Experimental Investigation Of Non-Linear Structural Dynamics of Shrouded Turbine Blade

ABSTRACT

Low Pressure Turbine (LPT) blades operate as one of the most crucial components of turbomachinery. These blades are subjected to highly stressed forced vibrations during the operation, which can cause high cycle fatigue failure. To avoid such type of a catastrophic failure during operation, the estimation and reduction of these vibration amplitudes is mandatory during the design phase. Generally, the vibration amplitudes are reduced by using friction-damping devices in the blade assembly like shrouds, under-platform dampers and snubbers. Shrouded turbine blades comprise of shrouds as covers at the blade tip that are in contact with the shrouds of the adjacent blades and engage due to the centrifugal forces. During blade vibration, the coupled shrouded turbine blades undergo relative motion where three-dimensional periodic shroud contact forces are activated resulting in energy dissipation because of the friction. To simulate the effect of the complex friction damping process on the dynamics of the shrouded turbine blade, numerical contact models are implemented in non-linear solvers to predict the nonlinear forced response of the shrouded turbine blades and shroud contact forces. Experimental validation of these contact models is necessary for continuous improvement and the need arises to also measure the contact forces acting at shrouds during the experiments. Furthermore, modern industrial requirement of more accurate and detailed simulations and models necessitates a comprehensive experimental validation, which demands the measurement of additional parameters from purposely designed application specific test rigs.

This doctoral thesis deals with the design, development and operation of an experimental test rig that provides for the simultaneous measurement of dynamic response of shrouded blade and three-dimensional shroud contact forces during forced vibration testing. The proposed experimental setup allows the collection of an experimental database that will be used for the experimental validation of the contact models implemented in nonlinear solvers to predict the nonlinear forced response and shroud contact forces. The description of the design phase starts with the outline of the design requirements of the test rig considering the research objectives. The design requirements and finite element analysis in ANSYS assisted in finalizing the design of the test rig components and their mechanisms. The major components designed for the test rig i.e. the mockup shrouded blade, tri-directional contact force measurement system and the torque screw mechanism are explained. The design, calibration and validation of the novel contact force measurement system is presented that was designed to engage both the shroud contacts simultaneously in order to measure three-dimensional static and periodic shroud contact forces.

The study highlights different aspects of the test rig commissioning that involve the experimental modal testing of the test rig to determine the actual natural frequencies of the system. Details of the experimental setup describe the role of the other involved components and instrumentation i.e. the force sensors, accelerometers, shaker and data acquisition systems. Experimental procedure and the defined test matrix demonstrate how the test campaign was performed for different normal preloads and excitation force levels. In the results section, the effects of the variation in the normal preload and excitation force levels on the measured response and shroud contact forces are discussed. The variation of the static contact forces during the experimental campaign was analyzed and the behavior of the periodic shroud contact forces during the stepped sine testing was also explained. Finally, the study demonstrates how the experimental results established the efficacy of the proposed test rig to provide a complete representation of the dynamic response of the shrouded blade and three-dimensional shroud contact forces that will lead to a more detailed and accurate experimental validation of the simulation tools.