An energy balance of blade-casing interaction.

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Long Abstract

Introduction

Clearance between rotational bodies and respective non-moving parts is a concern in designing aircraft turbomachines. Indeed, controlling the clearance between blade tips and surrounding casing ensures both engine reliability and performance in terms of energy efficiency improvement. The most commonly used technical solutions are abradable coatings thermally sprayed over inner parts of casings to soften potential interaction. Even if wear is present, some operating conditions can lead to divergent interaction phenomenon. Experimental invesgations on blade/casing interaction have shown that the blade may diverge after a more or less long period with various dynamic steps. The contact may change under the effects of thermal expansion and abradable wear. These two main factors may create “favorable” contact conditions in order to make the blade diverge. These observations have been validated numerically [1], showing the influence of the thermomechanical behavior on the blade dynamics. However the blade/abradable interaction is a very complex phenomena with different mechanisms activated : heating, rubbing, cutting, creation of debris, plowing or adhesive transfer. The determination of thermal expansions directly comes from heat flux partition generated between solids, hence the interest of investigating an energy balance including energies associated to mechanisms observed during interactions. Experimental investigations of interaction of a titanium simplified blade and a rotating cylinder, coated with AlSi-Polyester abradable, are carried out to identify generated heat flux and their respective partition coefficients. The overall goal is to manipulate thermal and dynamics measured data through both solid in interaction to introduce blade-abradable energy balances, inspired from [2].

Experimental Test Rig

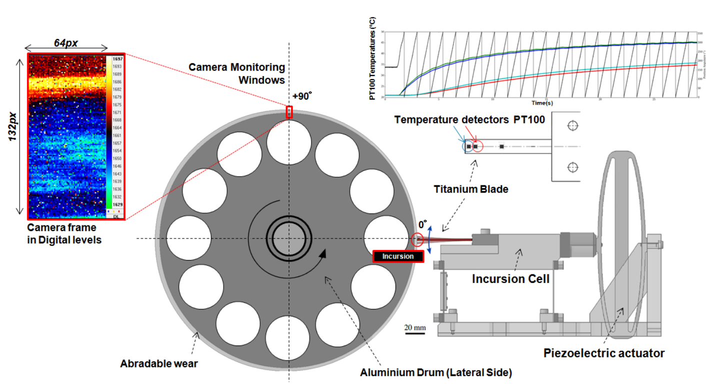

Figure 1. Instrumented Test Bench

The test bench (Figure 1.) and the initial experimental set-up are based on [3] works. The blade which is mounted on a translating casing is fed radially into the moving abradable drum in the operation of the piezoelectric actuator. Rotational speed, rub depth and respective incursion rate are perfectly managed to achieve a number of quasi-constant steady-state rubbing tests or shorter and deeper impacts. Rubbing-induced blade vibration data are sampled with laser bending measurement at blade-tip. To adapt the test bench to heating effect measurements, a thermal infrared camera equipped with a microscopic objective was added one quarter-turn after blade-coating incursion position. The measurement is deported on the side surface of the barrel to avoid emissivity variations due to wear during tests. Temperature gradient within the coating thickness can be observed through the monitoring windows after a blackbody calibration and after providing circumferential motion blur compensation with temperature level averages for each pixel line. On the blade, 6 resistance temperature detectors PT100 are used to measure blade temperatures symmetrically at different spacing from the tip.

Results

The energy balance is written for the 2 tests, a 1-minute rub-test and a short impact of a few deozen milliseconds :

$$e_{friction} = q_{blade} + q_{abradable} + q_{debris} + w_{blade\ bending} + w_{abradable\ wear}$$

The friction mechanical work $e_{friction}$ has been determined through the integration of relative velocities and interaction forces scalar product. Kalman Filter techniques adapted by [3] allow to express tangential interaction forces by an inversion process of bending measurement. Likewise, the bending mechanical work $w_{blade\ bending}$ is calculated as the sum of potential energy and kinetic energy from deflection measurement of the blade considering a free-clamped Euler-Bernoulli beam.

The blade heating q_{blade} is computed from the thermocouple datas using a one-dimensional analytical stationary model in a semi-infinite solid subject to a constant flow. The heat absorbed by the abradable coating $q_{abradable}$ is calculated from Infrared Camera raw data. Considering [4] original model, a moving heat band under steady conditions over a semi-infinite solid, the heat flow is directly adjusted to match with surface temperatures experimentally measured one quarter-turn after interaction. q_{debris} corresponds to the calorific energy stored in volume of debris. Finally, the remaining part of total energy $w_{abradable\ wear}$ is associated to other energetic losses due to damping and both reversible and irreversible mechanisms in the abradable.

For the rub tests, it is highlighted that terms referring to mechanical energies written for thermo-elastic closed-systems are negligible. Most of the work done by the frictional force is dissipated as heat. The average heat partition ratio is close to 95 % in the abradable coating and 5% in the blade.

For the impact test, analytical thermal approaches are limited, and therefore Finite Elements Methods and inverse heat conduction estimations are considered to calculate the heat partition coefficient. Only 25% of total friction energy is converted in heat according to temperature rises in both coating and blade. In such test, it is shown that the energy balance should consider the other terms of irreversible deformation, wear, stored energy in the debris, etc.

References

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