COMPRESSOR FOULING DETECTION BY IMAGE ANALYSIS

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ABSTRACT

Gas turbine fouling is commonly known as responsible for performance degradation in terms of compression ratio and efficiency. Fouling is promoted by the adhesion of airborne contaminants coming from natural or artificial sources. Natural contaminants are soil, pollen, or salt, while synthetic contaminants are usually generated by combustion processes such as soot powder. The adhesion of these micro-sized particles caused the modification of the blade shapes and the surface roughness. Both of these two effects determine the modification of the compressor performance over the unit operation.

During overhaul or off-line washing, the deposits on the compressor's internal surfaces are removed, restoring the original performance. However, both land-based units and aero-engines collect several micron-sized particles (soil and soot), which are able to stick to the blade surface depending on the engine load and environmental conditions. Due to the lack of capability to forecast the fouling intensity, it could be useful to estimate the fouling intensity during the machine overhaul, collecting strategical data by which a specific characterization of a given machine in a given operating site can be done. The present paper proposes and validates a methodology useful for estimating the deposit intensity by an image analysis procedure. An image-detection process has been carried out before and after the contamination process, and, using a subtraction process, a quantitative analysis of the fouled regions can be developed. Furthermore, image detection has been coupled to the localized quantification of the deposits by means of a dust collector to generate a relationship between the greyscale patterns and the contaminant mass.

The results show that, with a careful light and camera setup, the intensity of the deposits can be estimated with an acceptable tolerance band, which allows the possibility of collecting quantitative data on compressor deposits during overhaul operations. This generates a valuable starting point for predicting the overtime degradation of the unit and/or estimating the filtration section efficiency.

INTRODUCTION

The gas turbine technology has been developed to increase its efficiency using new technology and design by means of the increment of the firing temperature, aerodynamic performance, and the decrement in the emissions and fuel consumption. However, during the operation, gas turbines experience performance degradation due to flow path contamination [1, 2]. This effect is generated by the adhesion of micro-sized particles coming from the fuel and/or from the environment [3, 4]. The contamination provided by the fuel impurity affects the turbine section (hot section of the gas turbine, after the combustor), and it can be slowed down by adopting cleaner fuel. By contrast, the contamination provided by the airborne contaminant can be slowed down by using inlet filtering sections, but, in several applications, the filtration efficiency or the impossibility of using such systems (for example, for the aero-engines) determines the compressor's section contamination [3].

Aim of the work. This work proposed a new methodology based on image analysis able to detect the deposits over the compressor flow path that could be adopted for lab-scale tests and during the overhaul operation. The proposed methodology is carried out on an actual engine by controlling the contamination process. The novelty of this approach is mainly due to its wide range of applicability. Pros, cons, and guidelines are also highlighted.

RESULTS AND DISCUSSION

A specific test bench has been set up to test the image detection of fouled compressor regions. The experimental rig was equipped with the compressor of the engine Allison 250 C18. This is a multistage axial unit coupled with a centrifugal stage able to reach an overall pressure ratio of 6.2 and a mass flow rate of 1.36 kg/s at the design speed of 51,600 rpm [5]. The centrifugal stage has two semivolutes, each with a circular exit duct with a diameter of 0.056 m, and two flexible tubes link the outlet ducts to an exhaust outlet with a diameter of 0.100 m. The compressor is driven by an electric motor. During the current test campaign, the compressor unit was kept at 20,000 rpm, corresponding to a mass flow rate of 0.33 kg/s.

To explore the most exhaustive possibility, three diameter distributions have been considered. All of the soil samples are the Arizona Road Dust (ARD) sample, characterized by a density of 2717 kg/m^3. It is a natural-based powder consisting mainly of about 70 wt. % silica and 14 wt. % aluminum oxide and other minor iron, sodium, calcium, and magnesium oxides. The particle diameter distributions for the three powder sample named ARD N, ARD UF, and ARD M are reported in Fig. 1.

