ISROMAC 2017
International Symposium on Transport Phenomena and Dynamics of Rotating Machinery
Maui, Hawaii
December 16-21, 2017

[Extended Abstract]

Investigations on thermo-mechanical modeling of abradable coating in the context of rotor/stator interactions

Florence Nyssen, Département de génie mécanique, Ecole Polytechnique de Montréal, Montréal, QC, Canada

Alain Batailly, Département de génie mécanique, Ecole Polytechnique de Montréal, Montréal, QC, Canada

Context

In modern turbomachine designs, nominal clearances between the rotating bladed-disks and their surrounding casing are reduced to improve the overall efficiency of the engine. As a counterpart, this clearance reduction increases the likelihood of contact occurrences between static and rotating components and may lead to hazardous interaction phenomena. The addition of an abradable layer deposited on the inner surface of the casing is a widely spread solution in order to mitigate such phenomena. Nonetheless, contact interactions between blade-tips and the abradable coating may lead to unexpectedly high amplitudes of vibration of the rotor thus yielding very significant wear levels. Recent researches have focused on the numerical prediction of rotor/stator interactions featuring wear removal mechanisms [1, 2] but still neglect thermal effects. However, high temperatures have been experimentally observed [3] in the vicinity of impacted areas. Because elevated temperatures in the coating may reduce clearances through a dilatation of the abradable layer, the proposed work focuses on the numerical modeling of thermal effects that may be key to better understand the rotor dynamics following contact events.

Methodology

In addition to the mechanical mesh used to determine abradable coating wear levels, a thermal finite element mesh is superimposed in order to compute the temperature throught out the coating (figure 1). The temperature field in the abradable coating $\mathbf{T}(x, y, z, t)$ reads

$$\mathbf{T}(x, y, z, t) = \mathbf{N}(x, y, z)\ \mathbf{T}(t)$$

where $\mathbf{N}(x, y, z)$ is the interpolation functions matrix and $\mathbf{T}(t)$ contains nodal temperatures.

Weak coupling between thermal and mechanical effects is well suited in the case of impact dynamics and explicit time integration procedures [4]: thermal effects affect the mechanics of the system, but the mechanical deformation of the element has no effect on temperatures. Such coupling is assumed here. Also, heat transfer by conduction only is considered in this work, convection and radiation effects are neglected because of their lower contribution to heat transfer. Such approach yields a sequential solution algorithm in which, at each time step, a thermal computation follows the mechanical prediction.

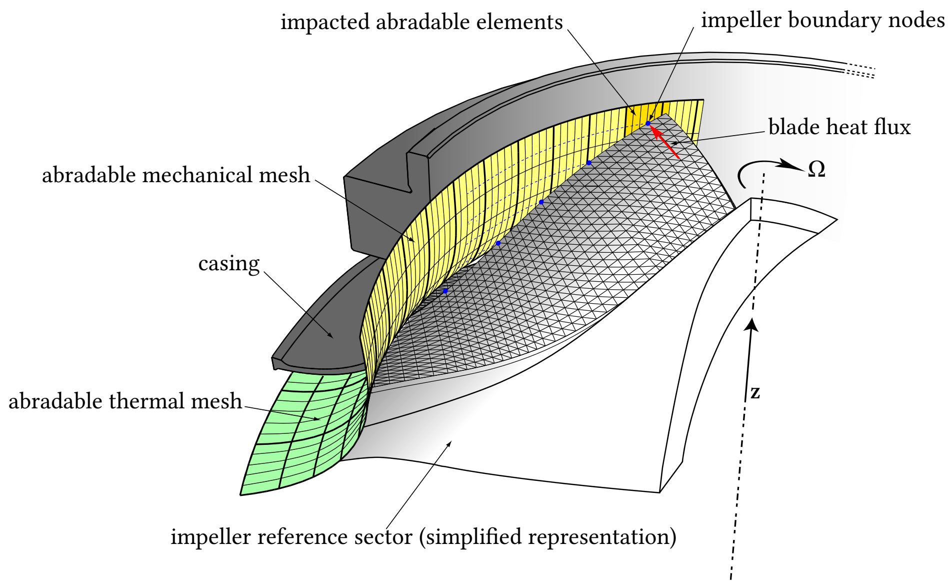

Figure 1. representation of the thermal mesh and blade heat flux

The temperature at time step $n+1$ is determined using the following system of equations:

$$\begin{aligned}\bar{\mathbf{K}}_{LL}\Delta\mathbf{T}_L &= \bar{\mathbf{F}}_L^n \\ \mathbf{T}_L^{n+1} &= \mathbf{T}_L^n + \Delta\mathbf{T}_L\end{aligned} \qquad \text{with:} \quad \begin{cases}\bar{\mathbf{K}}_{LL} = \mathbf{C}_{LL} + \alpha\Delta t\mathbf{K}_{LL} \\ \bar{\mathbf{F}}_L^n = \Delta t\left(\mathbf{F}_L^n - \mathbf{C}_{LP}\dot{\mathbf{T}}_P^n - \mathbf{K}_{LP}\mathbf{T}_P^n - \mathbf{K}_{LL}\mathbf{T}_L^n\right)\end{cases}$$

and the initial conditions $\mathbf{T}^{n=0} = \mathbf{T}_0$. $\mathbf{C}$ is the thermal capacity matrix, $\mathbf{K}$ is the conductivity matrix, α is the parameter of the iteration scheme and Δt is the time step. $\mathbf{F}$ contains the heat sources: the heat flux transmitted by the blade to the abradable coating during contact phase, as illustrated in figure 1. The subscript L denotes the degrees of freedom for which the temperature is unknown while the subscript P refers to nodes where the temperature is known. Knowing the temperature evolution in the abradable coating, the thickness of the abradable elements is then updated by computing the dilatation due to temperature increase.

The proposed numerical modeling strategy is applied on an industrial bladed disk to analyze the impact of thermal effects on the blade response and the system dynamics. A calibration of the results is carried out with respect to experimental data points. The developed thermo-mechanical model underlines the contribution of thermal effects during rotor/stator interactions.

References

[1] S. Roques, M. Legrand, P. Cartraud, C. Stoisser, and C. Pierre. Modeling of a rotor speed transient response with radial rubbing. *Journal of Sound and Vibration*, 329(5):527 – 546, 2010.

[2] H. Ma, D. Wang, X. Tai, and B. Wen. Vibration response analysis of blade-disk dovetail structure under blade tip rubbing condition. *Journal of Vibration and Control*, 2015.

[3] A. Millecamps, J.F. Brunel, P. Dufrénoy, F. Garcin, and M. Nucci. Influence of thermal effects during blade-casing contact experiments. In *Proceedings of the ASME 2009 IDETC & CIE conference*. ASME, 2009.

[4] L. Adam. *Modélisation du comportement thermo-élasto-viscoplastique des métaux soumis à grandes déformations. Application au formage superplastique.* Ph.D. thesis, Université de Liège, Liège, Belgium, 2003.