BLADED DISKS: NON LINEAR DYNAMICS

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1. Introduction

To prevent turbine axial blades from HCF failures, caused either by harmonic or by non-engine excitation like flutter or extreme part load condition, a freestanding airfoil can be coupled circumferentially in different manners. Blades with integrally machined shrouds or winglets, lacing wires or zigzag pins, which are threaded through a hole in the airfoil, are used often for minimizing the resonance responses. The bladed disc vibrations are characterized with the well-known interference (or the nodal diameter) curves and Campbell diagrams (see e.g. Ewins, 1973), while non-linear blade vibrations are assessed usually by using the performance diagram (Griffin and Labelle, 1996). Besides the friction dissipation on a shroud, a winglet or on a wire contact, friction dampers are in widespread use in disc assemblies with freestanding blades to control their vibration amplitudes. Several designs, such as a dog bone, a pin type or a wedge damper are employed in turbine blade design as devices for the frictional damping. In a good way Srinivasan (1997) outlines different aspects of the linear and non-linear dynamics of the tuned and mistuned disc assemblies, and there can be found more details.

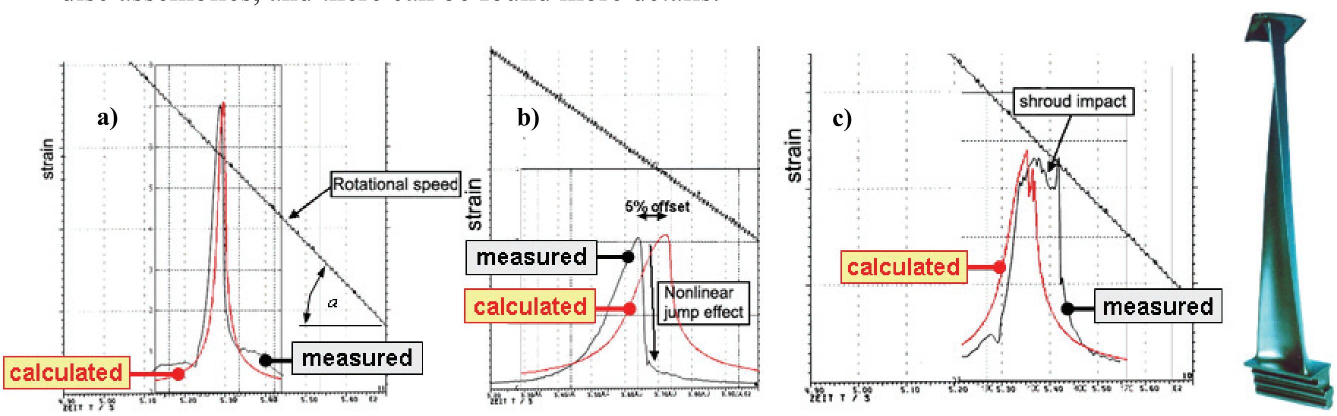

Figure 1 The measured (black lines) and computed (red curves) resonance response functions (RRF) of the shrouded blade passing its resonances in the spin pin condition and excited by an air jet (Szwedowicz et al., 2003)
a) Example of the RRF damped by the friction dissipation at the shroud contact
b) Case of the RRF with a rapid jump on the shroud interface caused usually by non-linearities on the contact
c) Instance of the RRF with chattering of sliding contacts of the shroud coupling

The non-linear dynamics of rotating blades corresponds principally to the physical phenomena of

- friction dissipation (see Figure 1a)
- elastic impacts or (Figure 1c)
- both of them as chattering (impacts) of sliding contacts of the airfoil interfaces (Fig. 1c).

At the blade root, only micro-sliding can occur due to the high centrifugal forces acting on the root contacts. At the shroud or winglet coupling, chattering of sliding contacts can occur, since the resulting normal contact force would be smaller than resonance reaction forces induced by the excitation load acting on the rotating blade. From the engineering point of view, impacts are undesired physical circumstance, which could lead towards fretting problem (Szwedowicz et al., 2005). In practice, the phenomena of impacts are seldom used for suppressing of resonance stresses of rotating blades, because of some technical difficulties in realization of those types of the dampers. Quite contrary to that, friction dampers are much more straightforward in their real application. Therefore, the non-linear dynamics caused by impacts of sliding contacts will be not taken into account in this work. In case of interest, theoretical backgrounds for the impact damper application in the rotating blade can be found in Duffy's work (2000), which provides also the experimental verification.

In general, alternating stresses among other things depends on the overall damping properties, which are caused by friction, aerodynamic viscous and hysteresis dissipation in material. These three damping sources in rotating turbine blades are shortly discussed here in relation to the well-defined practices used in engineering analyses. Following the historical development of a friction damper, showing typical damper's examples and explaining the fundamental theoretical backgrounds of the Harmonic Balance Method used for the linearization of friction forces, the physical interpretation of blade vibrations with friction dissipation at shrouds and on under-platform dampers is mainly taken into consideration. Aspects of contact stiffness, calculations of contact forces, uncertainty margins of friction coefficients and excitation levels is brought together with respect to needs for the design process.

2. Theoretical backgrounds of forced vibrations with friction

For many years the friction damping capability has been developed for rotating disc assemblies. At the beginning this process is based mainly on very simple analytical analyses and empirical knowledge. The understanding of the friction dissipation was gathered from various measurements on special test rigs, and from the experiences of the operating blade with friction devices. For the last 10 years, the numerical prediction of forced vibrations of the rotating blades with friction damping has done a remarkable progress. The existing numerical tools can predict the vibration blade with friction in more reliable sense. However, the experimental validation of these results seems still to be required. General difficulties in the mathematical description of the contact dynamics is the local elastic contact deformations, micro-slips deformations on sliding contacts as well as the variable normal contact forces, as it is illustrated in Figure 2a. In practice, an additional problem is to determine wear rate of sliding contacts (see Figure 2b), which also involves experimental verification.

According to Vingsbo and Söderberg's (1988) investigation, relative micro-slips on the contact should be below $2\ \mu m$ to suppress the wear of contacting parts. This is schematically demonstrated in Figure 2b. Indeed, these relationships among slip amplitude, wear rate, and