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Short communication

# Effect of additional holes on transient thermal fatigue life of gas turbine casing

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ABSTRACT

Gas turbines casings are susceptible to cracking at the edge of eccentric pin hole, which is the most likely position for crack initiation and propagation. This paper describes the improvement of transient thermal fatigue crack propagation life of gas turbines casings through the application of additional holes. The crack position and direction was determined using non-destructive tests. A series of finite element patterns were developed and tested in ASTM-A395 elastic perfectly-plastic ductile cast iron. The effect of arrangement of additional holes on transient thermal fatigue behavior of gas turbines casings containing hole edge cracks was investigated. ABAQUS finite element package and Zencrack fracture mechanics code were used for modeling. The effect of the reduction of transient thermal stress distribution around the eccentric pin hole on the transient thermal fatigue crack propagation life of the gas turbines casings was discussed. The result shows that transient thermal fatigue crack propagation life could be extended by applying additional holes of larger diameter and decreased by increasing the vertical distance, angle, and distance between the eccentric pin hole and the additional holes. The results from the numerical predictions were compared with experimental data.

## 1. Introduction

Mechanical joints, such as bolts, rivets, and pins are commonly-used in metallic structures, although they could lead to material weakening. Hole drilling creates geometrical discontinuities and concentrates local stress (and strain) under loading. In addition, surface roughness caused by machining will increase the likelihood of initiation and propagation of a surface fatigue crack under changing load conditions. Hole edge cracks have been observed in industrial components similar to gas turbine casing [1]; nevertheless, various techniques exist to increase fatigue life. These include drilling a hole at the crack tip [2,3], fatigue crack repair by infiltration [4], retardation of fatigue crack propagation by indentation [5], retardation of fatigue crack growth caused by crack branching [6], application of additional holes or notches [7], and crack-growth arrest by redirection of crack growth through the drilling of stop holes and insertion of pins into them [8]. The effect of interference fit on the fatigue life is widely studied in the literature; the effect of bolt interference fit on the fatigue life of lap joints in double shear have been investigated by conducting experimental fatigue tests and also analytically by FE simulation [9]. They showed the failure is affected using different levels of interference fit. The effect of interference fit on fatigue life of holed plate of mechanical joints have been investigated [10]. They found that the interference fit (depend on its size) reduces cyclic stress amplitude and increases mean stress. Local deformation around the hole by means of an interference fitted pin have been investigated [11]. The stress history and distribution in the neighborhood of the hole showed a significant reduction of the stress amplitude produced by the external loading (remote stress) when a residual stress field is generated by the pin insertion.

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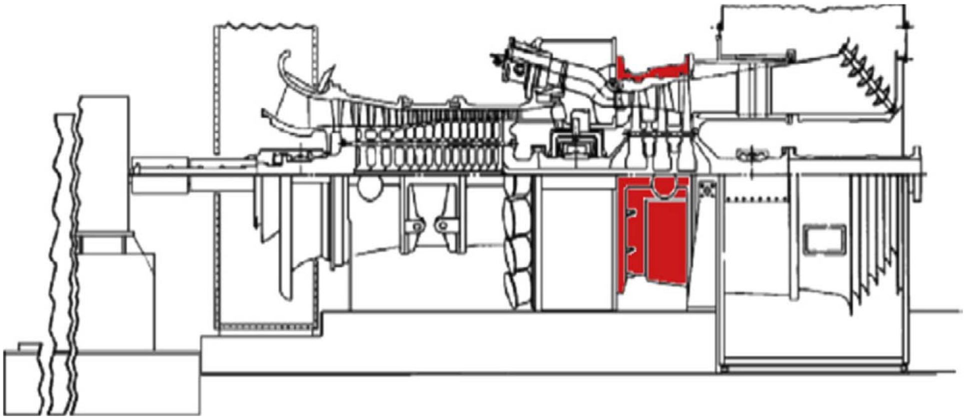

**Fig. 1.** Side-section view of gas turbine.

A previous study [1] investigated fatigue growth in a GE-Frame 9 gas turbine casing exhibiting linear elastic material behavior. The results showed that the crack growth rate decreased gradually and, after a period of time, the stress intensity factor reached a threshold value. The present study examines a crack detected on the edge of an eccentric pin hole of a GE-Frame 9 gas turbine casing and investigated the fatigue crack propagation life under elastic perfectly-plastic material behavior. The effects of drilling of additional holes on the crack growth behavior of gas turbine casings containing hole edge cracks were then examined with the goal of increasing the transient thermal fatigue crack propagation life of the gas turbine casing. The effect of the diameter of the additional holes, residual stress induced by pin insertion, vertical distance between the additional holes, the distance and angle between of the eccentric pin hole and the additional holes on the transient thermal fatigue crack propagation life of hole edge cracks exhibiting elastic perfectly-plastic material behavior was investigated.

## 2. Material and experimental procedure

Fig. 1 shows the turbine casing (red) and a side-section view of a gas turbine. The casing consists of two half-casings made of ductile cast iron and connected by flanges. Fig. 2 is a 3D drawing of the casing showing the position of the eccentric pin hole. The position of the crack on the casing surface was investigated using non-destructive tests. Fig. 3 shows a sample crack determined by penetrant testing. Table 1 lists the results of chemical analysis of the casing material and indicates good correlation with ASTM-A395 ductile cast iron. Table 2 lists the mechanical properties of ASTM-A395 ductile cast iron.

## 3. Finite element analysis procedure

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. The most important boundary conditions were temperature distributions on the inner and outer surfaces of the casing. 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. As a result of mechanical constraints, thermocouples were installed inside the retaining pins site of the shrouds and nozzles, the tip of the

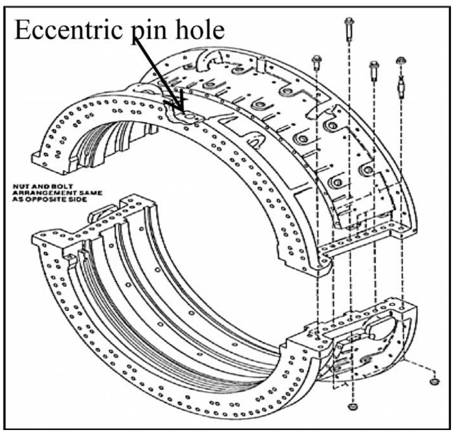


**Fig. 2.** 3D drawing of upper half-casing and location of eccentric pin hole.