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Failure analysis of a hydraulic Kaplan turbine shaft

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ABSTRACT

This paper shows the results of the failure analysis of a 105 MW Kaplan turbine auxiliary shaft from a hydropower plant. As a part of the failure analysis, the turbine operation history was revised and the metallographic study was done. A sample of the cracked turbine shaft was examined using optical microscopy and scanning electron microscopy. Failed auxiliary shaft was coupled to the main turbine shaft and its principal function was turning the runner blades according to flow direction. In order to complement the cause of failure, a finite element analysis (FEA) was done to calculate the stress level under the maximum and minimum turbine blade inclination position. The results of present investigation showed that failure was caused by high cycle and low stress fatigue. The presence of a stress concentrator on the turbine shaft was a crucial factor to the fatigue crack-initiation phase. The FEA revealed also that the frequently load variations, showed in the operation history, could have contributed to the crack propagation.

1. Introduction

The volumetric flow through a hydraulic turbine varies as function of the water level of the reservoir or according to the electric power required by the general electric grid. In consequence some turbine parts, like blades or shafts, are subjected to variable loads. As is known, the variable loads could cause fatigue and failure of turbine parts, sometimes with catastrophic consequences [1–3]. In recent years a variety of failed hydraulic turbines parts has been analyzed [4–10].

Failures of any turbo machinery parts usually initiate at the zone of high stress concentration that is in metallurgical discontinuities, or where corrosion is present, or in zones where the cross-sectional area changes or even in regions of excessive wear. Its analysis requires metallurgical examination through fractography and stress analysis through Finite Element Method (FEM) [8,9].

This paper describes the failure analysis of a 105 MW Kaplan turbine auxiliary shaft. This failed shaft is located inside the turbine runner and coupled to turbine blades and its main function was to turn the Kaplan blades according to flow direction in order to achieve optimum turbine efficiency. Before the outage, the hydraulic turbine was operated for about 108,768 h; this is approximately 12.4 years of effective operation.

In order to know the causes that led to the failure, the investigation include the next tasks: in situ visual inspection, revision of the turbine operation history, fractography and finite element analysis.

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The failure analysis results show that a stress concentrator located at the failed shaft and the frequently load variations were the main causes of the crack initiation and the subsequent crack propagation.

2. Visual inspection

Principal shaft of the 105 MW Kaplan hydraulic turbine is shown in Fig. 1, has 10.3 m of length, 1.1 m of diameter and 101,000 kg (runner included), runner has 6.60 m of diameter and five blades.

The failed turbine auxiliary shaft was made of AISI 1045 steel (see Table 1 for mechanical properties of the shaft material) and its dimensions were 3.520 m of length and 0.480 m of diameter. Besides the shaft have one central and two lateral orifices.

The position of this failed shaft in the runner is shown in Fig. 2 and its main dimensions are shown in Fig. 3. Characteristics of the hydraulic Kaplan turbine are shown in Table 2.

Visual inspection revealed that auxiliary shaft was cracked as shown in Fig. 4a–c. Magnified surfaces of the fracture of the turbine shaft are shown. Some results of visual inspection are:

- The failure on the shaft consists of a transversal fracture over a change of geometry from the shaft and also it is located near of one central and two lateral orifices.
- Failure is a fragile fracture with no plastic deformation.
- Failure manifested rectilinear appearance showing no ramifications during its development.
- Over auxiliary shaft outer surface mechanical damage is showed. Also was observed the presence of longitudinal cracks, which have rectilinear morphology free of branching.
- Fracture surfaces are characterized by smoothness in its largest area corresponding to the initial phase of the fracture, while the area corresponding to the end part of the fracture become coarser and crystalline, this last zone is significantly lower than the smooth areas.
- The beach marks on the surface indicate high frequency fatigue as a cause of the fracture. Also, during the visual inspection slight mechanical damaged was found next to the cracked region, but it not was associated as the main cause of the failure. The crack develops on a transverse way to its longitudinal axis and takes place on a section where the cross-sectional area changes.

By means of the technique of magnetic fluorescent particle is shown that longitudinal cracks in the sample on study are rectilinear and free of branches, Fig. 5a and b.

3. Turbine operation history

The turbine operation history turbine revealed that the turbine shaft was in operation during 12.4 years before the failure.

According to internal technical reports of hydro power plant, during its operation this turbine was subjected to load variations caused by the changes in level of the water reservoir and by demands of the general electric grid. During peak hours the general electric grid required that load turbine was increased. These changes caused the blades were adjusted frequently to new conditions of flow.

Fig. 1. Kaplan turbine runner.