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Procedia CIRP 59 (2017) 83 – 88

www.elsevier.com/locate/procedia

The 5th International Conference on Through-life Engineering Services (TESConf 2016)

Advanced characterization techniques for turbine blade wear and damage

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Abstract

This paper presents four complementary non-destructive measurement techniques for material characterization and damage detection of turbine blades. The techniques are macroscopic fringe projection with inverse fringe projection algorithms, robot guided microscale fringe projection, high frequency eddy current and pulsed high frequency induction thermography, both in the megahertz range. The specimen on which the measurements were carried out is a blade of the 1st stage high pressure turbine of a modern airplane jet engine. The turbine blade was characterized with regard to the macroscopic and microscopic geometry, cracks in the base material as well as the condition of the protective layer system.

Peer-review under responsibility of the scientific committee of the The 5th International Conference on Through-life Engineering Services (TESConf 2016)

Keywords: Fringe projection; thermography; high-frequency eddy current testing; turbine blade; wear; damage;

1. Introduction

The reliability of jet engines is crucial for the safety of airplanes. For that reason, the performance and condition of such engines is monitored on a regular basis. The highly valuable blades of the high pressure turbine are very important for the functionality and performance of a jet engine while they are subject to high load and are exposed to extreme conditions. In order to withstand the high temperatures and severe corrosive attack, those turbine blades are protected by a corrosion protection layer (e.g. PtAl, Al or MCrAlY) and a ceramic thermal barrier coating (TBC) with a thickness of approx. 100 µm.

This paper discusses means to non-destructively detect macroscopic defects in the turbine blade’s shape, measure defects on a microscopic scale and monitor the condition of the protective layers. For the detection of geometry defects, inverse fringe projection [1] is applied. It uses a single measurement image to visualize differences of the measurement object from its nominal shape. Next, the defects found are measured and classified with a robot guided microscale fringe projection system with a resolution of several micro meter. Defects like cracks on the surface and in the near subsurface base material as well as delamination are detected using pulsed high frequency induction thermography. Finally, high frequency eddy current testing is used to estimate the TBC thickness and to characterize the condition of the underlying corrosion protective coating. The specimen used in this study is show in fig. 1.

Fig. 1. Image of the turbine blade tested.

Nomenclature

HF-EC	High-Frequency Eddy Current
MRO	Maintenance, Repair and Overhaul
TBC	Thermal Barrier Coating

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doi:10.1016/j.procir.2016.09.005

2. Inverse fringe projection

Fringe projection is an often used technique employed for measuring an object's geometry. Usually a light source, like a projector, casts light patterns onto the objects. A camera, set up at a known angle, captures those patterns. The geometry is then calculated with the triangulation principle.

For this calculation, each camera pixel is correlated with a line in the projector image (e.g. a row or column). In order to compute the correlation of camera pixels and the projector image, several sinusoidal patterns with different frequencies and phases are projected. Higher frequency patterns have a better sensitivity but make disambiguation between the periods more difficult. A pattern with one period per projector image has a relative low sensitivity but is used to identify the waves of higher frequency patterns. At least two patterns with different phases per frequency are used to reconstruct the angle of each camera pixel in the projector image. As an example, eight patterns may be used, similar to the approach of Peng [2]: 1 period (0°, 90°), 6 periods (0°, 90°) and 36 periods (0°, 90°, 180°, 270°).

Inverse fringe projection is a newly developed algorithm for the detection of the deviances of an objects shape relative to the nominal geometry. The principle idea is to calculate an object adapted pattern, so that the camera captures regular and straight sinusoidal waves, if the object has no defects. The camera image of the measurement object is than compared with the ideal pattern to detect damages. The computation of the inverse pattern is done with ray tracing and a 3D model of the objects nominal geometry. In a virtual environment, the target pattern, regular sinusoidal waves, is projected from the virtual camera onto the object and captured by the virtual projector. For the measurement, the pattern captured by the virtual projector is used with the real projector and captured by the real camera.

Figure 2 shows the projected pattern and figure 3 the captured image. As expected, the fringes in the camera image are mainly regular and equidistant, which indicates that the measurement principle worked well and the blade has not been deformed too much.

Deviances in the objects geometry will cause discontinuities in the phase of the resulting image's sinusoidal pattern. The Hilbert transform [3] was used to calculate the phase of the image. Afterwards the phase image is compared with a reference phase map to create the error map (fig. 4). The reference phase map is the same as that used to calculate the inverse pattern. With a modern OpenGL graphics application the simlulation can be done in about 0.1 seconds. Projection and capturing takes approximately another 0.1 seconds while the computation of the error map takes 2 seconds. The latter could be accelerated using general purpose graphic processor programming.

The cooling holes have not been part of the model used to compute the inverse pattern. Therefore, they appear as phase error in the result. Areas with a large angle between the camera and the surface normal have a high phase error because they are extremely sensitive to calibration and positioning error. The tip of the blade is heavily worn out and hard to measure. Close to the tip are two major cracks which can be easily detected using the resulting error map.

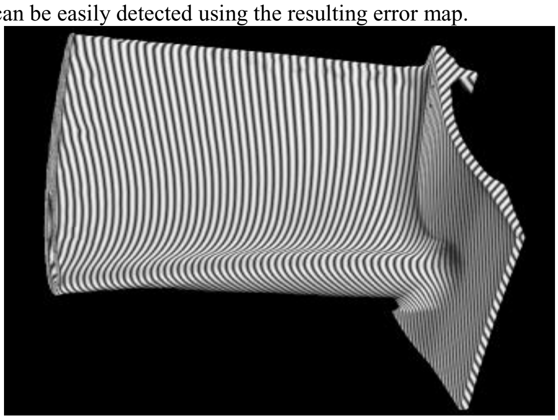

Fig. 2. Inverse pattern, projected on to the object.

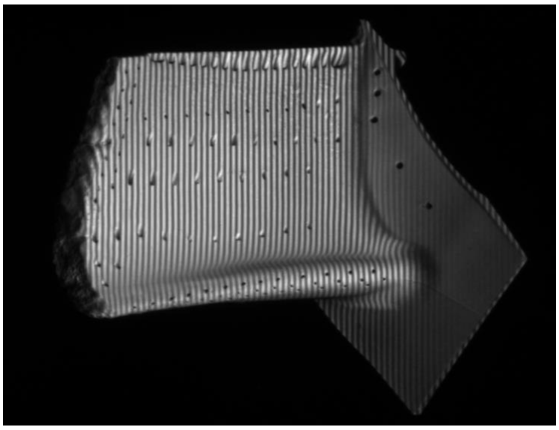

Fig. 3. Inverse pattern captured by the camera.

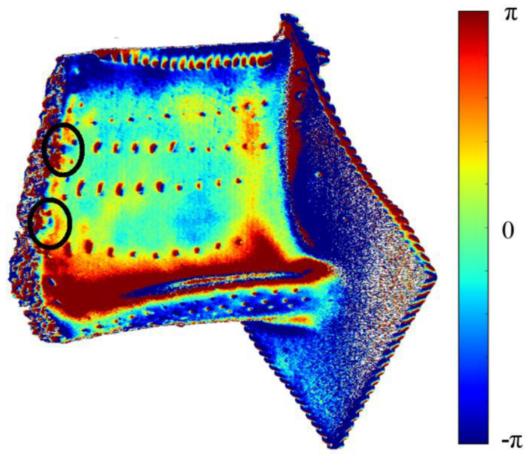

Fig. 4. Phase difference of the measured blade in radiant. Two cracks close to the tip are marked.