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Last stage blades failure analysis of a 28 MW geothermal turbine

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ABSTRACT

A last stage (L-0) turbine blades failure was experienced at a 28 MW geothermal unit after seven years of operation period. This unit has one flow intermediate/low-pressure turbine composed of nine stages with 25-in./3600 rpm last stage blades. The last stage row contains 62 free standing blades. Visual examination indicated that the 37 L-0 blades had cracks in their airfoils initiating at the trailing edge, near the blade platform. Laboratory evaluation of the cracking indicates the failure mechanism to be high cycle fatigue (HCF), and the cracks initiation was accelerated by erosion picks on the blade surface due to steam recirculation flow and corrosion. A last stage blade failure evaluation was carried out. The investigation included a metallographic analysis of the cracked blades, natural frequency analysis, blade stress analysis, unit operation parameters, history of events analysis and crack initiation and propagation analysis. This paper provides an overview of the failure investigation, which led to the identification of some operation periods with low load as the primary contribution to the observed failure.

1. Introduction

According to [1–3], steam turbine operation with low load/low vacuum induces last stage (L-0) blade excitation (vibration) by unstable flow developing high vibratory stresses. Due to the reduced mass flow, steam conditions are variable along the steam path; there are zones of different pressure, radial flows, counter flows, flow recirculation (flow instabilities). These operating conditions generate blade excitation forces that can lead to blade failures. Unit operation with reduced mass flow is also causing a reduction in flow velocity to the same degree. This results in changes of the blade entry flow incidence angle (change of stage velocity triangle); the flow is entering into the L-0 blades with negative incidence angle, striking the suction surface of the blades airfoil and exciting them. The pressure fluctuation, flow recirculation and counterflows, in conjunction with the negative incidence angle flow striking on the blades, can develop excessive vibratory stresses causing fatigue fracture of the blades.

This paper provides an overview of the last stage blades failure investigation of the 28 MW geothermal unit, which led to an identification of the combined effect of erosion–corrosion and operation periods with low load as the primary contributors to the observed failure.

2. Methodology

The blade under evaluation was a 25-in./3600 rpm last stage blade (L-0) of the 28 MW geothermal turbine. The blade was made of AISI 420 stainless steel. This unit has one flow intermediate/low-pressure turbine composed of nine stages. The L-0

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Nomenclature

C/Cc	damping factor
da/dN	velocity of crack propagation
da	crack size increment during one fatigue cycle
f	resonance frequency
N/dN	number of fatigue cycles
t	time of operation under resonance

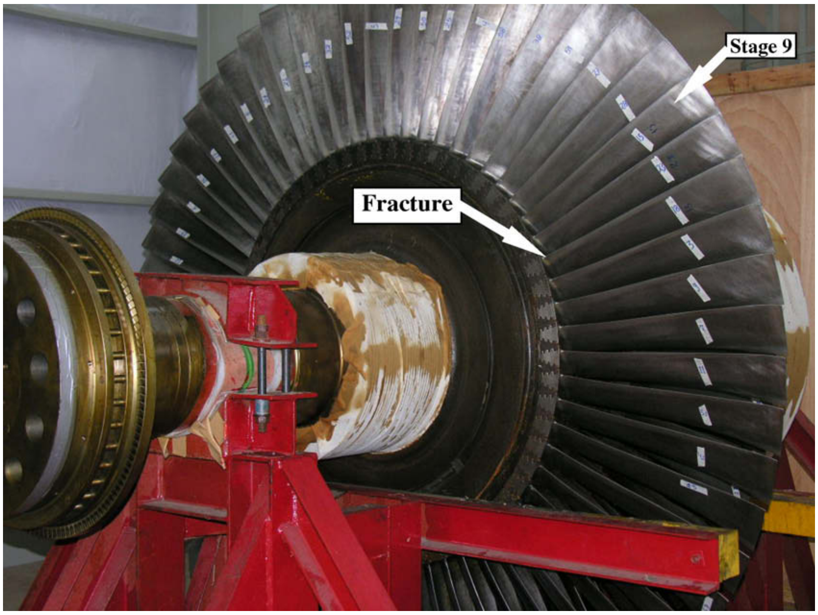

Fig. 1. General view of last stage blades (L-0) of the 28 MW unit.

row consists of 62 free-standing blades. The turbine accumulated 59,700 operation hours to failure. A general view of the last stage blades of Unit 1 is shown in Fig. 1.

Fig. 2 shows a detail of the blade #38 fracture which has about 45 mm longitude (maximum fracture length recorded). The fracture initiated at the trailing edge in the transition radius zone of the airfoil-root platform. Blade erosion can be seen in this zone (dark spot noted).

Among 62 blades of Stage 9, similar fractures were recorded in 37 blades (60%), having varied fracture lengths; from 3 mm (Blade #58) to 45 mm (Blade #38). A distribution of the fractured blades is shown in Fig. 3.

3. Blade stress analysis

Blades were measured using a 3D optical system to obtain their topology, which was exported to Finite Element Method (FEM) software, and a blade numerical model was prepared. The blade numerical model is composed of 13,479 nodes and 2576 solid elements of quadratic interpolation with one intermediate node at each edge to enable better modeling of the blade curved zones [4]. The blade numerical model (mesh) is shown in Fig. 4, including one segment of rotor disc (indicated by blue color).[1] The meshing process was carried out carefully to obtain solid elements in the best possible form using only hexahedrons and some wedge elements (triangular prisms).

3.1. Boundary conditions of the model

There were defined restricted displacement zones located at the blade root. The rotor disc segment was included to better model dynamic blade performance considering the rigidity of this zone. Each node of the blade root base (lower) was re-

[1] For interpretation of color in Fig. 4, the reader is referred to the web version of this article.