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[Extended Abstract]

A Finite Element Based Least Square Fit for the Assessment of Integral and Non-Integral Vibrations With Blade Tip Timing

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Introduction

A main challenge in the development of rotating turbomachinery is the safe and reliable design of blades with respect to high cycle fatigue (HCF). For many applications resonant operation cannot be avoided entirely and the apparent vibration levels need to be assessed with measurements. In this context the measurement of rotor blade vibrations is a difficult task. Traditionally, some of the blades are instrumented with strain gauges. Measuring blade vibrations very accurately, strain gauges have numerous drawbacks, since they influence aerodynamic as well as structural properties, need a complex telemetry system, have a very limited lifetime and nevertheless only the instrumented blades can be monitored, which may not be sufficient to capture the maximum vibration level of a mistuned bladed disk assembly.

Thus, recent work focuses on the enhancement of non-intrusive measurement techniques such as Blade Tip Timing (BTT). Meanwhile, BTT is an established technology allowing for the assessment of all blades in an assembly. However, this assessment is restricted to those modes showing a remarkable tip deflection and comes along with difficulties in the post-processing of the heavily undersampled BTT data. There are several algorithms reported in the literature. These can be classified by the presence of an "once per revolution" (OPR) sensor yielding a time signal of the circumferential position of the shaft and by the application of a specific structural model fitted to the data sets. The scope of this investigation is limited to OPR based BTT measurements without using specific structural models. The absence of specific structural models (e.g. single degree of freedom oscillator) allows a free interpretation of the observed forced response functions (FRFs) as those of a mistuned multi-degree of freedom (MDOF) system. Additionally, either the exciting engine order (EO) or the vibration frequency is assumed to be known or determined by other available algorithms.

A popular method to determine the necessary vibration amplitudes from the undersampled BTT data is the linear least square fit[1, 2]. However, BTT inevitably observes the superposition of probe and blade positioning errors, static deflection and blade vibration, see Fig. 1. Hence, a correction for positioning errors and static deflection needs to be modelled causing additional uncertainty in the measurement. Also, a suitable analysis block length (nr. of revolutions for fit) needs to chosen. This choice is always a trade-off between accuracy and robustness. One the one hand, it needs to be sufficiently long to minimize random errors and achieve a certain orthogonality to irrelevant signals contents. On the other hand, it has to be sufficiently short to resolve the maximum vibration

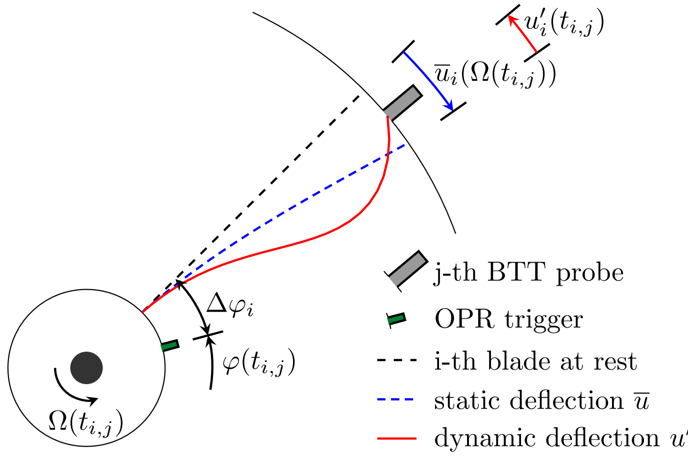

Figure 1. Sketch of the i-th Blade Tip Arriving at j-th BTT Probe at time $t_{i,j}$

amplitudes accurately.

This paper aims at improving the robustness and accuracy of the least square fit technique by proposing two modifications. The first proposal is to replace the lines of the original least square problem by differences of consecutive lines. Thereby, the static deflection as well as the circumferential blade positioning error cancels out and the robustness is improved by removing these uncertainties inherently.

The second proposal is a to replace the fit of piecewise constant vibration amplitudes within the chosen block length by a linear or cubic spline in the frequency (integral) or time (non-integral) regime. The splines are constructed based on finite elements with basic functions of appropriate order ensuring continuity of the vibration amplitude as functions of frequency or time as well as of the derivative for the cubic spline method. This does not only suppress overshoots due to distorted acceleration or deceleration manoeuvres but also allows for a ”coarser analysis grid” (i.e. larger block length) without loosing amplitude accuracy. Thereby it smooths out random errors more efficiently and increases the orthogonality of the relevant EO or vibration frequency to unwanted signal components.

This is especially of interest if the vibration response is a superposition of integral responses with different EOs and/or non-integral responses of multiple frequencies. It also improves the assessment of responses of higher modes with low signal to noise ratios.

Before the finite element based formulation of the least square fit is introduced, the paper recaps some fundamental BTT relationships to visualize the improvements by the proposed modifications. A subset of nominal system modes (SNM) representation[3] of a compressor rotor is used to generate BTT data. This allows to study the performance of the proposed algorithm with certain level of noise and mistuning as well as superposed vibrations of different mode families.

References

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