CHAPTER 1

LITERATURE REVIEW

Numerous scientists have studied the unsteady aerodynamic excitation phenomenon during the past years. As per Hilbert et al. [2], the unsteady aerodynamic forces are obtained by three major sources. The first source of unsteadiness is due to the interaction between the rotating turbine blades and the turbine stator vanes. Furthermore, the circumferential non-conformities such as flow loss for other means (cooling) and the variations in the blade tip clearances are also sources of unsteadiness. The second source of flow unsteadiness comes from the turbine blade vibration adjacent to the studied blade. The third and last major source of flow unsteadiness comes from the vortex created by the blades and vanes situated upstream and downstream of the turbine blade set. Ishiara [3] performed experimental and analytical studies on the blade vibration phenomenon by concentrating his efforts on the flow unsteadiness caused by the interaction between the stator vanes and the turbine blades. To perform his study, Ishihara assumed the following three hypotheses: the two dimensional flow is incompressible, the flow instability and the blade vibrations cause the unsteady aerodynamic forces, and the speed of the flow fluctuation is inferior to the flow average speed (Figure 1).

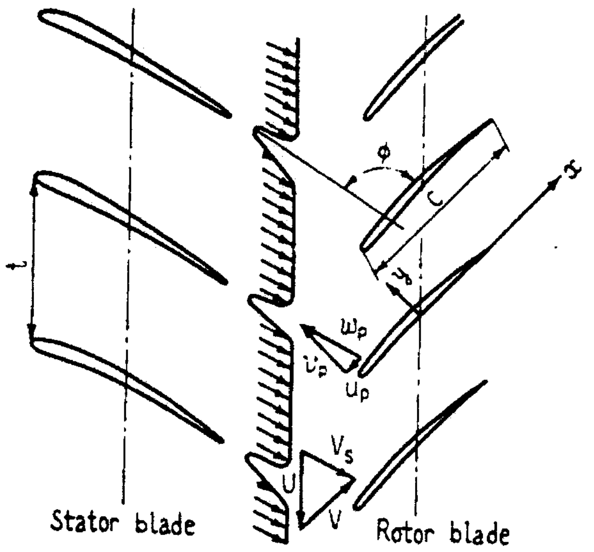

Figure 1 Aerodynamic excitation[1]

Hilditch et al. [4] performed studies on the unsteady pressures and the heat transfer of high-pressure turbines. They compared their experimental results with analytical results obtained from the program code UNSFLO. UNSFLO is a numerical simulation code to obtain results of two-dimensional unsteady pressures and it is used by multiple companies that design and build turbomachine engines. Krysinski et al. [5] also performed studies on three-dimensional unsteady flows. They experimentally investigated the effects on the performance of the turbine blades in regards to the angular positioning of the stator vanes. Jöcker et al. [6] performed studies on the influence of certain parameters of the parametrical excitations caused by the stator vanes on the high pressure turbine blades. Clark et al. [7] performed Computational Fluid Dynamics (CFD) analyses in three dimensions during the design process of a turbine blade with the goal of predicting with more accuracy the unsteady aerodynamic forces.

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[1] Reference [3], p. 6

A chapter of this thesis will define a finite element model using contact elements to predict the natural frequencies and mode shapes of a turbine blade. Meguid et al. [8] performed analyses with finite element modelling of the turbine fixation zone. However, these analyses were performed in the static domain to obtain the stress patterns and values. They compared their results with experimental results provided by photo-elastic testing. The type of contact elements that will be used are the ones available in ANSYS® and therefore will only be the ones used in this thesis. The contact elements that will be used must be three-dimensional and must be able to consider the friction phenomenon. The friction contact elements used in ANSYS® are based on the mixed variational principles. Cescotto et al. [9] have presented an original approach to the numerical modelling of unilateral contact by the finite element method. The alternative solution that Cescotto et al. have found was to discretize independently the contact stresses and the displacement field on the solid boundary. « It is based on a mixed variational principles and allows controlling the average overlapping between the solid boundary and the foundation. In other words, a node which is not yet in contact but only close to the contact is 'informed' by its neighbours that contact is going to occur soon. »[2] (Figure 2)