A set of images of the compressor flow path has been taken to detect the fouled regions during the experimental investigation. A proper light and camera setup was adopted to ensure the repeatability of the detection process, allowing the comparison between the clean and fouled conditions. The image detection was carried out by disassembling the compressor unit. Thanks to this, the half compressor case (stator) was positioned on a realized-on-purpose holder while the rotor was kept in its original position. The deposit patterns are taken directly from the lab-testing facility employing dedicated cameras (Canon EOS M6 mirrorless digital camera with Tokina 100 mm lens with a resolution of 3552 x 2664 pixels) positioned to detect the entire flow path of the axial compressor divided into according to the rotor and stator components. The white light setup is adopted for both parts of the compressor flow path with the intensity of 4000 K. Starting from these detections, the determination of the deposit pattern has been carried out through image processing based on the open-source image processing package named IMAGE J [6].

The results of the image post-process are reported in Fig. 1. Black and white patterns have been obtained by means of a subtraction process. Each black dot represents the difference between the detection for the clean and the fouled condition. Looking at the image detections, ARD M (the coarsest powder) has the scarce capability to adhere to the blade and vane surfaces. The sticking phenomenon increases by decreasing the particle diameter. The smallest powder (ARD N) determines the worst scenario. Evident contamination of the rotor pressure side and the vane leading edge is visible. These detections show the modification of the deposit patterns as a function of the impacts and adhesion behavior.

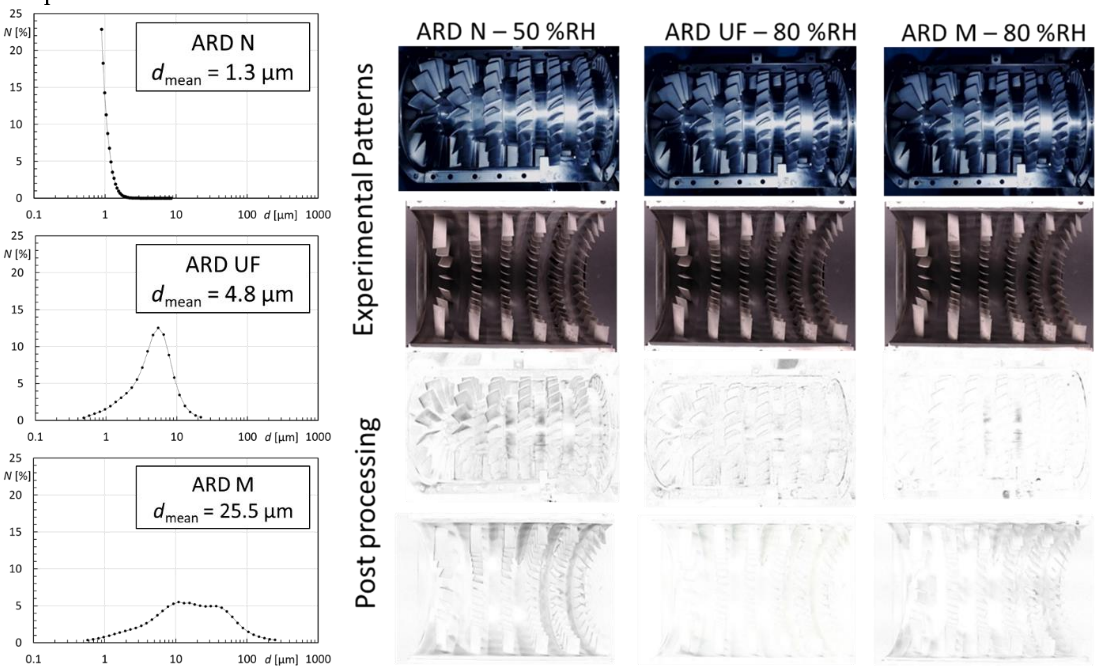

Figure 1. Diameter distributions of powder samples and the image detections of fouled regions

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