full sliding at the contacts leads to energy dissipation. This energy dissipation accumulated over a number of cycles leads to loss of material and alters the contact conditions. These new contact conditions affect the contact preload and alter the dynamic response, sometimes crossing over vibration amplitude limits. Especially, the blade tip shroud contacts are designed to provide structural rigidity, sealing and low vibration amplitudes and are assembled with a certain prestress. The fretting wear and reducing preload conditions can change the dynamic behaviour of the blade. In extremities, the blade can act as a free standing cantilever beam leading to unfavourable conditions. Therefore, the robust routines studying nonlinear dynamic behaviour including the effect of fretting wear and the evolution of the contact interface with changing preload are today more relevant than ever.

The objective of this dissertation is two parts - numerical and experimental. The numerical part is to develop a prediction tool to simulate the nonlinear behaviour arising due to friction contact and study the impact of fretting wear and changing preload. This is achieved by developing a coupled static/dynamic harmonic balance method (HBM) with a 2D Jenkins element contact model with variable normal load and adding a wear model using wear energy approach and an adaptive wear logic to accelerate wear. The prediction tool is studied on various numerical test cases, including a realistic turbine bladed disk with shroud contacts. Furthermore, as an industrial test case, the tool is applied on a gas turbine combustor leaf seal to predict the complex nonlinear dynamic behaviour arising due to soft contacts. The software is developed in `MATLAB` and is optimized to run on a super-computer.

For the experimental part, a novel forced response test rig is designed to simulate a friction contact with varying preload arising due to fretting wear. The test rig design, system identification and a set of long-term results until full loss of contact are presented. Next, the effect of fretting wear on the friction contact evolution, hysteresis loops, contact preload and the impact on the evolution of system dynamics are discussed. The experimental results are then validated with the numerical prediction from the reformulated HBM tool.