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Research Paper

Effects of emergency and fired shut down on transient thermal fatigue life of a gas turbine casing

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HIGHLIGHTS

- Evaluation of shell temperature by using thermocouples.
- Establish the transient thermal fatigue life of a gas turbine casing.
- Transient thermal stress analysis of a gas turbine casing.
- Establish the stress intensity factor of a gas turbine casing.

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ABSTRACT

The study aims to establish the transient thermal fatigue life of detected crack on the edge of eccentric pin hole of a gas turbine casing under the terms of linear elastic and elastic-perfectly plastic material behavior, in accord to engine work cycle to fired and emergency shut down. Using non-destructive tests, the crack position and direction were determined. The distribution of inner surface temperature was measured using ten thermocouples that were installed inside the casing's wall. In finite element simulation, the temperature data were applied as a boundary condition. Through the use of Abaqus software and Zencrack fracture mechanics code, the transient thermal stress and thermal fatigue crack growth were predicted. The analysis showed that the stress distribution is same for two terms of material behavior while crack propagation is different. The analyses also showed that the most important factor in thermal fatigue crack growth is the rate of cooling the turbine casing.

1. Introduction

Due to the sensitivity and high cost involved in the power sector, any damage to components of a turbine will cause considerable destruction. The most costly operations aside from fuel, is the cost to repair and replace turbine hot section. The cost of replacing these parts in some cases may be up to 30% the cost of the main engine. Therefore, the study of damage to gas turbines is important. As a result, the need to assess reiterative damages of gas turbine casings should be well studied. The GE-Frame9 heavy-duty gas turbines were designed on the basis of GE-Frame7 gas turbines and have been developed from B series with 85.2 (MW) outputs to FA series with 251.8 (MW) outputs [1]. Like any other turbine, fatigue and creep are the most common problems that GE-F9 might encounter. Fatigue crack initiation and propagation are common defects in turbine components. Turbine casing may encounter thermal fatigue phenomena, which is a low cycle fatigue that appears as a result of time variable temperature gradients during turbine working cycles. It is well known that gas turbines are subjected to severe thermal loads that give rise to intense thermal stresses in its components especially around the crack and other defects. The concentration of stresses around the defects often results in catastrophe, particularly when the structure is subjected to a thermal shock. Thermal shock failure is widely studied in the literature mainly because of its importance in the theory of brittle fracture and many potential industrial applications [2].

Kadlec [3] analyzed fatigue crack initiation and propagation in stainless steel bodies subjected to repeated thermal shocks under the term of linear elastic material behavior. Wang [4] analyzed glass crack initiation under thermal loads, to explore the correlation between temperature change and crack initiation. They carried out a series of experiments for float and Low-E glasses under uniform radiation conditions. Ayhan [5,6] studied surface cracks in finite-thickness plates subjected to thermal or displacement-controlled loads under the term of linear elastic material behavior and showed that the stress intensity factors along the crack front for plates under thermal or displacement-controlled loads, are lower than those of cracks under mechanical loads. Paffumi [7] carried out experimental and numerical investigations of the thermal fatigue of steel pipe components with a wall thickness of 14 mm, heated by induction

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Table 1
Chemical analysis results of casing.

Element	C	Si	Mn	Al	Cu	Ni	V	Cr	Mg	Ti	Co	Fe
W%	3.344	2.7	0.136	0.016	0.351	0.082	0.044	0.12	0.057	0.038	0.033	Balance

to 300–550 °C on the outer surface and cyclically cooled internally with water at room temperature. Chang [8] analyzed the thermal fatigue of district heating pipes. They examined fatigue life estimation schemes and applied to quantify the specific thermal fatigue life of each pipe. A gas turbine casing subjected to thermal fatigue have been analyzed by Poursaeidi [9], who showed that thermal fatigue is the main cause of crack creation. However, in the study, only condition linear elastic material behavior was considered as different states of shut down and the influence of the rate of cooling turbine casing on crack growth were not analyzed. Cheong and Karestensen [10] studied fatigue crack growth in a steam turbine casing and used elastic–plastic fracture mechanics to calculate the fatigue life of the casing. Chowdhury [11] analyzed the failure of a weld repaired steam turbine casing. They showed that thermal stresses are generated as a result of differences between thermal expansion coefficients. The amounts of stresses were near the yield stress of the casing and thermal fatigue was the reason behind the cracking.