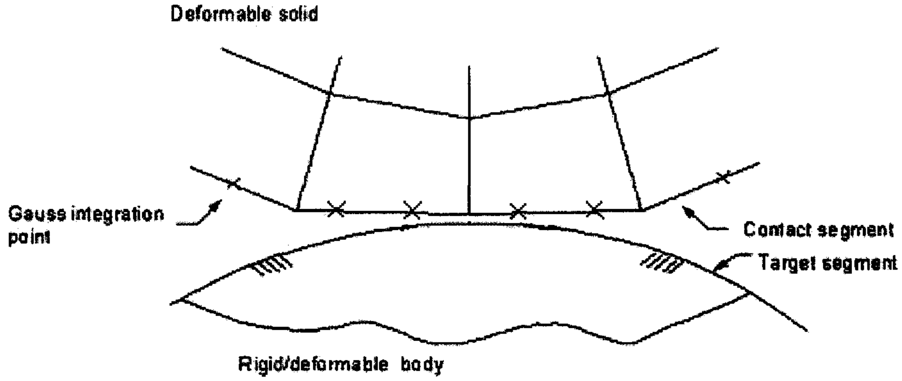

Figure 2 Solid versus foundation

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[2] Reference [9], p. 1681

« The finite elements are based on the penalty method for solving the unilateral contact and slip conditions and on the Coulomb model for the friction strength. When slipping contact appears, the constitutive equation of the contact element is unsymmetrical. Therefore, an unsymmetrical solver is used. »[3] This method is currently being used in ANSYS® to solve model which uses contact elements. In addition, Berger et al. [10] created a user-programmed function in ANSYS® to perform analyses of microslip damping on a turbine blade. They have created a "superelement" that would replace the contact elements currently used in ANSYS®. This new element contains a friction traction law definition based on the Coulomb friction model and a stick-slip transition logic based upon the force and velocity conditions. Although is still uses the contact elements from ANSYS® to determine the initial contact phase, the computational time per load step is greatly reduced. The overall energy dissipation, stresses and interface tractions are more accurately predicted. There are two reasons for which this methodology will not be used in this thesis. First, this macro is not yet available for the public. Second, the "superelement" in a two dimensional problem, while the fixing a turbine blade is a three dimensional problem.

A chapter of this thesis will describe a modal testing procedure to determine the natural frequencies and mode shapes of a turbine blade using an acoustical excitation. Li et al. [11] performed such experiments on an advance bladed disk prototype. The reason for an acoustical excitation is to produce a non-contacting measurement system and therefore, not affecting the system response. The measurement of the excitation is done using a calibrated microphone, while the measurement of the disk response is done with a Single-Point Laser Vibrometer (SPLV) and a Scanning Laser Doppler Vibrometer (SLDV). The speaker generates a signal, which excites the disk blades at their natural frequencies. Using the microphone, the sound pressure level is recorded so that a Frequency Response Function can be obtained. Li et al. used a travelling excitation wave

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[3] Reference [9], p. 1682

to excite all the blades of the disk. In this thesis, only one blade will be tested and therefore, a single speaker excitation will be needed.

Jay et al. [12] performed studies on turbine blades forced response. By performing experimental testing, they were able to identify the dynamic responses resulting from the interaction between the stator vanes and the turbine rotor blades. Furthermore, they performed an analytical description of the aerodynamic force originating in the difference between the number of stator vanes and the number of turbine blades. Moffatt et al. [13] also performed the same studies as Jay et al. [12], although using the program ANSYS® to determine the natural frequencies and mode shapes of the studied turbine blade and interpolated the results with the CFD meshing. The Navier-Stokes equations were resolved in the frequency domain by using a one-vane passage approach to obtain the aerodynamic excitation and the damped forces. This method was based on single-degree-of-freedom (SDOF) assumptions. Ultimately, Hilbert et Al. [2] performed the same studies on forced response in a three-dimensional field. The analysis consisted in a three-dimensional multi-stage turbine in which the stable and unstable dynamic fluid response was determined. A non-linear structural analysis and a linear dynamic analysis were performed to determine the displacement amplitude of the blade in resonance during the engine run. By combining a structural analysis and a dynamic analysis with a the fluid dynamic analysis, an iterative solution to the aeroelastic problem was obtained (Figure 3).

