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High temperature fatigue testing of gas turbine blades

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Abstract

With the increasing use of renewable energy sources, Gas Turbines (GTs) are currently required to accomplish more flexible operations for supplying the back-up energy. As a result, thermo-mechanical fatigue issues in the GTs components are emphasized. In this paper, the design of a novel rig for assessing the fatigue behavior in the trailing edge of full scale GTs blades is presented. Based on a detailed Finite Element (FE) analysis of the blade response under thermo-mechanical loads, it is demonstrated that the stress and strain cycles arising in this area during a start-up/shut-down transient can be accurately reproduced by clamping the blade in the shank zone and applying a transversal load to the trailing edge. It is also shown that the stress/strain states can be obtained using a Test Article (TA) extracted from the actual blade. In this configuration, the load magnitude and direction, and the distance of the application point from the blade platform are the test control parameters. A FE model simulating the TA test is developed to determine the test parameters. A tooling for clamping and loading the TA is finally proposed along with a rig apparatus consisting of standard equipment used in material testing.

Keywords: high temperature fatigue, gas turbine blade, test rig, finite element analysis.

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1. Introduction

The use of renewable energy sources is nowadays growing in the perspective of sustainable and environmentally friendly solutions for energy production. Traditional fossil fuel power plants are facing new challenges to become more flexible and efficient back-up power providers. The European Project FLEXTURBINE is aimed at developing new technological solutions to guarantee a significant improvement in the flexibility of existing power plants and favoring the growth of renewable sources in the European power grid [Gonzalez-Salazar and Kirsten, 2016]. In this framework, one of the goals is to improve the components life cycle management of Gas Turbines (GTs) subjected to more frequent start-ups, shut-downs, and load changes, while keeping the life cycle costs at the current levels.

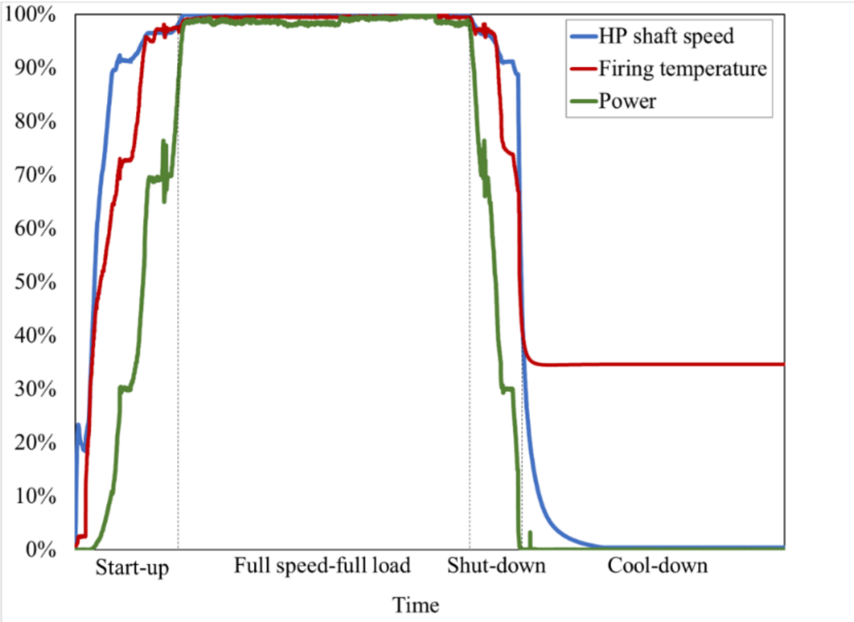

Fig. 1. Typical trends of the mission loading parameters for GTs.

Figure 1 represents the typical trends of the power, firing temperature, and High Pressure (HP) shaft speed in GTs. During a single mission, the GTs components withstand thermo-mechanical loads, which rise fast in the start-up to full speed-full load condition and then drop during the shut-down. Under these conditions, each GT component is subjected to stress and strain cycles pulsing from zero to maximum values given by the design full speed-full load condition. In the perspective of more flexible service conditions, it should be expected that fatigue becomes the most important damage process [Balevic et al. 2004, James et al. (2014), Kim et al. (2015), Wang et al. (2016), Vacchieri (2017)]. A deeper knowledge of the components fatigue behavior is needed to extend the service life of GTs, especially for those parts, which withstand the heaviest loading conditions such as the GTs high pressure first stage blades.

Extensive analyses of GTs blade mechanical response revealed that the disc-blade connection is usually the most critical part [Issler et al. (2003), Pineau et al (2009), Hu et al. (2013)]. However, the presence of the cooling system in cooled blades can determine critical stress and strain cycles in the airfoil too. It is reasonable to expect that these cycles are severe especially in the fillet region between the trailing edge and platform, because of the thin thickness of the trailing edge and the presence of cooling holes. The opportunity to study the behavior of the material in these regions through a rig testing full-scale blades allows to better estimate the service life of the components taking into account the actual geometry and manufacturing process [Bychkov et al. (2008), Hu et al. (2013), Wang et al. (2016)].

The aim of this paper is to design a novel test rig for studying the high temperature fatigue behavior in the above-mentioned fillet region. The identification of the test configuration and the component-like specimen definition are