In this work, transient thermal stress problem of an edge hole crack in gas turbine casings subjected to a heat transfer boundary condition was studied. The study aimed to establish the transient thermal fatigue life of detected crack on the edge of eccentric pin hole of gas turbine casing, in accord with engine work cycle to fired and emergency shut down under the terms of linear elastic and elastic-perfectly plastic material behavior as well as analyze the influence of the rate of cooling turbine casing on the fatigue crack growth.

2. Material and experimental set-up definition

This study used one of the most widely used ductile cast iron in the gas turbine industry, ASTM-A395 ductile cast iron. Table 1 shows the typical chemical composition of a casing material [9].

The mechanical properties are fully defined in Table 2. The crack position and direction were determined by penetrant test. Fig. 1 illustrates the geometry of a sample crack with 28 mm × 12 mm dimensions. Fig. 2, shows the gas turbine working cycle. The turbine casing undergoes three processes including transient temperature increase, steady state condition and transient temperature decrease. Therefore, the gas turbine undergoes 3 processes; start up, base load and shut down (fired shut down or emergency shut down). The inner surface temperature was measured with ten type K thermocouples, within the range of 0–1100 °C installed in ten different positions inside the casing. (Fig. 3). As a result of mechanical constraints, thermocouples were installed inside the retaining pins site of the shrouds and nozzles, the tip of the thermocouples penetrated inside the retaining pins site up to the casing's thickness. Temperatures were measured using thermocouples, and two digital recorders, model Eurotherm-6100A store (Fig. 4).

Table 2
Mechanical properties of the ASTM-A395 ductile cast iron.

Hardness (Brinell)	Tensile strength, ultimate (MPa)	Tensile strength, yield (MPa)	Modulus of elasticity (GPa)	Poisson's ratio
167	461	329	169	0.29

3. Modeling and solution process

In this paper, a 3D model was used to show stress (or strain) variations in a turbine casing (Fig. 5). In order to create the three-dimensional model of the turbine casing, the CATIA [12] software was used.

The ABAQUS software [13] was used to give the boundary conditions on the finite element model. Thermal stress distribution of the casing was obtained for the three working loads. Asymmetric distribution of temperature causes thermal stresses. Due to the low number and positioning of the sensors, temperature inside the casing was not available at all locations. Because of this reason, in addition to the distributed sensor locations, linear temperature distribution between sensors needed consideration. The turbine casing is constrained by other components so this stress will have considerable effect. Hence it is important to impose constrains in a real way. In the FEM model, the surfaces with red and black arrows

Fig. 1. A sample crack with 28 mm × 12 mm dimensions, determined by PT test.

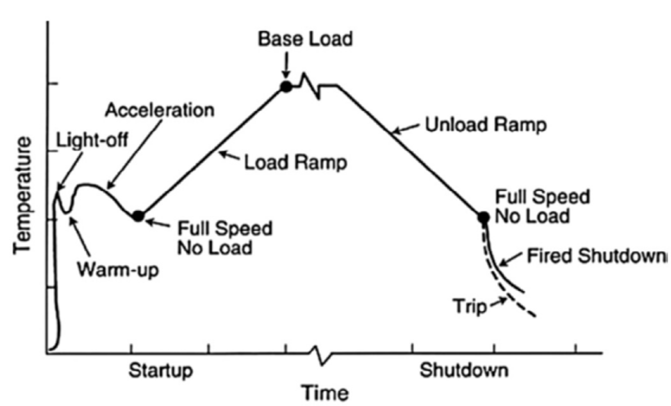

Fig. 2. Firing temperature changes occurring over a normal gas turbine cycle.