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Rubbing force estimation during blade/seal interaction

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1. Introduction

Turbofan compressor stages efficiency is improved by minimizing the clearance between rotating blade tips and stationary casing. The tight clearance combined with dynamical and thermo-mechanical loadings may lead to blade-casing interferences [1]. In order to protect the blade from severe wear and failure, the compressor casing is coated with an abradable seal, which is designed to be preferentially worn in case of blade-casing contact. The knowledge of abradable seal wear mechanisms and their link to blade dynamics and interaction forces is needed for the industrial design of the seal. To this end, a test rig has been developed at ONERA, The French Aerospace Lab [2]. This rig has the capability of reproducing blade-seal interaction in a simplified configuration and taking into account the blade dynamics. One of the main issues in the experiment is the estimation of the interaction forces between the blade and the abradable coating (figure 1). The test rig is instrumented in the blade incursion direction with a load cell whose signal can be processed to estimate the normal force. On the other hand, force measurement is not possible in the tangential direction of the interaction without modifying the blade dynamics. However, the test rig configuration allows non-intrusive instrumentation of blade kinematics during the blade-seal interaction experiment. The work presented in this paper aims to estimate the tangential - or rubbing - force from blade kinematics measurements, and consists of the two followings parts.

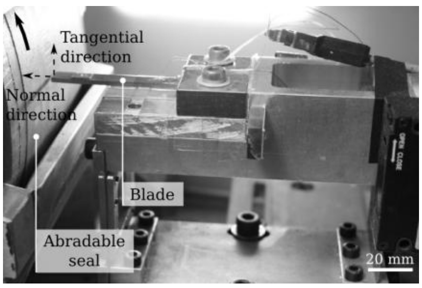

Fig. 1 – Blade/seal interaction test rig [2]

2. Analytical modeling of blade-seal interaction

The proposed model is a combination of a continuous Euler-Bernoulli beam model for the beam and a discrete spring-mass model for the rest of the incursion cell (figure 1). Previous experimental modal analysis of the incursion cell and time-frequency analysis of blade-seal interaction data have determined the model parameters and boundary conditions. The blade-seal interaction can be considered as an external force.

3. Inverse method for rubbing force estimation

Considering the previous part, some simplifications are made on the model, resulting in the simple one-mode Euler-Bernoulli beam model. The implemented inverse method has been published by Ma [3] and is based on a Kalman filter coupled with a recursive least-square algorithm. The observation equation of the Kalman filter is adapted to our case, where the blade deflection is the observed quantity.

4. Application to experimental data

The proposed method is applied to experimental data presented in [2]. The estimated rubbing force for one of these experiments is shown in figure 2. The force curve shape is consistent with the observation of blade bouncing made with a high-speed camera but also with the wear profile of the abradable coating.

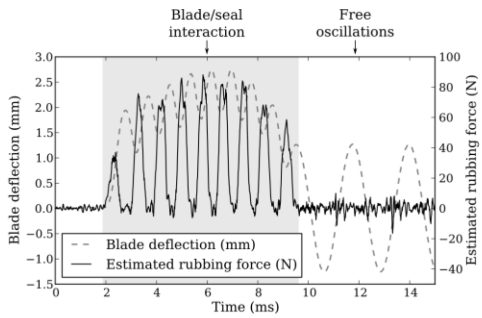

Fig. 2 – Blade deflection and estimated rubbing force during interaction

5. References

[1] Giovanneti I., "Clearance reduction and performance gain using abradable material in gas turbines", ASME Conf. Proc. 2008, GT2008-50290, 2008, 555-563.

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[3] Ma C.-K., Input forces estimation of beam structures by an inverse method, J. Sound Vibr. 259, 2, 2003, 387-407.