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Hot corrosion failure in the first stage nozzle of a gas turbine engine

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First-stage nozzles of gas turbines, which are the first elements after the combustion chamber, encounter hot gases from the combustion process and have the task of directing the fluid path and increasing the velocity of combustion products. This paper reports on the incidence and failure of the first-stage nozzles of a gas turbine in September 2013 at a seaside pump-house located in the South-West of Iran. The nozzle was made of nickel-based superalloy Nimonic105. Due to nozzle failure, the turbine was damaged severely. The cause of nozzle failure was investigated. The results of visual inspection, XRD analysis of deposits on the blade airfoil, SEM images and EDAX analysis showed the characteristics of hot corrosion. Finite-element analysis (FEM) revealed that the cause of blade trailing edge failure was thermal stress leading to thermal fatigue, which accelerated nozzle blade failure in addition to the hot corrosion.

1. Introduction

Gas turbines have long been used as generator or pump drivers in power plants and the oil and gas industries in order to produce power. Nozzle blades are one element of gas turbines and their function is guiding the flow of hot gases into the bucket of gas turbine at the maximum favourable angle of incidence [1]. Turbine-blade failure is always a serious problem encountered in these machines. Corrosion is an extremely complex damage mechanism, which depends strongly on material and environmental conditions. In the turbine blades, material is exposed to erosive particles from combustion gases, breaking the protective oxide scale on the surface of the blade [2]. Corrosion is one of the main reasons for blade failure. Corrosion of hot-section components depends on the turbine air inlet and fuel used in the turbine machine. Common fuels used in gas turbines include natural gas, propane or jet fuel, which contain sulphur, sodium, potassium, vanadium, lead and molybdenum. The consumed air depends on the atmosphere where the turbines are utilized. Oxidation and corrosion usually occur in turbines' hot components [3]. In general, metals, when exposed to high-temperature oxidizing gas, will be oxidized; if this atmosphere or metal surface contains corrosive molten salt, the process will be accelerated. This phenomenon is called hot corrosion. When the sensitive elements of a gas turbine are exposed to all the necessary components of corrosion, alkali salt compounds such as NaCl and Na_2SO_4 and vanadium compounds such as V_2O_3 and $NaVO_3$ enter into the turbine section from the outside environment, and a thin layer of molten salt is formed on turbine components, especially nozzles and rotor blades [4]. As noted, the presence of impurities in the site atmosphere and molten salt production due to the combustion process are the major hot-corrosion factors in turbine components.

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Na_2So_4 is formed by the following process:

$$NaCl + SO_2 + O_2 = Na_2SO_4 + Cl_2 \quad (1)$$

Significant amounts of chlorine and sodium can enter into the turbine from an outside environment, and since the air–fuel ratio in gas turbines is very high, the amount of sodium and chloride in air is more important than the amount of fuel [5]. Reports of failure due to hot corrosion in the last few years have shown that this mechanism is active in hot parts used in the oil and gas industry and power plants.

In 2010, Virk reported the failure of a heat-exchanger steam line of a polyester factory in Pakistan [6]. In 2011, Malekbarmi reported the failure of first-stage nozzles of a 32 MW gas turbine made of GTD111 near sea [1]. In 2012, Kosieniak studied the failure of nozzles and gas-turbine buckets in Poland [4] and Kargarnejad described the failure of first-stage gas-turbine blades made of Nimonic 80 [7]. In 2013, Tzeveleko showed the failure of hard-drawn copper tube [8] and Shirpay focused on the failure of repaired first-stage blades of a 32.5 MW gas turbine made of cobalt-based X45 superalloy [9]. Ziegler showed the failure of low-pressure blades of a 310 MW turbine in a thermal power plant [10] and Bhagi addressed the failure of first-stage blades of a steam turbine made of X20Cr13 alloy [11]. In 2014, Saha studied the failure of super-heater tubes of a 140 MW thermal power plant [12]. Jahangiri characterized the failure of gas-turbine compressor blades [13] and Kumari reported the failure of the first, second and third stages of the rotor blades of a gas turbine [14]. All these studies referred to corrosion and hot corrosion as the reasons for failure. In the present case study, failure of first-stage nozzles of gas turbines and the effect of hot corrosion on the nozzles is investigated. The gas turbine under study is installed in a seaside pump-house in the South-West of Iran; its power is 2 MW, it uses natural gas as a fuel and it drives a centrifugal pump.

2. Hot corrosion in gas turbine components

During combustion in the gas turbine, sulphur from the fuel reacts with sodium chloride from ingested air at elevated temperatures to form sodium sulphate. The sodium sulphate then deposits on the hot-section components, such as the nozzle guide vanes, nozzles and rotor blades, resulting in accelerated oxidation (or sulphidation) attack. This is commonly referred to as "hot corrosion" [15]. Hot corrosion was observed for the first time in 1960 in gas turbine blades made of Nimonic105 and GMR235 alloys, and was named "black plague" [16]. Corrosion of metals and alloys is accelerated when their surface is in contact with a layer of corrosive molten salt. A schematic diagram of a gas turbine is shown in Fig. 1. It can be seen that, after combustion, the first-stage nozzles and rotor blades of the gas turbine are the most susceptible parts for hot corrosion, because they are the first parts that the hot gas comes into contact with. Hot corrosion may be defined as a kind of accelerated corrosion resulting from the presence of salt contaminants, such as Na_2SO_4, NaCl and V_2O_5, which are combined to form molten deposits that can damage the protective oxide surface. There is a general agreement that condensed alkali metal salts, including Na_2SO_4, are a prerequisite for hot corrosion [4].

Sodium sulphate is one of the most important agents of corrosion. On a thermodynamic basis, sodium chloride is unstable in the presence of even small concentrations of sulphur in an oxidizing environment [17]. Bornstein has expressed the equation as

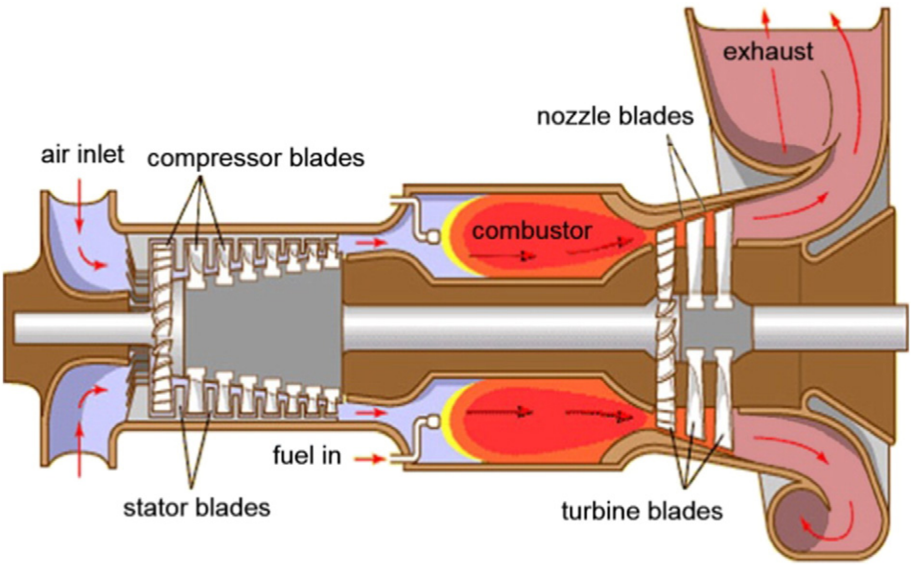

Fig. 1. Gas-turbine schematic.