ANALYSIS OF BLADE-TIP CASING INTERACTION USING HARMONIC BALANCE METHOD

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Abstract: This paper presents an application of the harmonic balance method for modelling the blade-tip casing interaction. A new nonlinear element has been implemented in the in-house code FORSE in order to take into account the contact with friction that can occur when blade tip touches the abradable coating of the casing. This approach permits to efficiently calculate the frequency response of the blade excited by the contact of the casing. Numerical results presented in this paper agree with other observations proposed in the literature both numerical and experimental.

Keywords: *friction induced vibrations, rubbing, harmonic balance method , continuation, modal interaction*

1 Introduction

In modern aeroengines, improved energy efficiency is achieved by controlling the clearance between the blade-tips and stationary surrounding casings so that aerodynamic leaks are minimized. This strategy inherently leads to more frequent occurrences of direct contacts between the blades and the casings that may lead to nonlinear vibrations and subsequent structural damages. New designs (3D shape) of the blades can create radial components of mode shapes, which leads to a decrease of the clearance between the blade tip and the casing. The non-linear behaviour of the blade-casing interaction can lead to an excitation of modes different to the one predicted by the Campbell diagram. In some cases the periodic solution can become unstable, which leads to non-synchronous vibration. The severity of the response when the blade touches the casing was experimentally observed in Millecamps et al. (2009); Almeida et al. (2015). In the present study we focus on the rubbing aspect of the rotor/stator interaction. Modal interaction related to travelling wave speed coincidence Schmiechen (1998) is out of the scope of this paper. Several papers deal with the numerical simulation of blade casing interaction Sinha (2004); Batailly et al. (2012). The results obtained in those studies agree with experimental observations. The authors used time domain method to calculate the rubbing-induced vibration of the blade. We proposed in this work to apply the harmonic balance method coupled with the alternating frequency-time approach for calculating the nonlinear forces and the nonlinear vibration of the blade.

2 Numerical model

The problem of blade casing interaction is studied in the rotating frame. The basis is defined by z for the radial direction, x for the circumferential one and y for the axial direction. The finite element model of the blade is reduced to the tip nodes using the Craig and Bampton method. The equation of motion is transformed into the frequency domain and frequency response function is used to get the displacement at the contact nodes Petrov (2011).

$$\tilde{X}_{\text{nl}} = [\boldsymbol{A}(\boldsymbol{\omega})]\,\boldsymbol{F}_{\text{rubbing}}(\omega, \tilde{X}_{\text{nl}}) \tag{1}$$

where $\tilde{X}_{\text{nl}}$ is the vector of Fourier Coefficients of the displacement at the contact nodes, ω the frequency of rotation, $[\boldsymbol{A}(\boldsymbol{\omega})]$ the frequency response function and $\boldsymbol{F}_{\text{rubbing}}$ the nonlinear forces due to rubbing.

In the rotating frame the casing moves at the constant velocity V_x relatively to the considered tip node of the blade. This velocity depends on the rotational speed of the bladed-disk and the radius at the tip blade node; $V_x = R_{tip}\omega$, where R_{tip} is the radius at the tip of the blade. The element allows contact with separation in the normal direction. The equation defining the force in the normal direction is:

$$f_z = \begin{cases} k_n(z(\tau) - g) & \text{contact} \\ 0 & \text{separation} \end{cases} \tag{2}$$

where k_n is the normal contact stiffness and g the initial clearance. The contact stiffness depends on the abradable coating and has to be experimentally identified. The tangential force in the x and y direction is defined by:

$$\boldsymbol{f_x} = \begin{cases} k_t(\dot{x}(\tau) - V_x(\tau)) & \text{stick} \\ \mu f_z(\tau)\frac{\dot{x}(\tau)-V_x(\tau)}{\|\dot{\boldsymbol{u}}(\tau)-V(\tau)\|} & \text{slip} \\ 0 & \text{separation} \end{cases} \qquad \boldsymbol{f_y} = \begin{cases} k_t(\dot{y}(\tau) - V_y(\tau)) & \text{stick} \\ \mu f_z(\tau)\frac{\dot{y}(\tau)-V_y(\tau)}{\|\dot{\boldsymbol{u}}(\tau)-V(\tau)\|} & \text{slip} \\ 0 & \text{separation} \end{cases} \tag{3}$$

where $\dot{\boldsymbol{u}} = (\dot{x}, \dot{y})$ is the velocity vector in the tangential direction, k_t is the tangential contact stiffness and $\boldsymbol{V} = (V_x, V_y)$ is the vector of the relative velocity of the casing in the rotating frame.

3 Numerical Results

The proposed approach is applied to a high pressure compressor blade. The contact between the blade tip and the stator is induced by an ovalization of the casing. This ovalization can be the result of an excessive loading on the aircraft engine (e.g. during a landing). Three nodes(leading edge, middle and trailing edge) were retained at the blade tip and can contact with the rigid casing. Figure 1 shows the frequency response of the blade for different initial clearance between the tip and the casing. The analysis of the response spectrum (not shown here) permits to understand the modes that are responding during rubbing events. They are excited by the harmonics of the contact forces. We were also able to get the lobe pattern on the circumference of the abradable coating. The harmonic balance method similar results compared to the ones obtained by time domain methods Batailly et al. (2012).

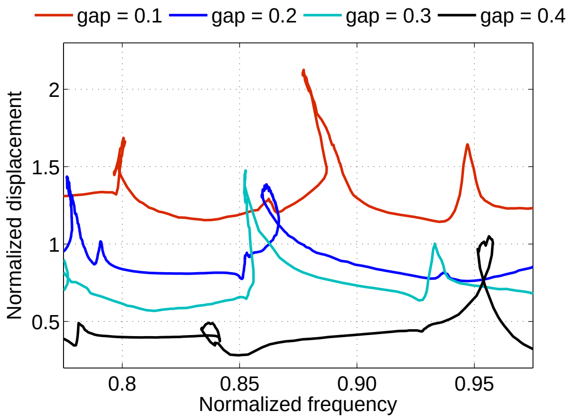

Figure 1: Frequency response at the tip of the blade for different initial clearance

4 Conclusion

A new approach has been proposed to calculate the vibration of the blade induced by the rubbing events. It is based on harmonic balance method, which permits fast calculation of the response. The results obtained during the study are very promising and HBM offers an alternative to the time domain simulation. Future work will focus on the improving of the rubbing model and detection of non-synchronous vibration.

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