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Fatigue failure of the bolts connecting a Francis turbine with the shaft

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ABSTRACT

This paper describes the failure analysis of bolts used to connect a turbine to the shaft of a hydroelectric power generator. Three of ten bolts were found broken during a disassembly process to replace the turbine. The methodology included visual inspection of the thread to detect eventual stress concentrations. Using loads measured on the turbine shaft for different power levels and the actual power generation history for a period of one year, a stress history on the bolts was obtained. With this stress history, damage was calculated for three preload values.

The results showed some scratches on the root of the thread produced during the machining process and by subsequent corrosion during operation, which likely significantly affected the fatigue life. A preload that was smaller than the recommended one was found in the maintenance report, which put the bolts at risk of loosening. A fatigue life of only 16.4 years was estimated if loosening occurs on the bolts.

Better preload control during the assembly process and a change in the bolt material to stainless steel are the primary recommendations from this analysis.

1. Introduction

Hydroelectric power plants are a source of electrical energy and are widely used around the world because of the low operational costs and the low environmental costs compared with fuel-driven plants. In a hydropower plant, a turbine is rotated by the potential and kinetic energy of water to transform it to mechanical work, which is transferred by a shaft to a generator where the mechanical energy is transformed into electrical energy (Fig. 1).

The interactions of the water with the turbine and the electrical network with the generator, under some conditions, may produce vibrations on the structural elements of the machine. Vibrations may produce important fluctuating stresses, which may produce fatigue failures [1,2]. In large hydroelectric power units, fatigue failure may be catastrophic, resulting in human casualties, high costs of repair or replacement of elements, and long repair times. High levels of vibrations are produced in Francis turbines, specifically when operating at partial load conditions due to von Carman Vortices that form at the vanes and Vortex Ropes at the draft tube [3,4]. These vibrations have been found to be sufficient to produce fatigue failures in the structural elements [5]. This paper describes a failure analysis on the connecting bolts of a Francis turbine belonging to an 18 MW hydro generator. During disassembling of the machine for maintenance, three of the 10 bolts were found to have broken.

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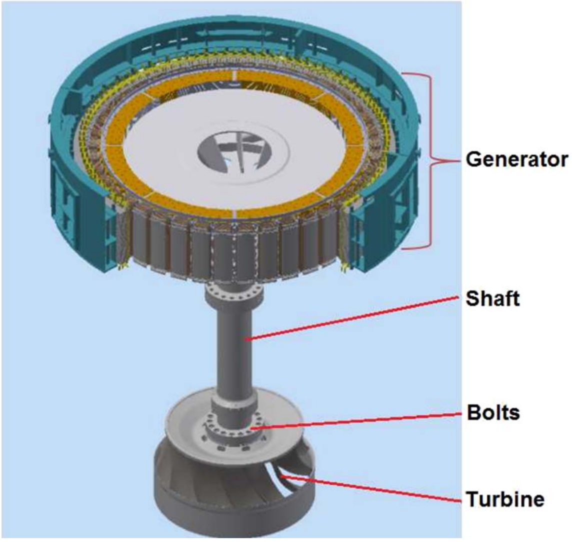

Fig. 1. Schematic of a hydroelectric power machine.

2. Description of the failure

The hydroelectric power unit that is the object of this study has been in operation during the last 50 years. The unit is powered by a Francis-type turbine, which is 1.3-m high and has a major diameter of 2.03 m. The turbine is connected to a 0.46-m diameter shaft using 10 bolt reference DIN 259 R2 ¼″, with a material that, according to the manufacturer, has a tensile strength between 784 and 931 MPa. The turbine disassembled approximately once per year for maintenance. By the year 2014, the company decided to replace the old turbine with a new one. To characterize the machine before and after turbine replacement, the company decided to measure the normal and shear stresses on the turbine shaft at several power generation levels. During disassembly of the old turbine, three of the 10 bolts used to connect the turbine to the shaft were found to have broken. The three broken bolts exhibited a fatigue propagation region and a final fracture region. Fig. 2 shows the shaft with the bolts including the three bolts that fractured. Fig. 3 shows the fracture surface of a bolt where the fatigue propagation region is clearly observed. The three bolts were found to have broken at the threaded region in the first fillet in contact with the nut, as observed in Fig. 3.

3. Methodology

A fatigue life analysis was performed on the bolts to establish the probable cause of the failure. The steps used in the analysis are explained in detail in this section. Visual inspection of the notched section of the thread was performed to evaluate the presence of stress concentrators. A model of the shaft was generated to calculate the forces at the joint using the stresses measured at the shaft in

Fig. 2. Turbine shaft with the bolts after turbine removal.