ON THE MODAL ANALYSIS OF FAST RESPONSE AERODYNAMIC PRESSURE PROBE DATA

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ABSTRACT

This paper presents the analysis procedure adopted to study the unsteady aerodynamic measurement data obtained from a Fast Response Aerodynamic Pressure Probe (FRAPP) downstream of a low pressure turbine (LPT) rotor in a 1.5-stage turbine test rig The method, which is based on the acoustic theory of Tyler and Sofrin, focuses on the investigation of the main structures constituting the unsteady flow field. The interactions between the stator and rotor wakes, secondary flows and the turbine exit guide vanes potential effect are identified, and their importance in the assessment of the aerodynamic and aeroelastic performance of modern low pressure turbines is analysed.

INTRODUCTION

The unsteady interaction between stator vanes and rotor blades influence significantly not only the aerodynamic performances of turbomachinery, but also have a strong effect on the noise emission and on the blade vibration of the rotor.

Investigations based on the modal decomposition proposed by Tyler and Sofrin [1] showed that superimposed circumferential and radial pressure patterns were identified as the origin of acoustic noise emissions. Lengani et al. [2] applied the modal theory to unsteady aerodynamic measurement data obtained in a turbine test rig proved that the mode detection technique can be successfully applied to get a deeper insight into the unsteady flow field. Zerobin et al [3] discussed the unsteady stator-rotor interaction in a turbine test rig including a turbine center frame duct.

The present paper presents the post-processing method of the unsteady aerodynamic data applied to decompose the complex flow field downstream of the LPT rotor, and then its application to the experimental data.

RESULTS AND DISCUSSION

The fluctuation of the aerodynamic quantities at any circumferential position θ downstream of a turbine stage can be described as the sum of harmonics, represented by a Fourier series. Thus, the measured flow field can be decomposed into an infinite number of modes m. The mode order m is related to the specific stator-rotor interactions by the linear combination:

$$m = hB \pm kV \tag{1}$$

where h is the harmonic index, B is the number of rotor blades, V is the number of stator vanes and integer the $k = -\infty\ldots,-1,0,1,\ldots\infty$. Depending on the blade number and the rotor speed, each circumferential pressure pattern associated with the azimuthal mode m rotates at a specific speed $\Omega_m = h \cdot B \cdot \Omega/m$. This leads to a specific inclination of each mode in a time-space diagram. To quantify the amplitude of each mode, the corresponding Fourier coefficient $A(m)$ needs to be evaluated at a fixed radial position, depending on the number of circumferential measurement points N_c:

$$A(m)_{r,f} = \sum\nolimits_{N_c} q(\theta)_{r,f} e^{-imN_c} \tag{2}$$

Figure 1 (a) shows the time-space diagrams of the total pressure at 96% span (tip). The rotor mode m_{-B}=-72 is depicted as an inclined blue line and follows the mean trail of the rotor induced flow structures, while the red line represents the azimuthal mode $m_{-B+V} = 24$, which is associated to the stator-rotor interaction and rotates against the rotational direction of the rotor. The other two modes represented in the picture are mode $m_{-B-V} = -168$ and mode $m_{-B+2V} = 120$, obtained replacing the index k in equation (1) respectively with -1 and 2.

A more detailed analysis of the modal structures, identified in the time-space diagrams presented in the above sections, can be obtained observing Figure 1 (b). The amplitudes of the rotor mode $m_{-B} = -72$ and of the interaction modes m =24, 120 and -168 are plotted over the span height. It can be observed that the dominant fluctuation is due to the rotor related mode -72. Furthermore, it can be noticed that the fluctuations induced at the tip and at the hub are higher than in the core flow.

In conclusion, time-resolved results and the modal decomposition analysis are applied to investigate the unsteady flow field downstream of a low pressure turbine rotor. This study provides new insight into the main interaction mechanisms and their importance in the aeroacustic and aeroelastic performance.

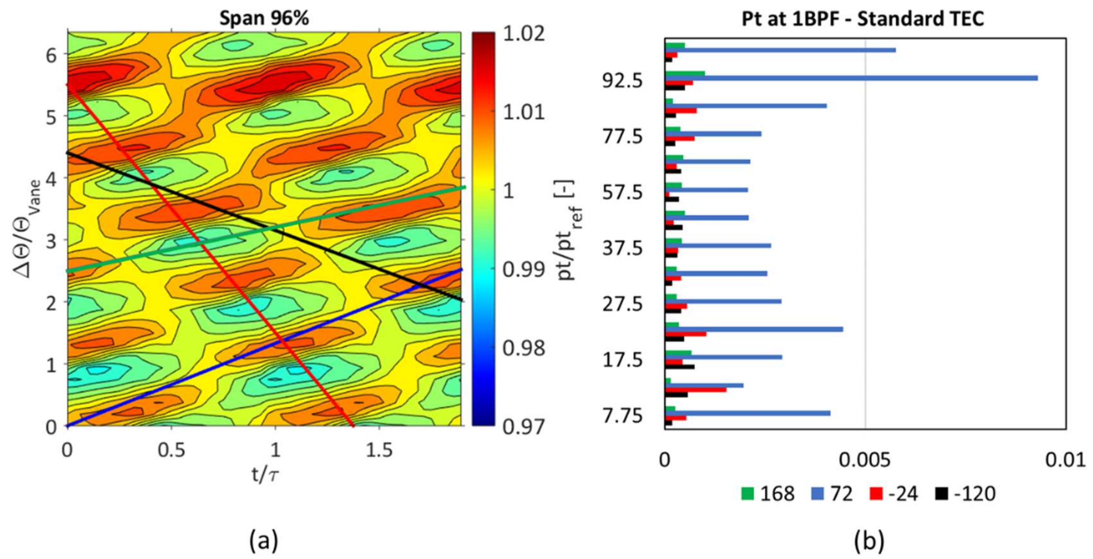

Figure 1: Results of the modal analysis. Time-space diagrams of total pressure with modes inclination (a) and normalised modal amplitudes of the total pressure over span height at the first BPF (b).

REFERENCES

[1] Tyler, J.M., Sofrin, T.G., “Axial flow compressor noise studies”, *SAE Transaction,* Vol. 70, pp.309-332, 1962

[2] Lengani, D., Selic, T., Spataro, R., Marn, A., Göttlich, E., “Analysis of the Unsteady Flow Field in Turbines by means of Modal Decomposition”, *Proceedings of ASME Turbo Expo,* Paper-No. GT2012-68582, 2012

[3] Zerobin, S., Bauinger, S., Marn, A., Peters, A., Heitmeir, F., Göttlich, E., “The Unsteady Flow Field of a Purged High Pressure Turbine Based on Mode Detection”, *Proceedings of ASME Turbo Expo,* Paper-No. GT2017-63619, 2017