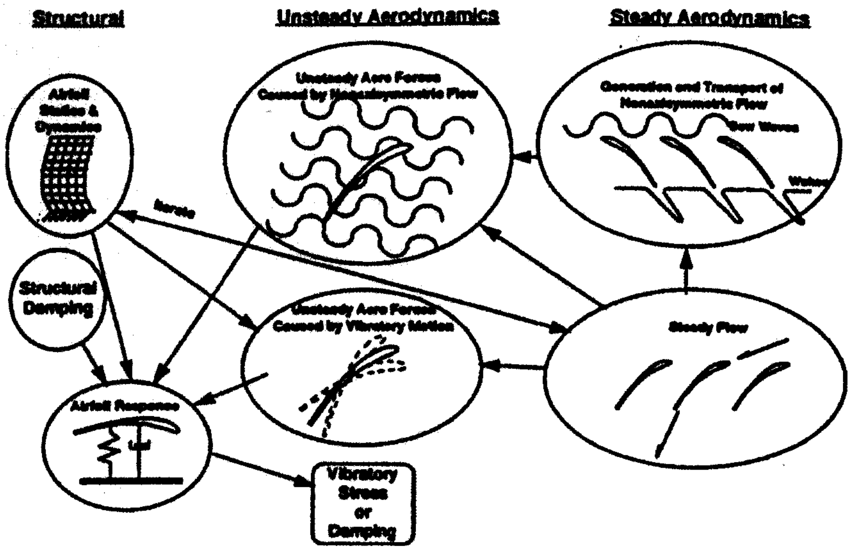

Figure 3 Method to predict the forced response of a turbine blade[4]

Busby et Al. [14] already performed studies on the axial blade spacing effect and determined that the increase in total relative pressure loss of the turbine blade was eliminated by the decrease in total relative pressure loss of the stator vane when the axial spacing was decreased. Furthermore, the predicted decrease in pressure loss of the stator vanes with the decrease in the axial spacing is mainly due to the reduction in wake mixing loss. Finally, the predicted increase in the total relative pressure loss of the turbine blade with a decrease of the axial spacing is mainly due to the increased interaction between the wakes produced by the stator vanes with the turbine blades.

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[4] Reference [2], p. 2

CHAPTER 2

OBJECTIVES AND METHODOLOGY

The forced response prediction, with accuracy, of the turbomachinery turbine blade forced response will be studied throughout this thesis. The turbine blades studied will be uncooled and unshrouded. The thesis objectives will be the following:

- Extract the total damping based on experimental data.
- Create a finite element model using contact elements for more accurate boundary conditions.
- Experimentally measure the natural frequencies, modes shapes and mechanical damping values.
- Create a methodology to predict vibratory stresses in the turbine blade.

To extract the total damping of the turbine blade, meaning the mechanical damping (material, friction, etc.) and the aerodynamical damping, the experimental data from previous tests will be used. This method consists in isolating the identified resonance and fit a theoretical curve over the experimental data. Using this theoretical curve, the total damping will be extracted. For the finite element model, a three-dimension turbine blade model and part of the disc will be meshed. No hypothesis will be made on the localization of the contact surface between the turbine blade and the disc. Therefore, the whole fixation zone of the blade and the disc will be meshed with contact elements. The finite element model will determine the natural frequencies and the mode shapes of the turbine blade. The analytical results will be compared to the experimental results. For the experimental testing, a laser vibrometer and an acoustic excitation will be used to determine the natural frequencies, modes shapes and extract the mechanical damping values. For the prediction of the vibratory stresses method, the FLARES [2] code will be used to superimpose the aerodynamic forces onto the turbine blade. From this, the modal participation factor will be obtained. This factor will multiply the modal stress vector obtained by the finite element model so that, finally, the vibratory stresses of the turbine blade can be obtained. Most of the work will be on the parametric study to obtain consistent stress values from FLARES and ANSYS®.